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Transfering
Energy Save
Laid on Agroindustry

Efficient Olive oil mills

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HANDBOOK

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1. INTRODUCTION

Olive trees growth is geographical limited due to soil and climate requirements. It is a crop specially adapted to the Mediterranean climate conditions, and therefore it is one of the predominant crops of the Mediterranean region. Olive trees originated in Anatolia (Turkey) 8000 years ago and from there spread to the Middle East, North Africa and the South of Europe.

Over time, it has assumed a great importance in the economy, culture and social life of the Mediterranean Basin civilizations. Olive oil production is an essential sector in the structure of agricultural production of Southern Europe countries.

Near 95% of olive grove area is located in the Mediterranean Basin. In 2010/2011, the countries from the European Union (Spain, Italy, France, Greece and Portugal) were responsible for 71,8% of the world olive oil production (figure 1).

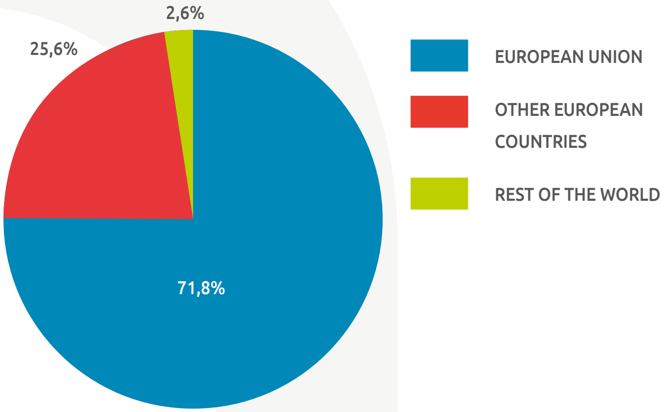

Figure 1. World olive oil production in 2010/11 (elaborated with data from IOC, 2012)

Olive oil production in the four countries analysed in this report (Portugal, Spain, France and Italy) presents significant differences, as shown in figure 2. Spain is by far the bigger olive oil producer contributing with 52% to 74% of the total olive oil production of the four countries. Italy follows Spain with 23% to 46% and Portugal and France are very behind with values between 2% to 3%, and 0,2% to 0,4%, respectively.

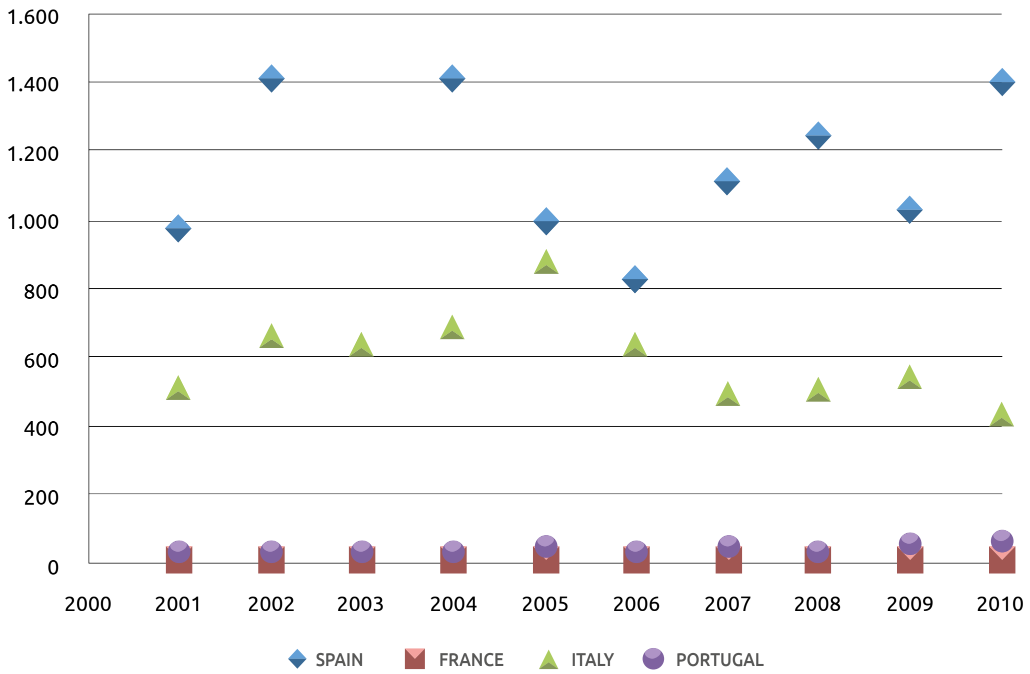

Figure 2. Olive oil production (1000 tons) (elaborated with data from IOC, 2012)

Table 1 shows some characteristics of the olive sector in the four countries according with data published by INE, 2012; IOC, 2012; INEA, 2012, and AFIDOL, 2012.

TABLE 1. CHARACTERISTICS OF THE SECTOR.

OLIVE OIL SECTOR - 2011	PORTUGAL	SPAIN	FRANCE	ITALY
Area olive groves for oil (ha)	338.048	2.584.564	55.000	1.144.400
Olives used for oil (ton)	510.733	7.820.000	16.740	3.122.500
Average productivity (kg olives/ha)	1.511	3.026	300	2.728
Olive mills in activity (nº)	527	1.750	254	4.809
Olive oil produced (ton)	76.200	1.651.000	3.348	464.900
Productivity (kg olive oil/ha)	227	639	58	406
Olive oil/Olives (%)	15	21	20	15
Olive oil consumption (ton)	78.000	574.000	112.000	610.000
Olive oil consumption per capita (kg)	7,4	12,3	1,7	10,3
Resident population	10.557.560	46.815.916	64.612.939	59.394.000

Source: INE, 2012; IOC, 2012; INEA, 2012; GPP, 2013; and AFIDOL, 2012.

1.1. Analysis of olive oil sub-sector

1.1.1. Production

SPAIN Spain is the biggest olive oil producer in the world, with average annual productions around 750.000 tons, and with a maximum of 1,4 million. The area of planted olive trees has increased in the last years, and has now more than 300 million olive trees, that occupied an area of about 2,5 million hectares, representing more than 25% of the world area planted with olive trees (ASOLIVA), and 50% of the EU-27 planted area (EUROSTAT). It is one of the most important crops in the country, which in a few decades has become a pioneer in research and technology development of the olive sector.

ITALY In Italy, as referred in the Economic analysis of the olive sector, (2012 European Commission, Directorate General for Agriculture and Rural Development), in 2008, a total of 1.350.000 hectares were dedicated to olive groves, with a mean tree density of 132 trees /ha. In general, Italian olive groves are small (70% have less than 2 ha). Olive yield is about 3.000 kg/ha. Annual olive oil yield in the decade 2000-2010 was between 500 to 600 kg/ha.

FRANCE According with IOC (2012), in 2011, there were in France 5,1 million olive trees scattered by 55.000 hectares. Olive groves occupied less than 0,18% of utilised agricultural area (UAA), and the average tree density was 92 trees/ha. Olive groves are not an important crop in France, and most of the olive groves are old plantations (in 64% of the total planted area trees have more than 50 years). New olive groves (less than 5 years old) represent only 4% of total planted area. Nevertheless, olive planted area has being increasing in the last few years, and there is an expectation for having near 59.700 hectares of olive trees in 2014.

PORTUGAL In 2011 olives trees were grown on 345.683 ha in Portugal, of which 7.635 ha were for table olives and 338.048 ha for olive oil. In this year the olive oil production was approximately 832.000 hl (76.200 ton). A mill with a production higher than 920 tons of oil/year is considered big; with a production lower than 95 tons of oil/year is considered small. Based on this and analysing data from INE considering 123 olive mills, 76% of the total production is obtained in big olive mills, 22% in medium size and only 2% in small olive mills.

1.1.2. Olive oil extraction methods

In Spain, most of the olive mills have being modernized and equipped with two-phase decanters. Nowadays 75% of Spain olive mills are two-phase olive mills, which allowed to increase the olive oil quality and to reduce the amount of waste water. Olive mills have different sizes, being the most commons those that produce between 100 to 500 tons of olive oil per year.

In Portugal between 2009 and 2011 the planted area of olive groves has increased which led to installation of new olive oil mills and the modernization of existent ones, from traditional to three-phase and two-phase olive mills and more efficient extraction processes. It also led to the investment in infrastructures to transform and use the pomace from olive oil production. Figure 3 shows the evolution in the last years, with the decrease of traditional olive mills and the increase in the continuous two-phase and three-phase olive mills.

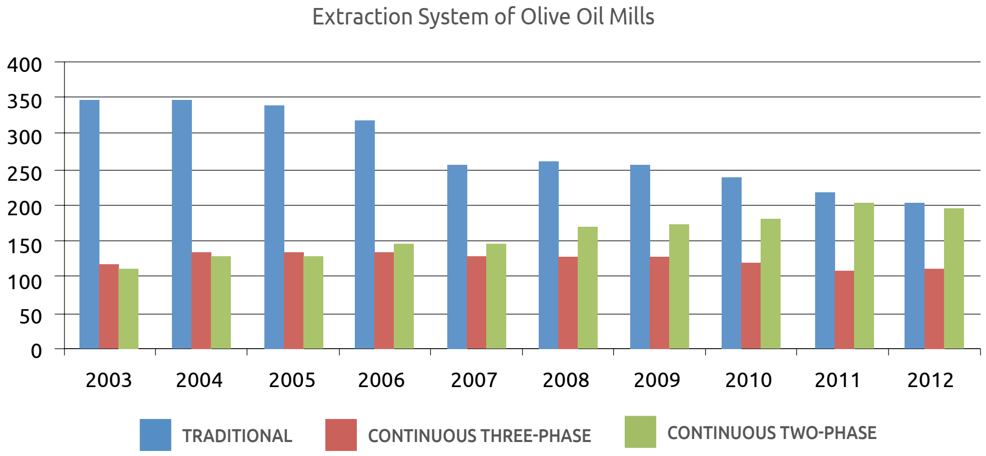

Figure 3. Number of olive mills in Portugal with different olive oil extraction system (data from INE, 2012)

1.1.3. Energy consumption

According with data recorded by INE in the annual industrial production survey of 2011, based on 123 Portuguese olive oil mills analysed, olive mills energy consumption is based mainly in electricity (98,3%), with low contribution for biomass, diesel and gas, with values of 1%, 0,5% and 0,2%, respectively. However, in those olive oil mills where olive pit is used as biomass for the boiler, energy consumptions is around 50% electricity and 50% biomass, according with CO2OP Project were six Spanish olive oil mills cooperatives were analysed.

1.2. Socioeconomic point of view

SPAIN In accordance with OSCAE 2009 (Cooperativas Agroalimentarias), FIAB 2008, and MARM 2009, there were 1.744 olive mills in Spain, being 951 of them cooperatives. Associated with the olive mills there are other infrastructures that work in the olive sector. Spain has 6.260 factories that extract oil from olive pomace. This pomace is still a significant source of oil, which is extracted by physical or chemical methods. The product, known as olive oil pomace, has an annual production of 96 thousand tons in 2010 (Anuario de estadística, 2011). There are also 1.519 packing factories, 90% of which are associated with olive oil mills.

ITALY In 2011, according to IOC 2012 data, there were 4.809 olive mills in Italy, for a total of 1.350.000 hectares of olive groves. Olive oil production is much more fragmented than in Spain. In 2007, according to Eurostat, the number of holding was 776.000, with an average size of 1,3 ha. Furthermore, there are some 5.000 mills, whereas downstream the industry is very concentrated with the major bottlers controlling almost half the virgin olive oil market that means the 80% of domestic consumption.

PORTUGAL According to the Portuguese National Statistics Institute (INE, 2012), in 2011 there were 527 olive oil mills in Portugal, being 138 of them cooperatives. Cooperative mills represent 30% of the total olive oil production (GPP, 2013).

FRANCE In 2009 there were 254 olive mills in France, with an average processing capacity of 21 ton/year (IOC, 2012). Besides that, olive trees are presented in near 29.243 agricultural farms, but 85% of them have less than 2 hectares of olive trees (IOC, 2012).

Regarding annual turnover, the following data were obtained about olive oil sub-sector:

PORTUGAL According with information of the National Statistics Institute, in 2011 the estimated production turnover of the sector was 465 million Euros.

SPAIN According to the Olive Oil Agency, turnover in 2010/2011 campaign was 2.492 million Euros, considering olive oil at the exit of the olive oil mill, before being bottled.

ITALY According to the study presented by ISMEA, in 2010 the production turnover of the sector was 1.513 million Euros.

FRANCE According to the study presented by AFIDOL, in 2011 the production turnover of the sector was 228 million Euros.

2. PROCESSES DESCRIPTION

Olive oil mills are an example of the agro-industries that have presented a positive evolution with modernization and technological adaptation in the last decades, in order to respond to hygiene and environmental requirements.

The general production process consists in: olives reception, cleaning and storing; grinding and paste homogenisation; phases separation; storage; and bottling.

2.1. Reception, cleaning and washing

After harvesting, there is a limited period of 24 hours, to produce the olive oil, in order to avoid olive fermentation and degradation, which would decrease the olive oil quality. As soon as the olives arrive in the olive mill, they are cleaned and washed. This process is performed by a cleaning machine (figure 4), which separates the olives from other vegetal materials (leaves, branches) and soil attached to the olives during the harvesting and collecting of olives in the field, and washes them. In the washing process the water consumption is about 10 to 12 litres per 100 kg of olives.

Figure 4. Cleaning and washing machine

After this process, olives are transported by conveyors to the storage containers were they stay until the beginning of the next processing stage. Before entering to the storage container, they pass through a balance and are weighted. Olives are separated in different storage containers according to their variety and quality, determined in the reception phase.

2.2. Grinding and paste homogenisation

In this stage olives are crushed in a steel drum mill (figure 5) resulting in an olive paste. The purpose of crushing the olives is to tear the flesh cells to facilitate the release of the oil from the cell vacuoles. The pit or seed of the olive represents 25% of the olive weight but has less than 1% of oil content. Most of the olive oil comes from the olive pulp, which has an oil content varying between 15 to 22% depending on the variety and cultural practices.

It is necessary to take special attention to the grinding time and the grinding degree, which depends on the sieve mesh size of the steel drum mill. A long grinding process may increase oxidation of the paste and reduce the flavour of the olive oil. In modern steel drum mills the grinding process takes about 20 minutes.

Figure 5. Steel drum mill

Olive paste is beat and mixed, with the objective of making an uniform paste, continuing the release of the oil from the olive pulp cells and break up the oil/water emulsion allowing small oil drops to combine into larger drops, which facilitates the mechanical extraction of the oil.

The horizontal mixer (figure 6) has three cylindrical double wall tanks with pierced blades. These blades have different speeds depending upon the type and dimension of mixer, but usually this rotation is low to allow a slow mixing. The capacity of the machine is determined by the quantity of olives processed by the mill.

Figure 6. Horizontal mixer

The mixing process occurs under moderate temperatures (between 25°C to 28°C), maintained by the heated water used in the mixer. The water is heated in a biomass boiler, which uses olive pit as fuel. These temperatures facilitate the release of the oil, without changing its organoleptic characteristics. Mixing time and temperature are the two parameters to take into consideration in this stage of the process.

Long mixing times (Table 2) will increase oil yield, decreasing the oil content of the pomace (the solid residue after the separation of the olive oil), but allows a longer oxidation period that decreases olive oil quality and validity.

Temperature influences directly the olive oil viscosity. High temperatures will allow higher olive oil yields, since it facilitates, in the next phase, a better separation between the water and the oil. However, if the olive paste temperature is too high it can produce a reduction of olive oil quality, producing olive oil with a pronounced bitterness (Petrakis, 2006).

TABLE 2. INFLUENCE OF HOMOGENISATION TIME IN OIL EXTRACTION YIELD

DETERMINATIONS		**Homogenisation time (min)**		
		15	**45**	**90**
OLIVE OIL EXTRACTION YIELD (%)		78,5	82,8	85,7
Olive pomace	Quantity (Kg/100 kg olives)	71,7	71,9	71,5
	Moisture (% on fresh pomace)	57,7	58,2	58,9
	Oil (% on fresh pomace)	4,4	3,6	3,1
	Oil (Kg/100 kg olives)	3,1	2,6	2,2
Waste water	Quantity (L/100 kg olives)	25	20	20
	Oil (% on vww*)	2,8	2,1	1,6
	Total oil lost in by-products (Kg/100 kg olives)	3,8	3,1	2,5

Source: adapted from Di Giovacchino et al., 2002.
*vww: vegetable waste water

2.3. Separation of the oil from water and solids

The next step consists in separating the oil from the rest of the olive components (solids and vegetal water). Traditionally this was done with presses, but now it is done by centrifugation processes, in large capacity horizontal centrifuges (decanters) (figure 7).

The centrifugation process in the decanters can be a three-phase centrifugation that allows to separate the oil (oil phase), the water (water phase) and the solids (solid phase), or a two-phase process separating only the oil from the wet pomace. The high centrifugal force created in the decanters allows the phases to be readily separated according to their different densities.

Figure 7. Horizontal centrifuge (Decanter)

Figure 8. Vertical centrifuge

In the three-phase oil decanters, a portion of the oil polyphenols is washed out due to the higher quantity of added water (when compared to the traditional method), producing a larger quantity of waste water that needs to be processed. The two-phase oil decanters use less water in the oil extraction process, producing significant less waste water, and thus reducing the phenol washing. The used water is expelled by the decanter together with the pomace, resulting in a wet pomace (62 to 75 % water content). This creates a higher quantity of pomace compared to the three-phase decanters (Table 3). In both cases, after leaving the decanter the oil goes to a vertical centrifuge (figure 8) to remove natural sediments and for separation of the small quantity of water remaining in the oil.

It should be noted that in the case of a two-phases olive mill one vertical centrifugal is enough while in a three phases olive mill two centrifuges are necessary to complete this process, one for the same function described before and the other to separate olive oil remaining in the waste water. Although the percentage of olive oil obtained is not big, at the end of the year the amount of oil collected can be considerable.

TABLE 3. CHARACTERISTICS OF OLIVE POMACE AND WASTE WATER OBTAINED WITH DIFFERENT CENTRIFUGATION PROCESSES.

DETERMINATIONS		Centrifugation process	
		2-phase	3-phase
OLIVE OIL EXTRACTION YIELD (%)		86,1	85,1
Olive pomace	Quantity (Kg/100 kg olives)	72,5	50,7
	Moisture (% on fresh pomace)	57,5	52,7
	Oil (% on fresh pomace)	3,16	3,18
	Oil (% of dry matter)	7,44	6,68
Vegetal waste water	Quantity (L/100 kg olives)	8,3	97,2
	Dry residue (% on vww*)	14,4	8,5
	Oil (g/L)	13,4	12,6
	Total oil lost in by-products (Kg/100 kg olives)	2,42	2,8

Source: adapted from Petrakis, 2006.
*vww: vegetable waste water

In each extraction process (two-phases or three-phases) the results of the components are different (Table 3).

In the two-phases case, after it the pomace passes through a sieve were the biggest solid particle (olive pits) are separated from the rest of the pomace. These solid residue particles can be used as fuel for a biomass boiler to heat the water, which is used in the horizontal mixer and for other equipment that require warm water for the operation (1 kg of olive pit per hour will produce 4.100 kcal). The remaining pomace is usually sold for producing pomace olive oil. It is transported to specialized facilities called extractors which heat the pomace between 45°C and 50°C and can extract up to 2 litres of oil per 100 kg of pomace using adapted two-phase decanters.

2.4. Storage

After the vertical centrifugation, the olive oil, completely clean, is weighed (figure 9) and is deposited into stainless steel containers (figure 10), where it stays for a period of approximately 2 to 3 months. This period is sufficient to make a final clean-up of the olive oil, by deposition of the particles in suspension, leading to a higher quality olive oil.

Figure 9. Oil weighing process

Figure 10. Olive oil steel container

2.5. Bottling

After the storage period the olive oil is ready to be consumed. Generally the olive oil is bottled in glass bottles (figure 11) and becomes ready to enter the commercial circuit.

Figure 11. Olive oil bottling process

3. ENERGY ANALYSIS OF OLIVE OIL MILLS

In the following paragraphs typical energy values are shown for two types of mills with different production volume. Mean values are for industries processing capacities of 1.600 and 300 tons of olive oil per year (both two-phase oil decanter and biomass boiler). Olive oil mills have a clear seasonal activity: from November to March, in the four countries studied, with small differences depending on the country.

The major source of energy for olive mills operation is electrical. From the olives reception, through cleaning and washing, grinding, mixing and beating, centrifugation and bottling, all machines work based on electricity. Hot water is also used, heated in a boiler that burns olive solid residues, diesel or other type of biomass.

3.1. Electrical and Thermal consumption

Tables 4 and 5 show average values of standard production process of two-phase olive mills with biomass boiler, for industries sizes of 1.600 and 300 tons of olive oil per year, respectively.

TABLE 4. VALUES OF A STANDARD PRODUCTION PROCESS, INDUSTRY OF 1.600 TONS OF OLIVE OIL PER YEAR.

PROCESS (SEQUENTIAL ORDER)	TYPICAL TECHNOLOGY	Electrical power installed (kW)	Electrical energy consumption (kWh/year)	Thermal power installed (kW)	Thermal energy consumption (kWh/year)
Olives reception, cleaning and storage	Electrical motors	750	21.000		
Mill and paste preparation	Electrical motors, biomass boiler	400	93.000	870	270.000
Separation of phases (decanter) and centrifuge	Electrical motors of the two phases decanter	170	120.000		
Storage	Electrical motors, biomass boiler	170	12.000	200	26.000
Bottling	Electrical motors	70	4.000		
Lighting and other electrical auxiliary processes	Fluorescents	40	38.000		
Thermal auxiliary processes	Heating boiler, forklifts			260	40.000
TOTAL		1.600	288.000	1.330	336.000

Source: Data from an analysis of Cooperativas Agro-alimentarias of six olive oil mills in 2010.

TABLE 5. VALUES OF A STANDARD PRODUCTION PROCESS, INDUSTRY OF 300 TONS OF OLIVE OIL PER YEAR.

PROCESS (SEQUENTIAL ORDER)	TYPICAL TECHNOLOGY	Capacity (t/hour or l/hour)	Electrical power installed (kW)	Electrical energy consumption (kWh/year)	Thermal power installed (kW)	Thermal energy consumption (kWh/year)
Olives reception, cleaning and storage	Electrical motors	40 t/hour	70	3.600		
Mill and paste preparation	Electrical motors, olive pit boiler	25 t/hour	100	13.000	175*	50.000
Separation of phases (decanter) and centrifuge	Electrical motors of the two phases decanter	1.000 l/hour (olive oil)	40	12.500		
Storage			0	0		
Bottling	Electrical motors	25 t/hour	6	710		
Lighting and other electrical auxiliary processes	Fluorescents		1	1.350		
Thermal auxiliary processes	Heating boiler	10 kg pit/hour			175*	10.000
TOTAL			217	31.160	175	60.000

Source: Data from an analysis of the University of Évora, of a representative olive oil mill.

*Thermal power installed is referred to boiler power heating water for both processes (mill and paste preparation and thermal auxiliary processes) which cannot be considered separately.

TABLE 6. COMPARISONS OF PERFORMANCE RATIO BETWEEN BOTH OLIVE OIL MILLS.

	Olive oil producing 1.600 ton of olive oil per year	Olive oil mill producing 300 ton of olive oil per year
Electrical energy consumption per production	180 kWh/ton of olive oil	104 kWh/ton of olive oil
Thermal energy consumption per production	210 kWh/ton of olive oil	200 kWh/ton of olive oil
Electrical power installed	1.600 kW	217 kW
Thermal power installed (boiler, vehicles, etc.)	12.280 kW (boiler) 50 kW (vehicles)	175 kW (boiler)

Source: University of Évora and Cooperativas Agro-alimentarias (2010).

Concerning the thermal energy consumption we can see in the Tables 4 and 5 that biomass consumption is only used in the boiler to heat water used in the production process or for heating the building offices. In most of the olive oil mills boilers olive pit is used as the source of biomass fuel, and in most cases they use the pit obtained during the olive oil production. In figure 12 it is shown the relative contribution of thermal and electrical consumption, and we can see that in the olive oil mills the distribution is approximately half for each component, 54 and 46%, respectively. Some differences can be found between companies in the percentages of energy consumed per process, depending on each olive oil mill processing technologies.

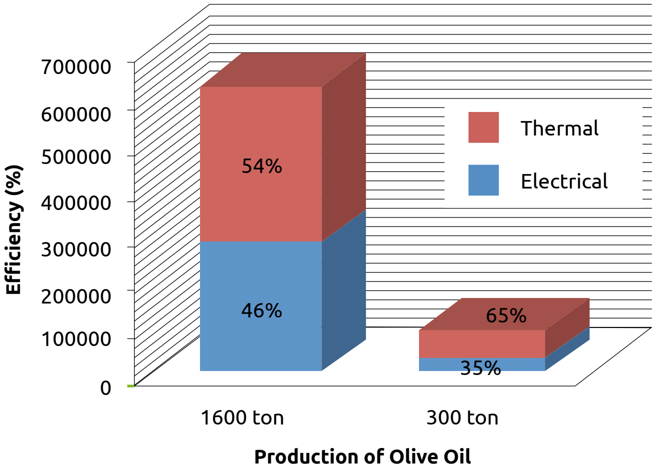

Figure 12. Relative distribution of energy consumption in olive oil mills

3.2. Energy costs

Typical electrical energy cost in the industry is about 0,08 to 0,12 €/kWh; and typical thermal energy cost in the industry is about 0,015 to 0,02 €/kWh. Assuming an average price of 0,10 €/kWh for the electricity and 0,017 €/kWh for the thermal energy we can say that the total energy costs vary between 4.136 and 34.512 € per year for the analysed olive mills, representing a cost per ton between 13,8 €/ton and 21,6 €/ton. Electrical energy represents from 75 to 83% of the total energy costs. However, since most of olive oil mills use their own olive pit residues as biomass for the boilers, thermal energy cost is usually low and related with the olive pit drying and screening. Thus, almost 100% of energy costs come from electrical energy.

3.3 Energy balance (Sankey diagram)

Figure 13 shows the energy balance (thermal and electrical energy) using the Sankey diagram for the analysed industries with 1.600 tons of olive oil processed per year. It is possible to observe the relative distribution of thermal and electrical consumption per production phase. Concerning the thermal energy, the higher consume is for the mill and paste preparation while electrical energy is mainly for the phases separation and paste preparation. This shows that measures to improve energy efficiency need to be focused on this production processes. Reception and lighting are also important, using 4% of the total energy consumption.

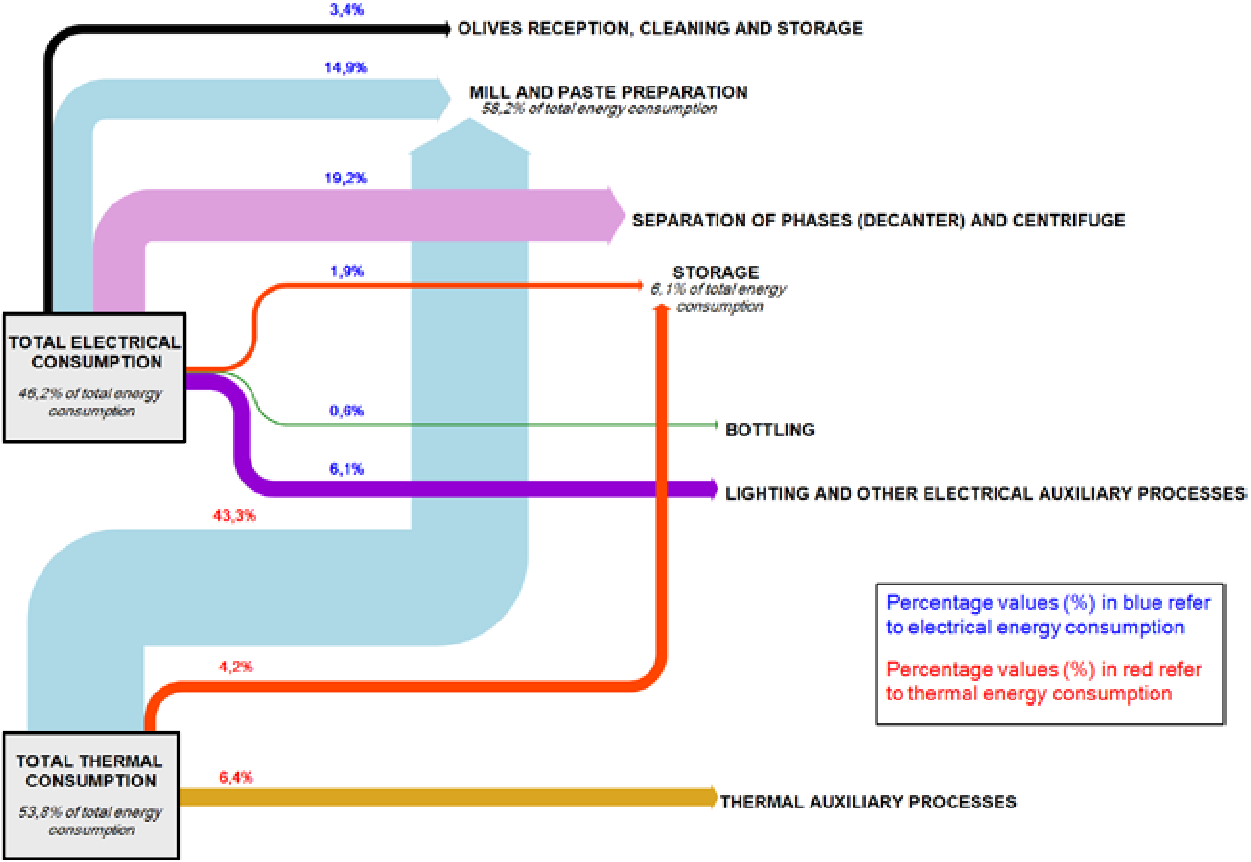

Figure 13. Electrical and Thermal Energy Balance for the standard production industry of 1.600 tons of olive oil per year.

3.4. Sub-sector particularities

This sector is characterized by a seasonal production, concentrated mostly between November and March, and this has great influence in the energy consumption, either electrical or thermal energy. According with the study executed by Cooperativas Agro-alimentarias (2010) the maximum values for total energy consumption are between December and March, which is the full phase production. During the rest of the year energy consumption is only for bottling and for administrative facilities.

Another important aspect is the use of the olive pit, which is a sub-product of this industry. An increasing number of olive mills use their own olive pit residues as biomass for the boiler. The surplus olive pit, or the whole olive pit residue in some olive oil mills, is sold to other companies, being another contribution for the company's incomes. The price is function of the quality, availability in the market and the price of other types of biomass, but as average we can mention values between 75 and 100 €/ton.

4. ENERGY SAVING MEASURES

In the last years, energy efficiency and energy saving measures are common objectives for European politicians and technicians. Improving energy efficiency will contribute to reduce GHG emissions and production costs.

In the following pages some energy saving measures for olive oil mills are presented, based on the TESLA Best Practices Collection (Ortego and Gutierrez, 2013) and on the results of Cooperativas Agro-alimentarias (2010).

4.1. Biomass used in olive mills boilers

In olive oil production it is necessary to separate all olive components after the grinding. In these phases olive dough may be keep at a temperature of 28°C, which is achieved using a boiler with hot water as heat fluid transfer. Due to the high amount of waste produced in the olive oil mills, it is very feasible to use the olives pit as fuel for the biomass boiler to produce heat.

In the case that the olive oil mill has a boiler using fossil fuels (such as natural gas or diesel) a good practice will be to change this boiler by another suitable for solid fuels. These biomass boilers can also use industrial wastes like olive pit. These boilers have the advantage of allowing the industry to use its own waste, save energy and decrease CO_2 emissions.

Considering the change of a diesel boiler by a new one that uses biomass fuel, energy costs are reduced from 46 €/MWh to 13 €/MWh of net heat (considering thermal energy costs due to olive pit drying and screening, and other thermal energy necessities). In olive oil cooperatives in which this change has been implemented, payback time has been 3 years.

Besides that, by establishing a control system in the consumption of biomass, this process could be optimized and extra olive pit could be sold to obtain extra incomes. This biomass boiler can also became more efficient by incorporating an automation system controlling the boiler supply and the input water temperature. Although this measure will not imply any economic saving (biomass is free for olive oil mills using their own olive pit) it could represent and extra source of income by selling extra olive pits.

4.2. Installation of Listellos grinds instead of a screen one

After the reception, the olives have to be grind. The grinding process has a high energy demand due to the use of relatively high power electrical motors. The type of grinding affects the energy demand according to the type of screen used. This is an important stage because it also affects olive oil quality.

A good practice could be to change conventional grinds by a new one that uses listellos. This system allows reducing the size of the particles with less energy consumption due to its design.

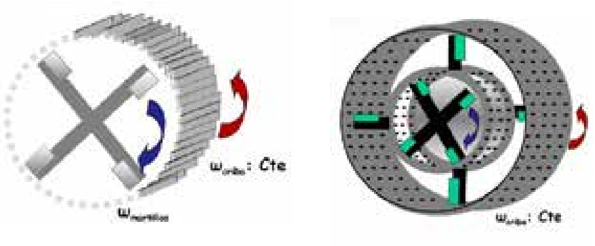

Figure 14. Listello grind scheme and Screen grind scheme

Rotating listellos grind is a kind of grind having a rotating hammer which rotates at 1.500 and 3.000 r.p.m. It includes only one sieve rotating in the opposite direction of the hammers, and with a perforating diameter depending on the desired grain size.

According to available commercial data, with the same energy consumption it is possible to increase olive oil production up to 35%. However, this increase depends on the grind size and on the production quantity. The following figure shows that with the same energy consumption more production can be obtained with listellos grinds than with other types of grinds.

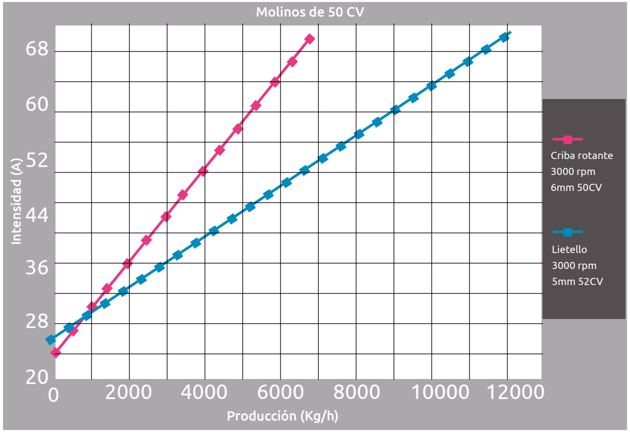

Figure 15. Power versus Production in screen grinds (30 HP) and in listellos grind (50 HP) (Pierallisi).

4.3. Improvements in the separation process

This phase is one of the most energy consuming phases of olive oil processing. The main objective is to separate the olive oil from the rest of the olive components (liquid and solid). In order to reduce the energy consumption of this process, a good option is to install integrated Direct Drive separators in which the homogeneous paste can be easily separated according to different densities of each component.

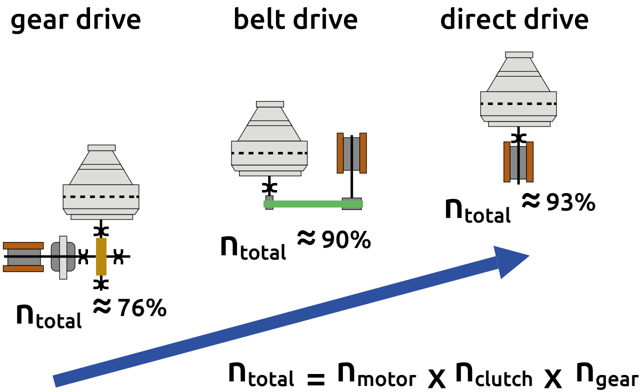

Figure 16. Energy efficiency improvement with different drive systems (GEA Westfalia).

The technology of the separation process is the same, but the power transmission is more efficient. In this integrated Direct Drive separator, the bowl is driven directly by an integrated, frequency-controlled and three-phase motor, improving the level of efficiency. Neither clutch nor belts are used for the transmission.

Although every case must be carefully analysed to evaluate the potential savings, in general terms, savings of up to 15% can be reached.

4.4. Decanting process by tanks instead of vertical centrifuge

Nowadays, a new technology is being implemented to replace the vertical centrifuges by decanting tanks. It implies important energy and water savings. This decanting system is static and 100% of energy savings are possible (compared with vertical centrifuge), as well as a reduction in water consumption and a decrease in liquid effluents from oil washing process. The main disadvantage of this measure is the required space to install the decanting tanks. Studies done by Cooperativas Agro-alimentarias (2010) showed a payback time between 2 and 4,5 years.

4.5. Oil cleaning by mechanical decanting: Oleosim

This systems is similar to the previous one, but it requires less space (so, can treat more oil volumes) and consumes some energy (around 96% less energy than energy consumed by vertical centrifuges, according to provider's data).
Oleosim system separates, clarifies, and purifies the olive oils without discharging effluents. The equipment consists in three modules:

- The dilating equipment will wash olive oil and dilate organic particles by mechanic means activated by a motor at low rotation. It uses a little amount of water to dilate the particles.

- The stabilizer will stabilize the oil, release air from the previous phase and block air to get into the purifier. It will also control the entrance of oil into the purifier.

- The purifier equipment will separate oil from water and will eliminate the water added during the process, as well as organic particles treated in the previous phases. It will also retain solutes from the water-oil dissolution obtained in the stabilizer.

This Oleosim system is equipped with an automatic control system which emits discharges to precipitate impurities to the bottom while clean oil is removed from the top and brought to the cellar. Studies done by Cooperativas Agroalimentarias (2010) showed a payback time for this system between 3 and 5 years.

4.6. Efficient motors

The electricity consumption of motor systems is influenced by many factors. In order to benefit from the available savings potential, the users should aim to optimise the whole system that the motor sub-system is part of, before considering the motor section. The following points will be taken into account to improve motor systems efficiency.

HIGHLY EFFICIENT MOTORS. Energy efficiency classification of electric motors is shown by IEC 60034:2007 legislation. According to this classification there are four possible levels:

- *IE1 : standard efficiency*
- *IE2 : high efficiency*
- *IE3 : premium efficiency*
- *IE4 : super premium efficiency (currently it is not available in the market)*

The European directive EuP (Energy using Product), which concerns the motors defined by IEC 60034-30 legislation, requires to market high performance motors: IE2 from 16th June 2011; IE3 from 1st January 2015 for motors from 7,5 to 375 kW; and IE3 from 1st January 2017 for motors from 0,75 to 375 kW. Figure 17 shows the differences between each motor type.

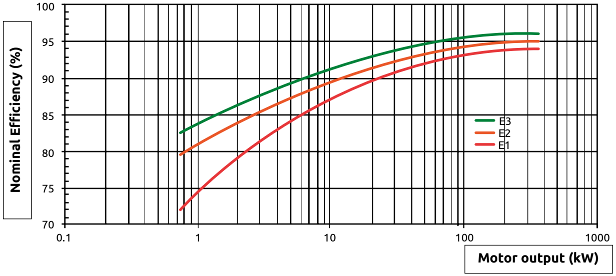

Figure 17. Comparison of the energy efficiency curves for the different motor levels (CIRCE)

PROPER MOTOR SIZING. The maximum efficiency is obtained for the motors working between 60 to 100% full load. The induction motor efficiency typically peaks near 75% full load and is relatively flat down to the 50% load point. Under 40% full load, an electrical motor does not work at optimized conditions and the efficiency falls very quickly. However, motors in the larger size ranges can operate with reasonably high efficiencies at loads down to 30% of rated load. The efficiency of an electric motor according to the load is shown by the figure 18.

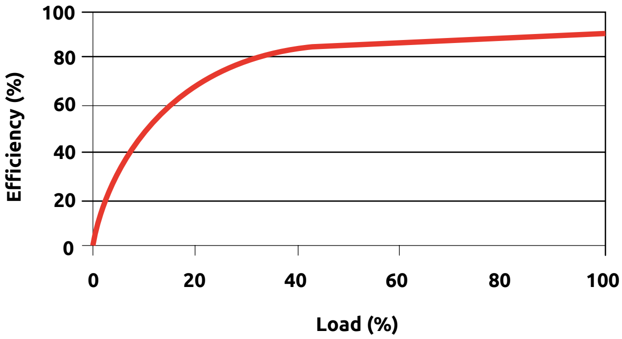

Figure 18. Efficiency of an electric motor according to the load (BREF, 2009)

MOTOR CONTROLS. The aim is to limit to the minimum necessary the motor idling (no load run mode) for example by a presence sensor, a clock, a controlling process, etc. Thus, the way contributing to energy efficiency is switching off the motors when they are not needed, for example by a switch or a contactor to connect and disconnect the motor from the mains.

The adjustment of the motor speed through the use of variable speed drives (VSDs) can lead to significant energy savings associated to better process control, less wear in the mechanical equipment. When loads vary, VSDs can reduce electrical energy consumption particularly in centrifugal pumps, compressors and fan applications. Materials processing applications like hammer mill for example, as well as materials handling applications such as conveyors, can also benefit both in terms of energy consumption and overall performance through the use of VSDs.

Transmission equipment including shafts, belts, chains, and gears should be properly installed and maintained. The transmission system from the motor to the load is a source of losses. These losses can vary significantly, from 0 to 45%. Direct coupling has to be the best possible option (where technically feasible).

4.7. Compressed air system (CAS)

Almost every industry has compressed air systems for many different aims: press machines, cooling systems, compressors, conveyors, etc. This compressed air needed can be produced by the machine itself, or by one (or more) compressed air equipments supplying the overall industry necessities. Energy efficiency in compressed air systems can be controlled by the following measures.

OPTIMIZING SYSTEM DESIGN. Many existing CASs lack an updated overall design. The implementation of additional compressors and various applications in several stages along the installation lifetime frequently results in a suboptimal performance of a CAS. One fundamental parameter in a CAS is the pressure value which must satisfy 95% of all needs, using a small pressure-increasing device for the rest. Another fundamental design issue for a compressed air system is dimensioning the pipework and positioning the compressors. A properly designed system should have a pressure loss of less than 10% of the compressor's discharge pressure to the point of use.

VARIABLE SPEED DRIVE (VSD) AND STORAGE VOLUME. Every time the air requirements of the process fluctuate (over times of the day and days of the week) the VSD and the storage volume will help reducing energy demanded by the compressed air system. The savings can be up to 30%, although the average gain in a CAS, where one compressor with a variable speed drive is added, is about 15%. In the other hand, a storage volume helps to reduce the pressure demand fluctuations and to fill short-timing peak demands.
Variable speed drives on compressors, have also other benefits: stable pressure, higher power factor which keeps reactive power low, and smooth start-up at low speeds extending the operating lifetime of the compressor.

REDUCING COMPRESSED AIR SYSTEM LEAKS. The reduction of compressed air system (CAS) leaks often has by far the highest potential gain on energy. Leakage is directly proportional to the system pressure (gauge). Leakages are present in every CAS and they are effective 24 hours a day, not only during production. The percentage of compressor capacity lost to leakage could be less than 10% in a well maintained large system, and up more to 25% in a poorly maintained 'historically grown' CAS.
Preventive maintenance programmes for compressed air

systems should therefore include leak prevention measures and periodic leak tests. An additional way to reduce leakage is to lower the operating pressure of the system: with lower differential pressure across a leak, the leakage flow rate is reduced.

FEEDING THE COMPRESSOR(S) WITH COOL OUTSIDE AIR. For thermodynamic reasons, the compression of warm air requires more energy than the compression of cool air. This energy can be saved simply by feeding the compressed air station with outside air. A duct can be installed connecting the outside and the intake of the compressor, or to the entire compressed air station. The outside intake should be placed on the north side or at least in the shade for most of the time.

OPTIMIZING THE PRESSURE LEVEL. The lower the pressure level of the compressed air generated, the more cost effective the production. However, it is necessary to ensure that all active consumers are supplied with sufficient compressed air at all times. The cheapest way to adjust the pressure range of a compressor is to use mechanical pressure switches. Pressure can also be readjusted by means of a frequency converter compressor functioning as a peak load compressor and adapting its speed drives to specific compressed air needs.

4.8. Variable speed drives

Variable speed drives can be installed in every process working at variable load, for example: centrifugal pumps, fans, grinds, hoppers, conveyors, compressors for compressed air systems or for cooling systems, etc. Using it, the energy consumption of motors is lower since consumption is adapted to real process needs.

Figure 19. Variable speed drive

Variable speed drives, also called adjustable speed drives, control the rotation speed of motors located in pumps, fans, conveyor belts or other machines. These drives operate converting constant electric grid input parameters (volt, frequency) in variable values. This change of frequency causes a change in the motor speed and also in the torque. It means that motor speed can be regulated according to external parameters such as temperature, flow or charge level in conveyors or hoppers. Speed control can be very important in the energy efficiency of processes.

Energy savings depends of motor power, load, motor operation profile, and yearly operation hours. A motor working with or without speed drive can vary its energy consumption up to 50%.

4.9. Insulation

In several TESLA sub-sectors it is necessary to transfer heat either for heating or for cooling processes. It takes place, for example, in cooling fermentation of wineries in which several pipes transport a cold fluid from cooling machines to the fermentation tanks; or in boilers where hot water or steam is transported in pipes from boiler to the place in which it is used. In this kind of facilities, the maintenance conditions of insulation materials are very important for avoiding thermal losses and condensation problems. Thus, insulation materials must follow several recommendations: to avoid rust problems, to protect from UVA rays, to be dry (pay attention to leaks that affect insulating capacity of insulating materials), to be flexible and easy-to-install, and to have low thermal conductivity (0,04 W/m°C or lower). Common range of working temperatures for insulating materials is between -50°C and 110°C.

PIPES INSULATION. Potential savings achieved will depend on: pipe diameter and length (or insulating surface size), temperature difference, insulating material thermal resistance and insulating material thickness. Following, a simple example is presented: two pipes which transport a hot fluid, one with insulation material and the other without insulation material. In both cases, the fluid temperature is 60°C, air temperature is 15°C, pipe length 350m, pipe diameter 150mm, and the insulation material is polyurethane with 31mm thickness and thermal conductivity of 0,04 W/m°C. Comparison between heat losses in these two pipes shows that energy losses of the pipe with insulating material will be reduced in 85%, which means that a huge amount of energy can be saved simply by using thermal insulation in pipes.

VALVES INSULATION. Besides that, the fittings, valves and other connections are usually not well insulated. Re-usable and removable insulating pads are available for these surfaces. Considering an operating temperature of 150°C, room temperature 20°C, and valve size 150mm, potential energy savings for installing removable insulated valve covers are up to 970W (BREF, 2009).

Moreover, as a general rule, any surface that reaches temperatures greater than 50°C where there is a risk of human contact, should be insulated to protect personnel.

Figure 20. Pipe insulation in good conditions.

4.10. Heating water or air

Hot water is needed in all industries for many different uses: from hygienic and sanitary water till preheating water for boilers or steam production. Several systems can be used for heating water. In this handbook three of them are mentioned, since they do not imply an increase in energy consumption.

HEAT RECOVERY FROM AIR COMPRESSORS. Most of the electrical energy used by an industrial air compressor is converted into heat and has to be conducted outwards. In many cases, a properly designed heat recovery unit can recover a high percentage of this available thermal energy and put to useful work heating either air or water when there is a demand. Two different recovery systems are available:

- **Heating air:** the heat recovered can be used for space heating, for oil burners or any other applications requiring warm air. Ambient air is passed through the compressor where it gains the heat resulting of the compressed air process. The only system modifications needed are the addition of ducting and potentially another fan to handle the duct loading and to eliminate any back-pressure on the compressor cooling fan. These heat recovery systems can be modulated with a simple thermostatically-controlled hinged vent.

- **Heating water:** it is also possible to use a heat exchanger to extract waste heat from the lubricant coolers found in packaged air-cooled and water-cooled compressors to produce hot water. Depending on design, heat exchangers can produce non-potable or potable water. When hot water is not required, the lubricant is routed to the standard lubricant cooler. Hot water can be used in boiler systems or any other application where hot water is required.

Heat recovery systems are available for most compressors on the market as optional equipment, either integrated in the compressor package or as an external solution. A properly designed heat recovery unit can recover approximately 50 - 90 % of this available thermal energy.

HEAT RECOVERY BY ECONOMIZERS OR CONDENSER. Install a heat recovery system in boilers allows recovering heat from exhaust gases. In boilers too many heat is lost by fumes so by recovering part of this heat, fuel energy consumption will be reduced. A heat recovering is only a heat exchanger installed in fume smokestack that transfers heat from fumes to the boiler water or to other thermal process.

The installation of economizer after the boiler allows reaching an energy saving up to around 5% (fumes temperature decrease cannot exceed a limit because it would entail corrosion in heat exchanger and in fume smokestack).

Condenser allows recovering energy that is contained in combustion fumes by means of condensate the water steam of them. The energy saving depends on combustion fumes temperature decrease. In real cases, the installation of condenser after the boiler allows reaching an energy saving up to 15%.

SOLAR THERMAL FOR HEATING WATER. High performance solar collectors are equipped with a special glass with an energy transfer higher than 92%. The absorber is manufactured in copper with a selective treatment (TINOX) and they can they can be used at a maximum temperature of 250°C and have an optical performance of 75% and transmittance coefficient of 2,9 $W/m^2°C$.

Potential savings achieved will depend on desirable solar energy cover rate. Common savings are around 50 - 70% depending on weather conditions and energy demand. It means that energy consumption in boiler can be reduced, and so, less fossil fuel will be consumed and less CO_2 will be emitted.

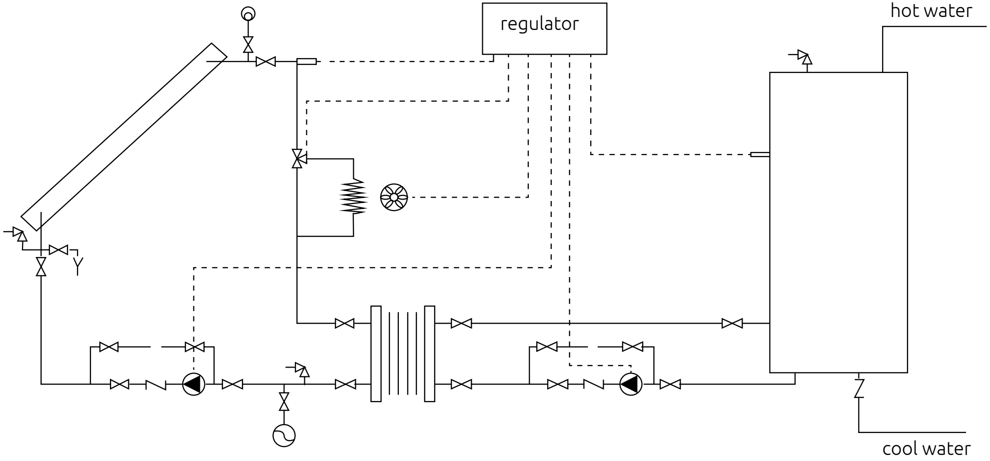

Figure 21. IMS Solar thermal system scheme (CPC solar).

4.11. Lighting

In TESLA industrial sub-sectors a large amount of lighting inside buildings is necessary. Currently there are installed a large variety of lamps, mainly gas discharge lamps (fluorescents, high pressure sodium or mercury steam) or halogen technologies. These devices are very inefficient and can be easily replaced by new ones using new LED technologies. This LED technology has longer lifetime (more than 50.000 hours), less maintenance operations, colour index of 80%, colour temperature of 4.000 K, and energy saving up to 75% (compared with gas discharge lamps or halogens). Lighting flow is 10.000 lm (for 110 W) and 20.000 lm (for 210 W). Besides that, light replacement is very easy due to LEDs design. The following table shows energy savings considering the replacement of fluorescent lamps by LEDs.

TABLE 7. ENERGY SAVINGS ACHIEVED.

CURRENT SITUATION	ENERGY EFFICIENCY SITUATION	POWER REDUCTION
2x18W fluorescent tube (total installed power 42W considering an electromagnetic ballast)	LED18S (19W)	54%
2x58W fluorescent tube (total installed power 136W considering an electromagnetic ballast)	LED60S (57W)	58%
250W mercury steam lamp (total installed power 268 W considering auxiliary devices)	BY120P (110 W)	58%
400W mercury steam lamp (total installed power 428 W considering auxiliary devices)	BY121P (210 W)	51%

Source: Philips

4.12. Capacitor batteries to decrease reactive energy

Many different devices, such as motors or discharge lamps, need an electromagnetic field to work. Since not all motors work at nominal charge, it causes a reactive energy consumption that must be paid within the electricity bill. This reactive energy consumption can be avoided by using capacitor batteries.

Figure 22. Capacitor batteries.

Capacitor batteries are available for different power, from 7,5 kVAr to 1.120 kVAr, and are installed next to power transformer of the facilities. Power factor compensation is usually done for the overall installation's machines.

This is more an economic saving measure than an energy saving measure, although this equipment has also benefits for the electricity grid due to the increase of energy transmission capacity obtained for the electrical grid.

4.13. High efficiency in power transformers

All industries' facilities have a power transformer to convert electricity that comes from the grid. However in old installations transformers are very old, use oil and their efficiency is not as high as possible. The worst the transformer current situation is, the higher the energy consumption will be. This measure will be specially recommended in those industries having high yearly operation hours, such as animal feed factories or fruits and vegetables processing plants.

Dry transformers reduce transformer losses up to 70 %, and are: safe, free of maintenance, excellent capacity to support overload and excellent resistance to short circuit.

4.14. Management tools

Industries have a lot of electrical devices to develop their processes. Consequently, a lot of electrical devices are distributed along the facilities, and having them in right operation conditions and with the highest efficiency value is very complicated. To control and monitor all processes from the energy point of view allows taking the best decisions to improve energy efficiency.

Energy management software is composed by measuring devices, a communication grid and a software program that allows managing, monitoring and using information to improve energy consumptions in the facilities.

These tools are recommended for the implementation of an energy management quality system in an industry according to EN 16.001/ISO 50.001 Standards requirements.

Figure 23. Control panel.

5. CONCLUSIONS

In the last years, energy efficiency and energy saving measures are objectives of European countries in general and also for the agro-food industry. Improving energy efficiency will contribute to reduce GHG emissions and production costs. Several factors influence energy consumption, and has shown in this document there are important differences in energy consumption during the several phases of the olive oil production process.

As a conclusion, in olive mills, it is necessary to optimise energy consumption and with that energy efficiency will be improved and will also contribute to reduce energy costs and GHG emissions. With the study of the energy consumption along the several production phases and with the knowledge of the energy balance, it is possible to identify critical points and to use suitable techniques.

In olive oil mills it is possible to improve energy efficiency essentially with some interventions in the equipment, lighting, automation, and the use of olive pit as biomass fuel for the boilers. Also the use of insulating material in the pipes that transport hot water can minimize heat losses and decrease energy consumption. Another important aspect is to use equipment correctly designed for the production volume, improving the production system functioning and saving energy. Finally a correct and frequent maintenance of the equipment is also very important to save energy.

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