Technical Assessment Report on Solar Thermal Energy Use in Cork Industry

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1. Introduction

Nowadays, current industrial applications seek, whenever possible, to meet thermal needs on sustainable technologies that are economically viable and environmentally friendly. Despite the high potential, a number of challenges still have to be overcame. Those include maximum attainable temperatures, seasonal and daily transience in solar heat supply and its integration in the industrial processes (among others).

For that purpose, the implementation of solar thermal energy into industrial applications has been recognised and addressed by IEA Solar Heating & Cooling Programme (established in 1977), in a number of different research studies, including those ones found in Task 33 and Task 49 (IEA, 2015[a]; IEA, 2015[b]; and IEA, 2016) supported by the International Energy Agency (IEA) agenda. In this area, a task called Solar Heat for Industrial Processes (SHIP) emerges, which suggested that solar thermal systems have a significant potential in the sector, even though in an early stage of progress. This activity was led primary by the Commonwealth Science and Industrial Research Organization (Fuller, 2011).

General motivations to implement solar systems in cork industry include: i) economics, with respect to worldwide increasing gas prices, and ii) environmental, with respect to the carbon-dioxide footprint associated to this specific industrial sector.

The main objective of this report is to assess the technical assessment of solar thermal use in the cork industry, more specifically in the António Almeida - Cortiças S.A., located in the north of Portugal. For that purpose, a close collaboration was establish with this industry through several activities namely: i) energetic audit and ii) different actions of monitoring and implementation of the Energy Consumption Rationalization Agreement (ECRA).

Considering these issues, a target reduction for energy consumption was establish both according to the current consumption of the installation as well as with the Portuguese legislation. For that purpose, a full energetic characterization of major energy-intensive equipment's and systems were of concern.

Moreover, the identification of measures with technical feasibility to be implemented were addressed whenever deemed suitable in order to increase energy efficiency and/or reduce the energy costs associated. Approached methodologies and procedures towards the implementation of solar systems for thermal energy use in the facility are also of concern and were conducted according to current best available practices or through data from energy suppliers.

The information reported is based on available data and findings addressed on the energetic audit report (David Salema et al., 2012), on a later report on the implementation and progress of rationalization of energy consumption agreement (David Salema and Miguel Miranda, 2018) as well as on other site visits.

2. Characterization of cork industrial production

In Figures 1 to 3 are presented the flowcharts of natural corks, cork stoppers and disks and, cork shavings production (respectively) as well as all major thermal energy needs that may allow the integration of solar thermal solutions (highlighted in dashed red).

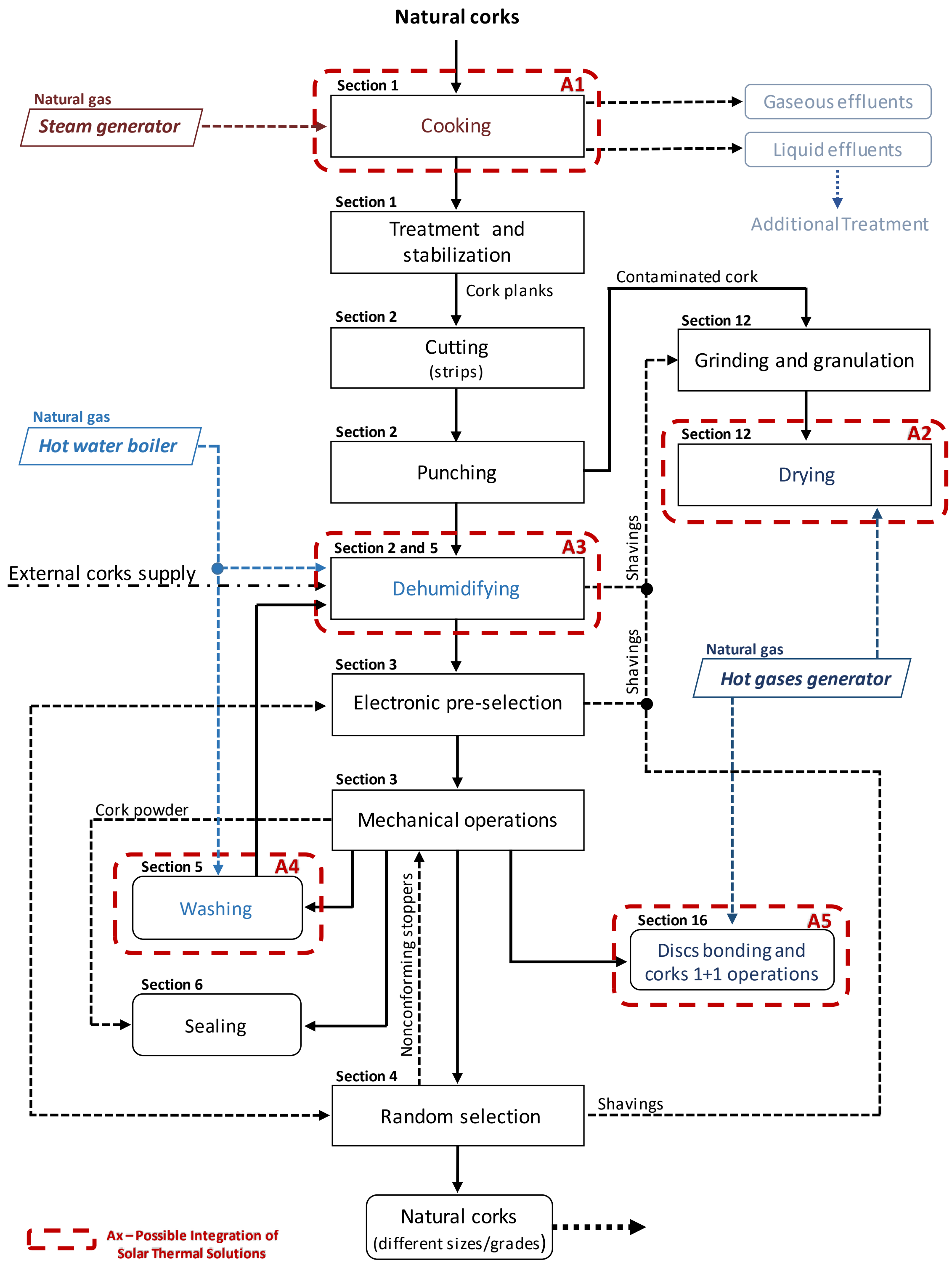

Figure 1 - Flowchart of natural cork stoppers industrial production

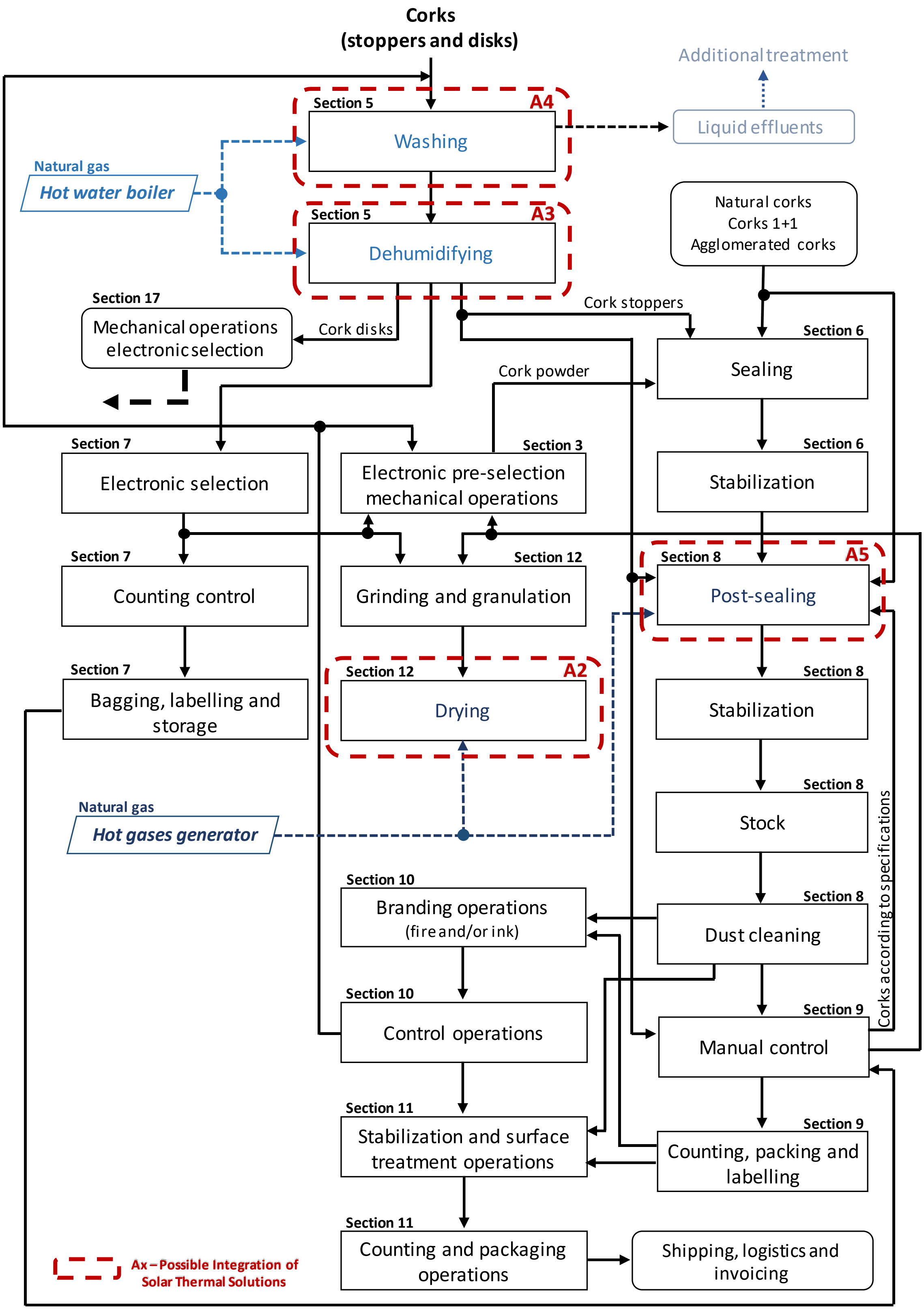

Figure 2 - Flowchart of cork stoppers and disks industrial production

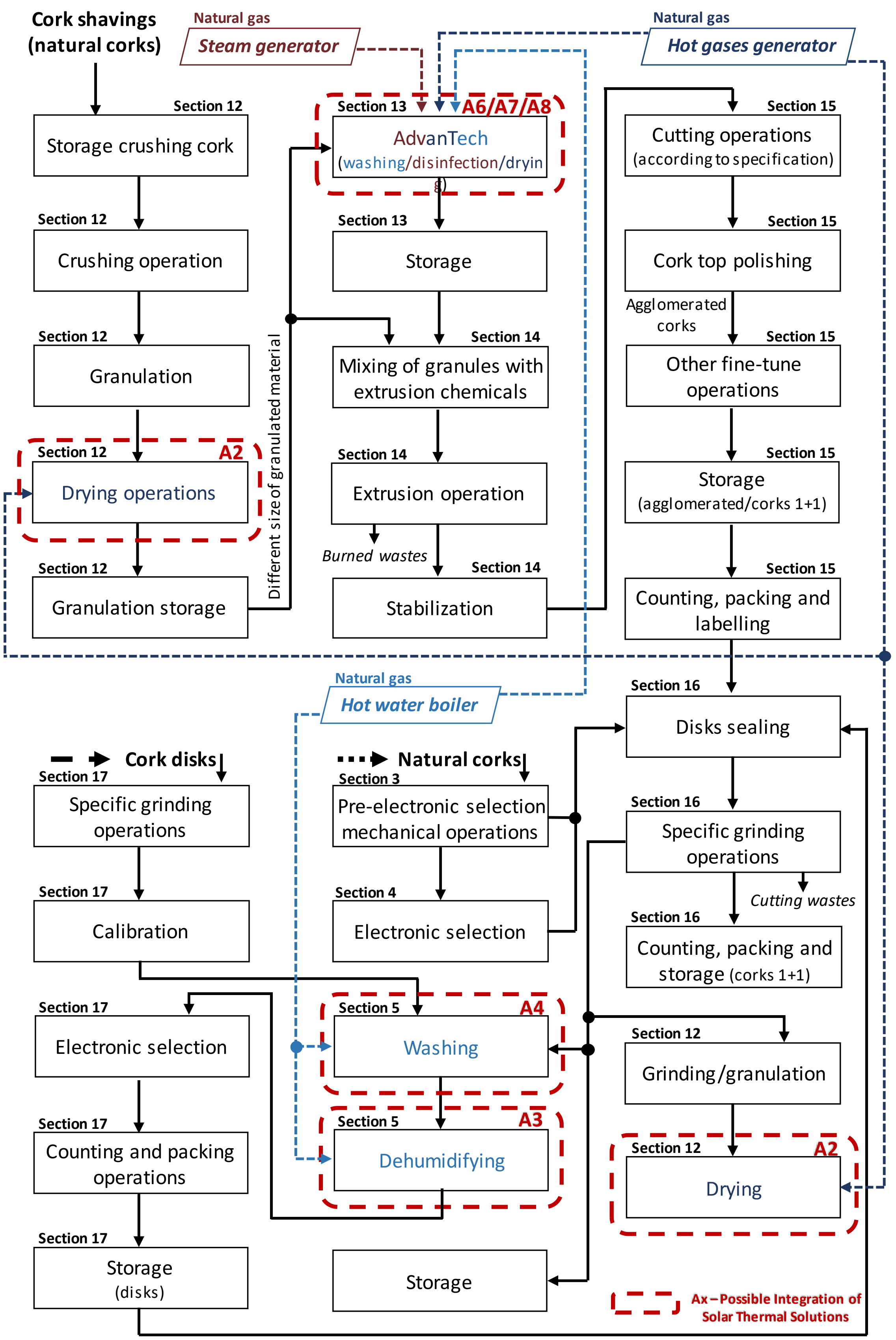

Figure 3 - Flowchart of cork shavings (of natural corks) industrial production

The company focuses mostly its production on cork stoppers reaching an annual production of around 180 million in 2017. Stoppers industrial production are distributed according to process as being: i) natural corks (10.1%), ii) corks 1+1 (22.7%), iii) cork stoppers (61.0%) and iv) micro-granulated stoppers (6.3%). Because the main goal is the production of corks of different sizes and grades, the cork boards (planks) are the primary raw material for the industrial process which require high quality standards in the different phases of production (Sefton and Simpson, 2005; Cork, 2015; Oliveira et al., 2015). For that purpose, different quality control systems could be found in a number of sections during production.

Currently, the major thermal energy requirements used in the different processes are mainly supported on natural gas, which is used in different energy production systems. Those are the following: i) steam generators, ii) hot gases generators and iii) hot water boilers.

In addition to those, other major thermal energy intensive consumer is the AdvanTech system (used for disinfection and decontamination of cork granulates). This system gathers all three previously referred thermal production systems for the following equipment: i) a granulated washing machine (directly fed by steam from a steam generator) and by hot air from an flue gas/air exchanger system, ii) a dehumidifying machine fed by both hot and dry air from a chiller and a hot water boiler.

Concerning natural cork production (Figure 1), thermal energy needs are used in cooking process (A1) in which cork planks are treated by immersion in stainless steel batch reactor with hot water at 95-98ºC (during 1h40min.). This process uses direct injection of saturated steam at 135ºC (3bar) produced in a water-tube steam generator. This process also aims at removing the organic material embedded in the cork planks and enable the cork to reach the ideal moisture content for processing. Then, cork planks are submitted to direct steam, during 40 minutes, to complete the internal physical structural treatment as well as to avoid any bacteriological contamination. This process aims also at extract water-soluble substances as well as to increase the thickness and to improve cork flexibility and elasticity.

Other major thermal energy requirements could be found (in subsequent processes). Those include the drying (A2), dehumidification (A3), washing (A4) and disks bonding and cork 1+1 operations (A5).

In the drying process, a direct counter current combustion flue gas (natural gas burning from hot gas generator) is mixed with air to dry the cork material at temperatures of around 155ºC. This late process is crucial to stabilize the material, to reduce internal stresses in order to improve technological characteristics as well as the quality of finish product. Those include (among others) colour, porosity, elasticity, moisture and oxygen permeability (Carpintero et al., 2015; Belghit and Bennis, 2009).

After cutting and punching stages, natural corks from the company could be mixed with other ones (external corks supply) and submitted to a dehumidification (A3) treatment. The dehumidification consists of two hot-air chambers and two forced-air condensing dehumidifiers. These systems allows recirculating the produced hot air for drying purposes at temperatures of around 70ºC.

Near the end of the process, the natural stoppers are polished (mechanical operations), resulting in a clean and smooth finish and then submitted to a washing (A4) process, in an aqueous hydrogen peroxide (H_2O_2) solution (both for disinfection and homogenization purposes). A water-boiler system supply all the hot water required to the washing machines at 75ºC.

After similar mechanical operations, corks 1+1 (technical corks) used as raw-material for cork shavings and, granulated cork as surplus material from cork boards (after production of natural cork stoppers) are submitted to discs bonding and corks 1+1 operations (A5). In this stage, all thermal energy requirements are supported by a hot gases generator, which through a heat exchanger (hot gases/air) allows a constant air temperature flow inside the chambers of around 85ºC.

The production of corks (Figure 2) and cork shavings (Figure 3), although different in process layout, are similar in thermal energy systems. From those, the most intensive thermal energy consumer is the AdvanTech system (60-144 ºC) and using different heat transfer mediums.

In Table 1 is presented the information regarding the process specification and main technical requirements, in Table 2 the thermal energy consumption by process/operation (on annual basis), while in Table 3 all major thermal energy intensive consumers (on annual basis).

Table 1 - Process specification and main technical requirements (David et al., 2012)

Process Type / System	**Equipment**	**Temperature**	**Process Requirements**
		ºC	**heat medium**
A1 - Cooking	batch reactor	95-98	direct saturated steam
A2 - Drying	rotative driers	154	direct combustion gases
A3 - Dehumidifying	dehumidifier	70	hot water/air exchanger
A4 - Washing	washing machine	75	hot air/water exchanger
A5 - Hot-air chambers	hot air chamber	85	hot gases/air exchanger
A6 - AdvanTech	advanTech	144	direct saturated steam
A7 - AdvanTech	advanTech	76	hot gases/air exchanger
A8 - AdvanTech	advanTech	60	hot water/air exchanger

Table 2 - Thermal energy consumption by process/operation (David et al., 2012)

Process / Operation	**Thermal Energy Consumption (1)**	
	MWh	**%**
A1 - Batch reactor/Sterilization	156	6
A2 - Rotative driers	213	8
A3 - Dehumidifier	55	2
A4 - Washing machines	208	8
A5 - Disks bonding and Corks 1+1 operation	51	2

(1) - annual values report to 2011

Table 3 - Thermal energy intensive consumptions (David et al., 2012)

Possible Integration of Solar Thermal Energy Solutions	Thermal Energy (1)			
	Consumed (2)	Effective (3)	Overall	
	kW	kW	MWh	%
General Systems				
Steam generator - (A1)	394	335	156	6
Hot gases generators - (A2) + (A5)	59-88 & 14-19	5-8 & 11-15	264	10
Hot water boiler - (A3) + (A4)	151	140	263	10
Total (1)			*683*	*26*
AdvanTech System				
Steam generator - (A6)	280	223	439	17
Hot gases generators - (A7)	161	83	562	22
Hot water boiler - (A8)	127	115	192	8
Total (2)			*1193*	*47*
Other Unidentified Consumptions				
Branding operations + Manual control + Others	---	---	669	27
Total (3)			*669*	*27*
Total (1+2+3)			***2545***	***100***

(1) Annual values report to 2011
(2) Thermal energy consumed in the process
(3) Thermal energy require for the process

3. Integration of solar thermal solutions into industrial process

3.1 Some considerations

The industrial sector (in general) needs to minimise their exposure to the increasingly volatile costs of energy supply and the instability in supply as well. Despite all technical potential as well as all environmental benefits of using solar heat in industry, actual deployment levels remain quite low. Market penetration could be achieved through more awareness of the benefits of solar process heating, especially in industrial clusters of small- and medium-size enterprises.

On the topic of solar renewable energy use, current technological improvements made solar thermal systems more reliable and economically viable for industrial thermal energy processes (Amir et al., 2015). Thus, solar heat have great potential to be used at both different temperatures ranges and profiles. Moreover, the integration of solar thermal energy within an industrial process could provide significant achievements towards both energy efficiency and reduction of carbon dioxide emissions. Currently less attention has been given to the integration of solar thermal systems in industry to low and medium temperature heat process (Mathias et al., 2016)

Although the substitution of conventional systems that burn fossil fuels for their performance for solar-base systems seams suitable, the integration of renewable solar energy into industrial processes could present a number of challenges. Some examples include the non-continuous nature of supply when featuring process energy characteristics (e.g. continuous or non-continuous operating rates and heat transfer medium), the relatively low energy cost of current used fossil fuels (e.g. natural gas) and the high capital cost for existing solar technology (especially for small-scale solutions without financing mechanisms) (IEA and IRENA, 2015).

In order to find the available solar heat, radiation and temperature data for the plants site are most required. Due to the non-continuous nature of the solar resource, storage and control systems are usually required and need to be carefully considered as they may add significant costs to the system (Tobias et al., 2017).

Considering the solar thermal energy profile, processes characteristics/needs, and targeting optimal profile for solar fraction, two main scenarios may be consider in the integration of solar thermal into industrial processes: i) solar system provide all the process heat demand at a target temperature or ii) solar system can be designed to provide partially the process heat demand at a target temperature or even at a variable temperature which maximizes solar system efficiency (Martin et al., 2010).

When considering the first scenario, the daily demand considering a non-continuous profile, the site specific nature of solar radiation and ambient temperature profiles need to be known to calculate the required collector area and, if appropriate, the thermal storage system. Note that the specific solar radiation and the micro-meteorological factors could change significantly due to seasonal variations. Consequently, these variations needed to be quantified accurately in a statistical manner in order for the trade-off between thermal storage system and solar collector area can be carried out with a degree of confidence (Martin et al., 2010; José et al., 2011).

When considering the second scenario, in which the system is design to partially support the heat demand of the industrial process, the short-term variations in the heat supply and demand as well as overall seasonal differences are of less importance.

Regardless the chosen scenarios, it will be expectable that after the solar energy is capture (whenever it is available), the balance of the heat demand needs to be supplied through other hot utility, either considering a target temperature (changing the mass flow rate through the collectors), or a fixed mass flow rate (variable outlet temperature) (Tobias et al., 2017). Moreover, the location of type of collector, working fluid, storage and heat exchange system and loads are factors that need to be consider as well (Mekhilef et al., 2011).

3.2 Main available solutions

According to different targeting temperatures and profiles, plants thermal energy consumption, site location and available radiation, type of process, heat transfer medium and, time and period of use (among others), different solutions could be technically implemented in the industry, thought each collector may feature a specific application.

For example, flat-plate collectors are properly designed for low-temperatures applications, concentrating and sun-tracking parabolic trough collectors (PTC) are more suitable for high temperature applications (> 250ºC), two axis tracking collectors are generally applied to power generation, stationary (non-tracking collectors) and single-axis PTCs are mainly used in industrial heat processes.

According to Soteris, in Table 4 are presented the most common solar energy collectors as well as the main characteristics according to motion criteria (Soteris Kalogirou, 2004). The concentration ration, defined as the aperture area divided by the receiver/absorber area of each type of collector is presented as well. Moreover, in Annex A is presented some additional features of solar thermal systems for integration into industrial processes, while in Annex B is presented an overview of some low-to-medium range temperature collectors approached in the course of IEA SHC Task 33.

Table 4 - Solar energy collectors (main solutions and characteristics)

Motion/Collector type	**Absorber Type**	**Concentration Ratio (1)**	**Temperature Range (ºC)**
Stationary			
Flat Plate Collector (FPC)	Flat	1	30-80
Evacuated Tube Collector (ETC)	Flat	1	50-200
Compound Parabolic Collector (CPC)	Tubular	1-5	60-240
Single-axis tracking			
Fresnel Lens Collector (FLC)	Tubular	10-40	60-250
Parabolic Trough Collector (PTC)	Tubular	15-45	60-300
Cylindrical Trough Collector (CTC)	Tubular	10-50	60-300
Two-axis tracking			
Parabolic Dish Reflector (PDR)	Point	100-1000	100-500
Heliostat Field Collector (HFC)	Point	100-1500	150-2000

(1) Concentration ratio = aperture area divided by the receiver/absorber area of the collector

3.3 Solar thermal main considerations featuring most intensive thermal cork processes

When considering the integration of solar thermal energy into industrial processes, a number of issues should be considered. Those include:

a) The overall thermal energy consumption of the installation (on annual time-scale);

b) The process/system that require thermal energy;

c) The period of the day and the time in which thermal energy is required;

d) Solar fraction;

e) Process requirements (temperature range and type of heat transport medium).

The production of natural cork stoppers (Figure 1), cork stoppers and disks (Figure 2) and cork shavings (Figure 3) as well as the heat demand of each main process (cooking, drying, dehumidification, washing, discs bonding and cork 1+1 operations, post-sealing and the AdvanTech system for different purposes), are currently supported by a number of natural gas thermal energy production units (steam and hot water generators and hot water boilers).

Water is the main running fluid in most of the thermal applications due to its availability, thermal capacity, storage convenience and low cost. Nevertheless, for temperatures above 100ºC, pressurized systems are require and cracking and oxidation are few concerning issues involving these systems (Mekhilef et al., 2011). As a result, costs of storage systems may increases remarkably.

Although the technology of solar thermal collectors for medium temperature applications is not new, only few collectors are available worldwide. Existing collectors are currently based on different technologies, designs and concepts, sizes and materials. Therefore, no standardized designs of collector components are still available (Iñigo et al., 2016).

For an adequate integration of solar thermal energy solutions, the acquisition of additional equipment such as storage systems, heat exchangers and control units and piping (among others) could be of concern and all technical adjustments must be considered in such way that previously production conditions are the same.

3.3.1 Hot gases thermal needs/operations

A number of cork operations are carried out in different stages of the process and require hot gases at different conditions (provided by specific thermal energy producer equipment's). The major thermal consumers identified are the following:

a) AdvanTech system (A7), producing hot gases at 154ºC for a process temperature condition of 76ºC. A total of 5.7 ton/h of hot air are produced (80 min/cycle and 4 cycles/day) which represents a thermal energy consumption of 83 kW. The annual thermal energy consumption is around 562 MWh fully supported on natural gas;
b) Two rotative driers (A2), operating at 155ºC in which direct combustion gases are used in counter current flow, which represents a thermal energy consumption of 5 to 8 kW. The annual thermal energy consumption is around 213 MWh fully supported on natural gas;
c) Cooking batch reactors (A1), operating with direct saturated steam at 95-98ºC (499 kg/h), which represents a thermal energy consumption of 335 kW. The annual thermal energy consumption is around 156 MWh fully supported on natural gas;
d) Cutting and punching operations (cork planks) require drying cycles of 24h in hot-air chambers at 40ºC to 50ºC (180m^3 of total hot air per cycle);

e) Four cork 1+1 machines (A5) (including discs bonding and post-sealing chemical treatment), require hot air at 85ºC, which represents a thermal energy consumption of 11 to 15 kW. The annual energy consumption is around 70 MWh supported on electrical resistances.

Considering an approach based on hot air as heat transfer medium at low-temperature demand (up to 85ºC) without changing current process heat transfer medium, Flat-Plate Collectors (FPC) and Compound Parabolic Collectors (CPC) could be suitable for the AdvanTech system (A7), for cutting and punching operations and cork 1+1 operations (A5), thought the use of heat exchangers for air heating purposes is most require. Although dehumidifying (A3) process uses hot water/air heat exchangers for operating temperatures of around 70ºC, these collectors type could be considered suitable avoiding the use of current heat exchangers.

Considering saturated steam as heat transfer medium for low-to-medium temperatures ranges (< 200ºC), Parabolic Trough Collector (PTC) and Fix Focus Trough Collector (FFTC) may be suitable for the Cooking batch reactors (A1). These collectors may also be used to support the AdvanTech system (A7) which produces hot gases at 154ºC for heating air for a process required temperature of 76ºC. Moreover, the use of solar driers considering the used of an additional heat exchanger system for continuous airflow systems (rotative driers (A2)) could also be a suitable solution and have been successfully used in a number of other applications (Hans et al., 2007; Mekhilef et al., 2011).

3.3.2 Other hot gases thermal needs/operations

a) AdvanTech system (A6), producing saturated steam at 144ºC (3 bar), which represents a thermal energy consumption of 223 kW. The annual thermal energy consumption is around 439 MWh fully supported on natural gas;

Considering saturated steam as heat transfer medium for low-to-medium temperatures ranges (< 200ºC), Parabolic Trough Collector (PTC) and Fix Focus Trough Collector (FFTC) may be suitable for the AdvanTech system (A6).

3.3.3 Hot water thermal needs/operations

Regarding cork operations in which thermal needs are supported by the use of hot water as heat transfer medium, the major consumer systems are:

a) Washing machines (A4), operating with hot water at 75ºC. The annual thermal energy consumption is around 208 MWh supported on natural gas and electrical resistances and, the Dehumidifier (A3), operating at 70ºC with two hot water/air heat exchangers. A standard dehumidification process is around 14 hours/cycle. The annual thermal energy consumption is around 55 MWh fully supported on natural gas. Both systems represents a thermal energy consumption of 140 kW.

b) AdvanTech system (A8), producing hot water at 60ºC (11.6 ton/h for a 5 to 6 h/day operating time) for different purposes (e.g. drying and dehumidification processes), which represents a thermal energy consumption of 115 kW. The annual thermal energy consumption is around 192 MWh fully supported on natural gas.

Considering the hot water as heat transfer medium for low-temperature operation, Flat-Plate Collectors (FPC), Stationary Compound Parabolic Collectors (SCPC), Compound Parabolic Collectors (CPC), Maximum Reflector-Collectors (MRC) and Combined Heat and Power Solar Collector (CHPSC) could be a possible solution for washing machines (A4) operations and the AdvanTech system (A8). Although dehumidifying (A3) operations require hot air at 70ºC, these collector types may also be used taking advantage of the heat exchangers already existent in the installation.

Regardless the technology level, the continuous working periods found in current cork production will require the use of heat storage systems in order to enhance solar integration for those periods in which solar radiation is not available. This issue is not type-dependent of either production system or heat transfer medium (Soteris Kalogirou, 2003).

4. Conclusions

The use of solar thermal energy systems in cork production is currently not prevalent. However, its implementation is most suitable for a great number of processes where currently fossil fuels are widely used. From those and featuring its integration, a technical assessment of the thermal use in cork industry was conducted considering some technical issues namely process operating temperature and type of heat transfer medium.

Although cork industry major thermal needs range from low to low-medium temperatures (up to 155ºC), overall heat demand is sufficiently great for considering the implementation of a solar energy system for thermal purposes. Annual thermal needs of António Almeida - Cortiças facility extents to values of around 2545 MWh, being distributed by a number of thermal processes mostly of them supported on natural gas consumption.

As major thermal processes use different thermal energy producing systems and heat transport mediums (also at different conditions), an adequate integration of a solar system(s) could, in different stages of the process, consider the acquisition of additional equipment (e.g. storage systems, heat exchangers, control units and piping, among others) as well as on some technical adjustments (in such way that process conditions will suffer no changes).

Industrial thermal needs were assessed according to process temperature and heat transfer medium type. Considering processes temperatures up to 85ºC and, based on hot gases as heat transfer fluid, Flat-Plate Collectors and Compound Parabolic Collectors were considered technically suitable, while for higher temperatures (< 200ºC), Parabolic Trough Collector and Fix Focus Trough Collector may exhibit better thermal performance.

When considering both hot water as heat transfer medium and temperatures up to 75ºC, possible solution include the use of Flat-Plate Collectors, Stationary Compound Parabolic Collectors, Compound Parabolic Collectors, Maximum Reflector-Collectors and Combined Heat and Power Solar Collector.

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Annex A

Table A - Additional features of solar thermal systems for integration into industrial processes

System	Cash ratio	Storage	Process control	Heat demand	Heat transfer medium	Type of collector
Direct heat transfer	Low	No	Continues	Always much higher than solar system	Air	Air collectors
					Water	Depending on temperature level of the process
					Steam	PTC
Indirect heat transfer	Low	No	Continues	Always much higher than solar system	*Primary*: water, water/glycol, thermo-oil *Secondary*: air, water, steam	Depending on temperature level of the process
Indirect heat transfer with storage	High	Yes	Semi-continues	The same or higher than solar system	*Primary*: water, water/glycol, thermo-oil *Secondary*: air, water, steam	Depending on temperature level of the process

Annex B

Table B - Overview on some active medium temperature range collectors for industrial applications (IEA SHC Task 33)

Collector type	Temperature Range (ºC)	Heat Transfer Medium
Double-Grazed Flat-Plate Collector (FPC)	80-150	Water-Glycol
Stationary Compound Parabolic Collector (SCPC)	80-110	Water-Glycol
Compound Parabolic Collector (CPC)	80-120	Water-Glycol
Maximum Reflector-Collector (MRC)	50-90	Water-Glycol
Parabolic Trough Collector (PTC I)	100-200	Water or Steam
Parabolic Trough Collector (PTC II)	130-300	Water
Modular Parabolic Trough Collector (PTC)	80-300	Water
Fix Focus Trough Collector (FFTC)	100-200	Water, steam, thermal oil and air
Linear Concentrating Fresnel Collector (LCFC)	100-400	Water, steam and thermal oil
Combined Heat and Power Solar Collector (CHPSC)	80-150	Water