SOLARNA TERMIČKA ENERGIJA U PROCESNOJ INDUSTRIJI – STANJE I PERSPEKTIVE

SOLAR THERMAL ENERGY IN PROCESS INDUSTRY – STATE AND PERSPECTIVES

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The process industry sector uses a large part of total energy consumption, where the most of energy being used to generate low, medium or high temperature heat, known as process heat, that is used for different process applications . Therefore, it is necessary to know better the processes in a particular industrial sector in which solar process heat can be used and to identify the processes that are most compatible for the integration of the solar thermal system. The paper presents the temperature ranges for the usual processes in industrial applications that use process heat. It also provides an over-view of the state in the global market in terms of the number and capacity of installed solar systems, types of solar collectors, industrial sectors and countries of application.The paper attempts to identify sectors with significant potential for the application of solar thermal energy and to indicate technological and other challenges and perspectives for future development.ectives for future development.

Key words: *solar thermal energy; process industry; state and perspectives*

U procesnoj industriji koristi se veliki deo ukupno potrebne energije, pri čemu se većina energije koristi za generisanje nisko, srednje ili visokotemperature toplote, procesne toplote, koja se koristi za različite procesne primene. Zbog toga je neophodno bolje poznavati procese u određenoj grani industrije u kojoj se može koristiti solarna procesna toplota i identificirati procese koji su najkompatibilniji za integraciju solarnog termičkog sistema. U radu su prikazani temperaturni opsezi za uobičajene procese u industrijskim primenama u kojima se koristi procesna toplota. Rad takođe daje pregled stanja na globalnom tržištu u smislu broja, veličine i kapaciteta instaliranih solarnih sistema, tipova solarnih kolektora, industrijskih sektora i zemalja primene. Rad pokušava da identifikuje sektore sa značajnim potencijalom za primenu solarne termičke energije i da ukae na tehnološke i druge izazove i perspektive za budući razvoj.

Ključne reči: *solarna termička energija; procesna industrija; stanje i perspektive*

1 Introduction

In simple words, while we get the energy from heat conversion gained from solar radiation, is termed as solar thermal energy. Solar thermal conversion systems use different type of solar collectors that transform solar radiation into heat used in commercial or industrial plants. The type of solar collector, working fluid, installation parameters, heat exchanger specifications must be considered for a specific process.

Compared to other renewable energy sources, low-temperature and medium-temperature solar thermal energy has not played a important role for a long time. Generally, attention is focused on the generation of electricity, although almost 50% [1] of total energy use refers to thermal energy ie heat. The use of solar thermal energy is mainly considered for heating water where technologically justified. However, the situacion is significantly changing. For example, a European target for the use of 20% renewable energy can only be achieved by increasing the use of renewable energy in the heat generation sector. The increase in oil and gas prices, then the import dependence, the exhaustion of reserves and the negative impact of fossil fuels on the environment, further direct the attention and interest of the society to the use of renewable energy.

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The processing industry sectors use a large part of total energy consumption, where most of the energy is used to generate low, medium or high temperature heat. The need to use clean, cheap and efficient renewable energy sources in industrial applications follows from an increasing concern about greenhouse gas emissions and global warming. As an inexhaustible source, solar energy has proven potential for application. The use of solar energy in industrial applications is currently insignificant in relation to the swimming pools and household use. The most solar applications for industrial processes are at a relatively small scale and number of large systems in use around the world is insufficient. On the other hand, if we compare energy consumption in the industrial, transport, household and service sectors, then we can see that the industrial sector has the highest energy consumption. In the OECD countries it is around 30%, followed by transport and household sectors [2], while industry in the EU has a share in total consumption of around 28% [3].

The largest part of the energy needed for industrial technological processes is below 250°C. The low temperature level can be easily achieved by solar thermal collectors already on the market, while one of the main goals for the future must be the development, improvement and optimization of solar thermal collectors for a temperature range of 80°C to 250°C.

At present, on global level, approximately 40% of industrial primary energy consumption is provided by natural gas and approximately 41% by petroleum [4]. Industry uses about 75% [5] of its energy consumption as thermal energy, so there is a huge potential to increase the share of solar thermal energy in the industrial sector.

2 Solar thermal technologies

In general, there are three groups of solar thermal technologies that can be used for heating in the industrial processes: solar liquid systems, solar air systems and solar concentrators. Conventional solar liquid systems, such as flat-plate collectors (FPC) or evacuated tube collectors (ETC) are primarily used in household applications, but they can easily be installed to ensure the need for heat in process industry up to 125°C. More than a few hundred such systems exist worldwide. Flat-plate solar collector absorbs incedent solar radiation and then transmits it to working fluid. They are popular for high efficiency, long durability and relatively low cost. In an evacuated collector a separate cylindrical glass envelope prevents the absorber surface from heat loss due to convection. Numerous advanced FPC and ETC designs are currently on the market and can generate temperatures up to 250°C but, they are also more expensive than conventional FPC and ETC. Solar air systems are found primarily in the food industry to replace drying based on gas or oil or reduce food spoilage due to outdoor drying. In this type of collectors, solar radiation reaching the collector heats the absorber plate and air passing through the collector picks up heat from the absorber plate. They can be built locally, and their price depends on local building materials and work. Solar concentrators include linear parabolic collectors, linear Fresnel collectors and parabolic dish collectors. The solar radiation first falls on the reflective surface and then concentrated onto a absorber. Inside the absorber tube a heat transfer fluid circulates to transfer thermal energy to the target process. Sach type of collectors track the sunshine over day and over year. They can generate heat to temperatures up to 400°C.

Except heating applications, solar thermal systems can also satisfy cooling demands. In this case, solar thermal cooling systems can be used to replace electricity driven vapour-compression air conditioning or gas-driven or electricity-driven absorption/adsorption chillers systems.

3 Requirements for temperature range for process heat

The temperature level required for an industrial process is crucial for assessment of the feasibility of solar thermal systems. Many industrial processes can be found at temperatures below 40°C and between 40°C and 60°C. Industrial processes in the temperature range from 60°C to 100°C are also of great importance. Figure 1 shows the significance of the above-mentioned temperature levels to the most promising processes for integration of solar heat that were identified within several studies [4], [5], [7]. Vast majority all heat needs in industrial processes require heat in temperature ranges which can be provided by a solar thermal system. Typical applications and most prospective process industry sectors suitable for solar systems applications are listed in Table 1 [4,8]. Most applications are in low-temperature ranges. A very high percentage of heat demand in the low temperature range is found in food, beverages, paper and textiles industries, while in the medium temperature range heat is need in the plastic and chemical industries. More than 60% of total process heat is required in a temperature range of up to 250°C for various applications such as drying, cooking, cleaning, extraction and many others [9].

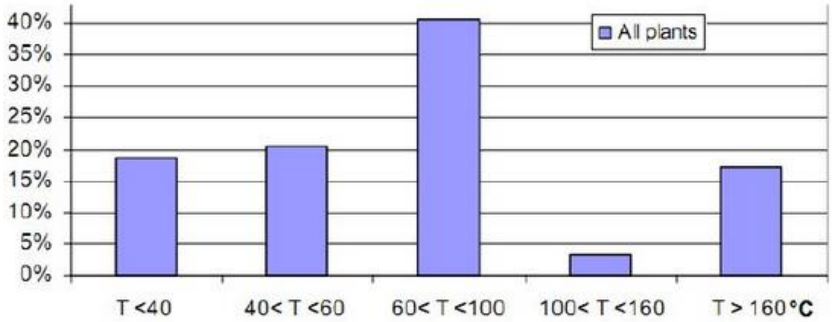

Figure1: Temperature level of the supported processes of existing solar heating systems, [5]

Absorption and adsorption cooling systems use liquid or solid refrigerants for cooling the desired object/space. In absorption coolers (the most common systems), solar energy is used to evaporate the cooling fluid from the solution. Two common systems are: closed absorption chiller systems with ammonia-water (NH_3/H_20) or systems with water-lithium-bromide (H_20/LiBr) as refrigerant/absorber fluids. Desiccant systems are used to provide air conditioning, and use a desiccant material to absorb or adsorb water from the air and pass cooled air back into the building. Solar energy is used to regenerate the desiccants. Single-stage effect chillers require lower temperatures (80°C to 110°C) [10] to operate but also have lower efficiency. Two-stage effect absorption chillers are only available for higher capacities and have higher efficiencies but also have requirements for higher temperature range (150–180°C) [11].

4 Solar heat in process industry - current state

The cumulated solar thermal capacity in operation by the end of 2017 was 472 GW_{th} (gigawatt thermal) and solar heating and cooling was again the largest solar sector worldwide followed by photovoltaics (402 GW_{el}) and concentrating solar power (5 GW_{el}), Fig. 2. The two key areas of growth were solar heat for industrial processes and solar district heating. Solar thermal energy yields amounted 388 TWh in 2017 and 134.7 million tons of CO_2 emision avoided.

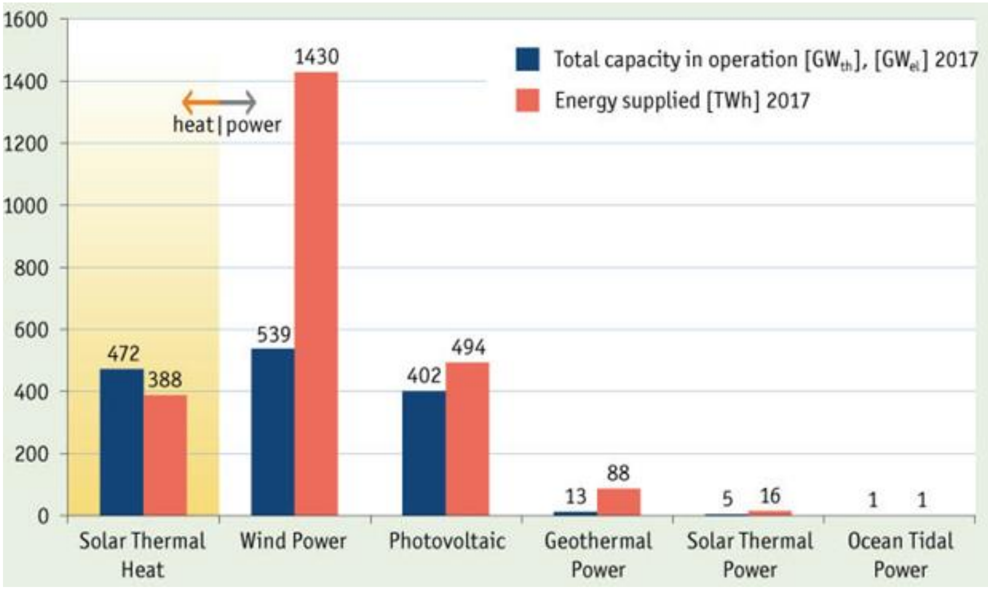

Figure 2: Total capacity in operation [GW_{th}], [GW_{el}] and energy delivered [TWh_{th}], [TWh_{el}], [12]

Table 1: Industrial processes and temperature levels [4,8]

Industrial sector	*Unit operation*	*Temperature range [ºC]*
Food	drying	30-90
	washing	60-90
	pasteurising	60-80
	bioling	95-105
	sterilising	110-120
	heat treatment	40-60
Beverages	washing	60-80
	sterilising	60-90
	pasteurising	60-70
Paper industry	cooking and drying	60-80
	boiler feed water	60-90
	bleaching	130-150
Metal surface treatment	treatment, electroplating...	30-80
Bricks and blocks	curing	60-140
Textile industry	bleaching	60-100
	dyeing	70-90
	drying, degreasing	100-130
	washing	40-80
	fixing	160-180
Chemical industry	soaps	200-260
	synthetic rubber	150-200
	processing heat	120-180
	preheating eater	60-90
Plastic industry	preparation	120-140
	destillation	140-150
	separation	200-220
	extension	140-160
	drying	180-200
	blending	120-140
All industrial sectors	preheating feed water	30-100
	industrial solar cooling	55-180
	heating of factory building	30-80

A record year when it comes to the use of solar heat in industrial processes (SHIP) was 2017. That was driven by economic competitiveness, a strong supply chain and policies to reduce air pollution. The year ended with 124 new SHIP plants installed worldwide with new 192580 m^2 collector area [13]. India and Mexico are at the top of the list by the number of new plants, while the largest plants in 2017 year were built in Oman, China and Afghanistan. The solar plant in Oman is 100MW_{th}

parabolic trough collector field installed in a greenhouse structure to generate the steam which is used in place of natural gas to extract heavy oil on the oil field. According to the latest data [14], in terms of newly installed solar thermal systems for industrial applications, the year 2018 was very similar to 2017 year. In 2018, 105 new systems of total surface area of at least 200140 m^2 (140MW_{th}) were installed.

Of the 635 documented SHIP plants by the end of 2017, 271 has more detailed information on the area and type of collectors, installed capacity and type of application that can be found in the IEA SHC Task49/IV SHIP database. The following figures show the analysis for the systems whose detailed information are available. Figure 3 shows the data on the size, number and thermal power of the 271 mentioned systems. It is possible to see that 2 systems have thermal power exceeding 21MW_{th}, 26 systems have installed power between 0.7MW_{th} and 21 MW_{th} (1000-30000 m^2), 45 systems have installed power between 0.35 MW_{th} and 0.7 MW_{th} (500-1000m^2) and 198 systems have power below 0.35 MW_{th} (<500m^2).

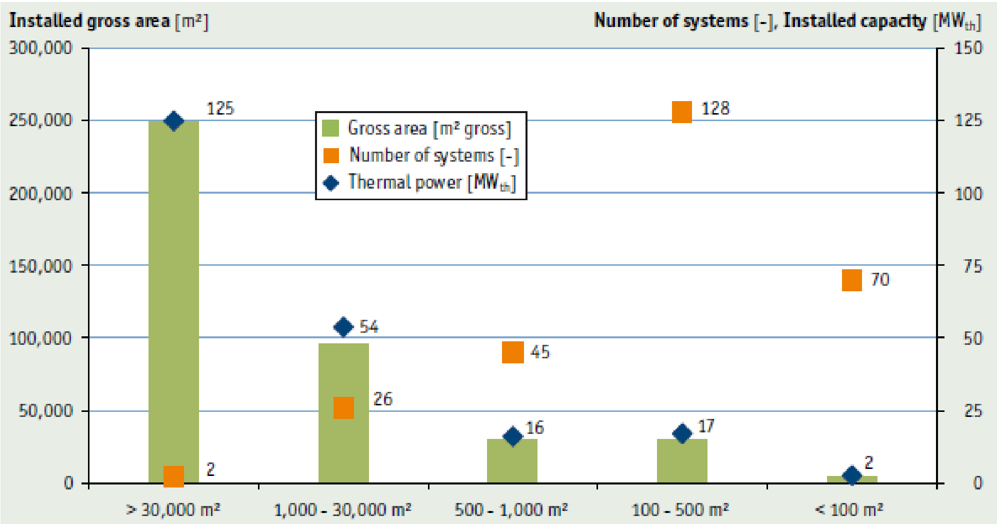

Figure 3: Solar process heat plants in operation, [13]

The most systems use flat plate solar collectors, while the largest installed systems (in terms of area and power) and systems with parabolic trough collectors (Fig. 4).

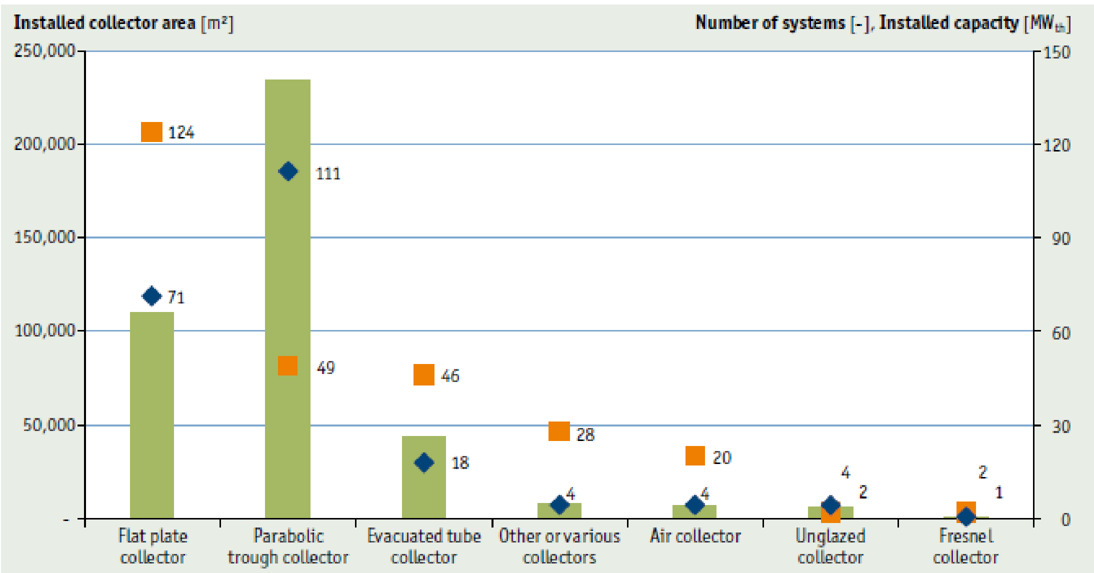

Figure 4: Solar rocess heat application by type of collector, [13]

According to the number of installed systems, the main sectors of application are food, beverage, textil and others, while the highest power and area of the systems are in the mining sector (Fig. 5).

The food industry sector is characterized by the largest number of systems (104), but these are smaller or medium-sized systems, which represent around 13% (around 26 MW) of the total

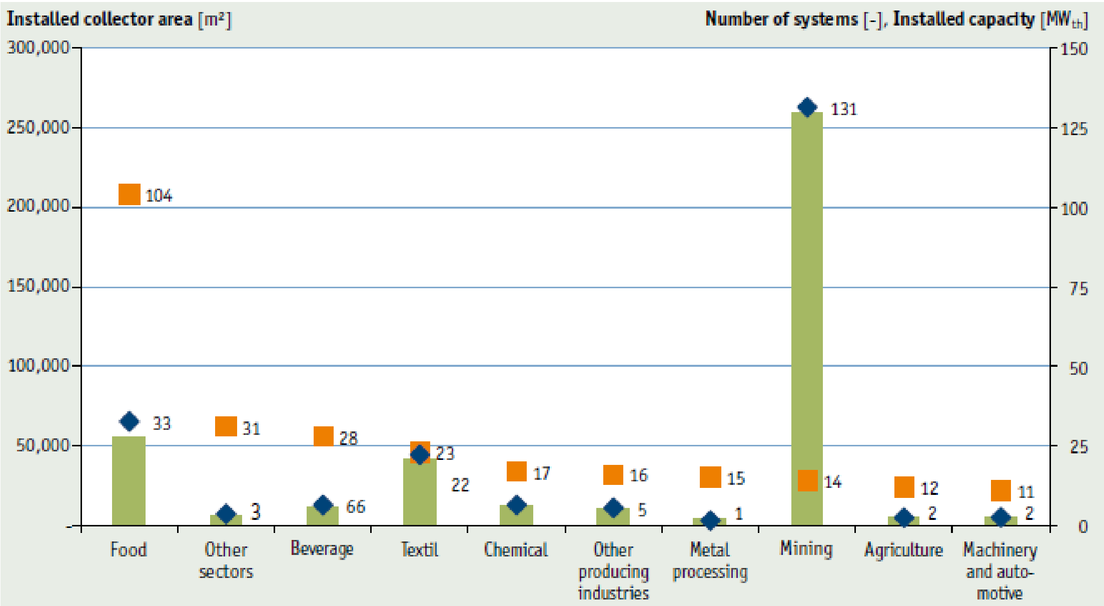

Figure 5: Solar process heat application by industry sector, [13]

installed thermal power. By countries, Mexico and India have the highest number of systems, followed by Austria and Germany, USA, etc. Looking on power of installed systems, Oman is the leader, followed by China, Chile, etc (Fig. 6).

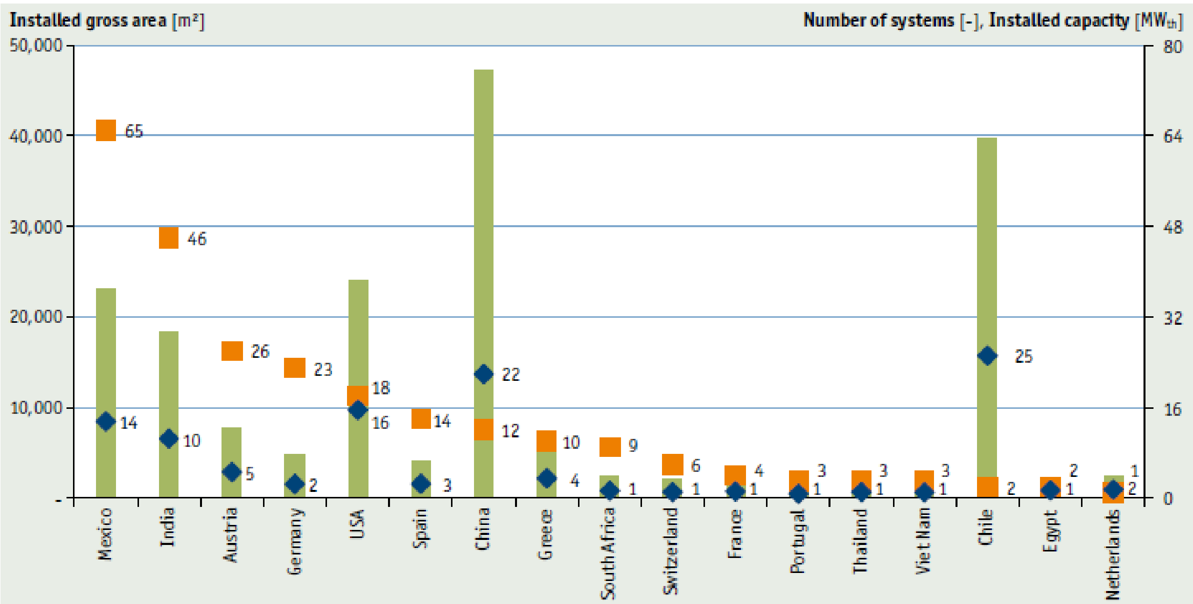

Figure 6: : Solar process heat plants in operation by country, [13]

In a global market, cooling will keep growing worldwide and there is a huge potential for cooling systems that use solar energy. By the end of 2015, an estimated 1,350 solar cooling systems were installed worldwide. More recent global data are not available as data collection is difficult with more and more participants entering the market. Approximately 70 % of the small and medium capacity (<350 kW) solar cooling systems worldwide are installed in Europe (Fig.7).

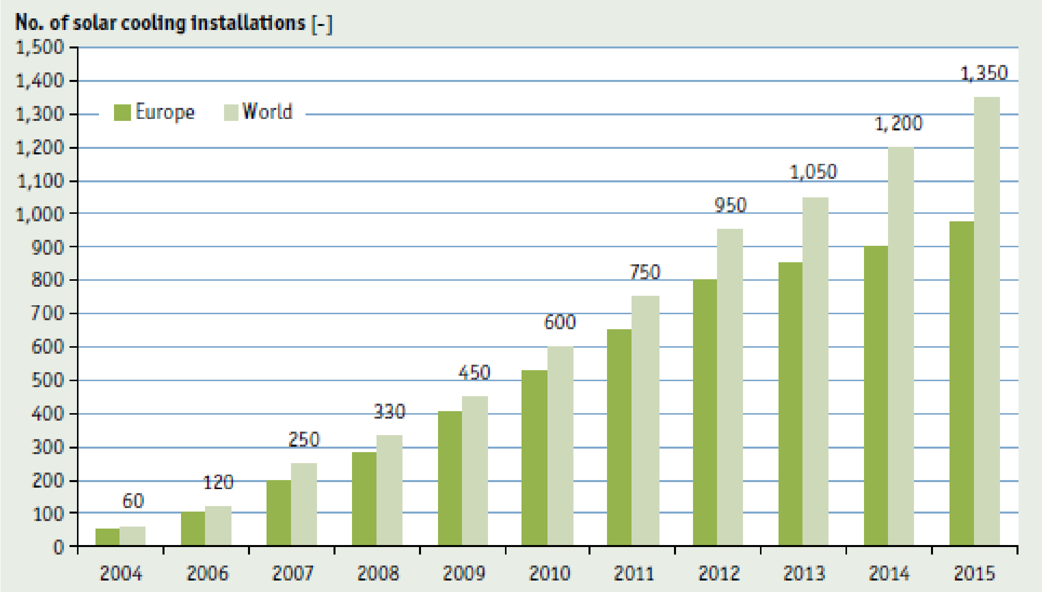

Figure 7: Solar cooling systems – market development, [13]

In recent years, there has been a tendency of a steady increaseing the share of solar systems for process industrial applications and solar disctrict heating systems, even it still at a low lavel. In newly installed systems in 2016, this share was around 3% globally, while in Europe this share was larger and accounts for about 10% (Fig.8).

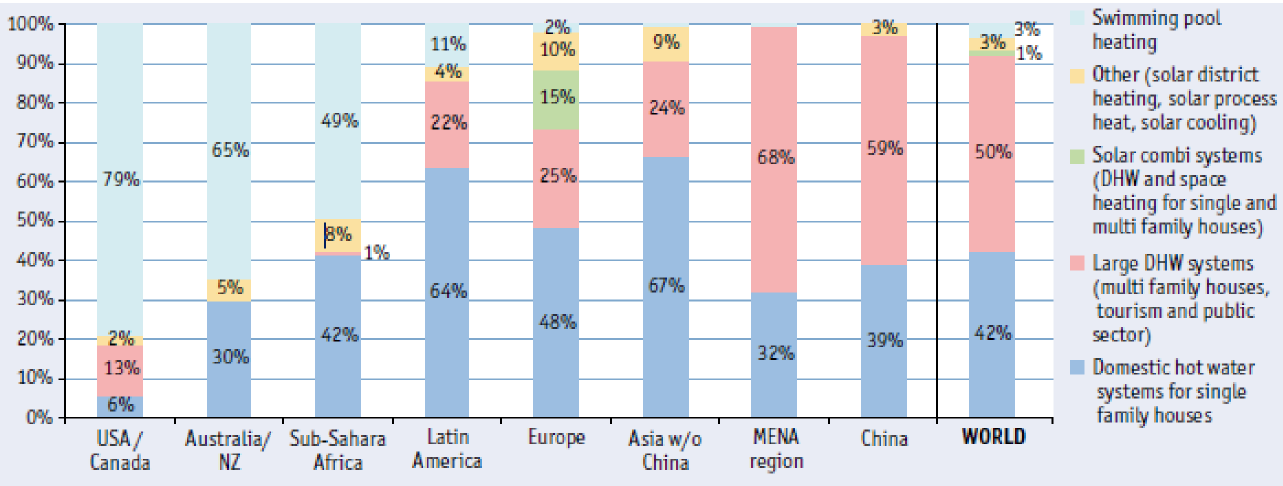

Figure 8: Distribution of solar thermal systems by application and by regions installed in 2016, [13]

According to the literary source from 2015 [4], the total investment costs for solar thermal systems range from 180-500 EUR/m^2, leading to average energy costs of 0.02-0.05 EUR/kWh for low-temperature applications and 0.05-0.15 EUR/kWh for medium-temperature systems. In comparison, in 2000 investment costs were in the range of 250-500 EUR/m^2. It indicates that the investment costs range in the interval 450-1100 EUR/kW$_{th}$ with differences at national level. In Austria and Spain, the investment cost (plant size < 350 kW$_{th}$) is in the range of 470-700 EUR/kW$_{th}$, while costs calculated for Germany and Italy are higher on average. It should be noted that the cost of standard FPC and ETC collectors (2-2.5 m2) have halved between 1995 and 2010. The data show that FPC and ETC in India and Turkey are, in average, 50% cheaper, while the costs for solar process heat in South Africa are estimated to be 25–50% cheaper than in Europe [4]. The investment costs for solar concentrators are more expensive than conventional FPC and ETC but they give higher temperature ranges. For example, parabolic trough collectors costs are estimated to be in the range of 600-2000 USD/kW, but with relatively large differences at national level [4]. Figure 9 shows the trend of changing specific invest costs of small thermal systems in central Europe.

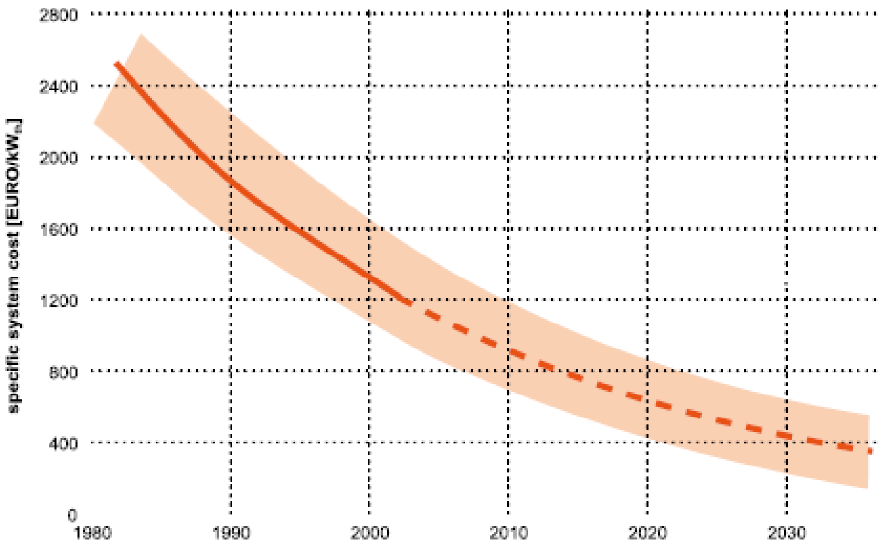

Figure 9: Trend of changing specific invest costs of small thermal systems in central Europe, [1]

5 Perspectives and challenges for future development

The use solar thermal energy in processes industry is currently at the relatively early stages of development and the most of existing systems are relatively small scale. Since industrial processes are large consumers of thermal energy, that means that there is great potential for market and technological developments in the area of solar themmal energy application.

According predictions, in the future, in the short term, solar heat will be mainly used in low temperature processes. With technological developments and changes in energy prices on the market, more and more medium temperature applications, of up to 250°C, will become market feasible.

In the EU, and other technologically developed countries, the main consumer of energy is the industry. The relevance of each sector in regards to solar thermal market development also depends on the local industrial profile, for example, breweries represent an important industry in Austria and Germany, while dairies are important in Italy and Greece. The studies [9] and [6] showed that in EU the solar thermal systems could provide the industrial sector with near 4% of heat demand, while the study [4] gives the optimistic prediction that at global level there is a potential to increase the share of solar thermal energy and possibly reach the solar thermal deployment in the industrial sector of around 10% by 2030 while in the future the share could reach about one third.

It is clear that the use of solar heating for industrial processes should be part of a comprehensive approach, which should take into account the improvement of technological processes, reduction of heating and cooling demands, the implementation of energy efficiency measures, and so on. The key areas for technilogical and market development are: development medium-temperature collectors and components, thermodynamic optimization of processes, development of design procedures, reduction of investment costs, financial incentives and widespread public-funded demonstration projects, applied research related to solar thermal plants.

A large selection of solar heat collectors are commercially available for low temperature (operating temperatures to about 80-90°C) and for high temperatures (> 250°C, mainly used for generating electricity). Between these two temperature ranges, there is great potential for many new applications in the medium temperature range. This is relevant for process heat, including various industrial processes and thermally driven cooling technologies. So, it is necessary to develop economical and reliable collectors for medium temperature, which meet the requirements of most industrial processes. Other components of solar systems must also be adapted to this temperature range (for example, the development of a new generation of energy storage systems, the development of advanced controllers, etc). The thermal energy storage allows the use of energy when there is demand for it - so it covers the possible time mismatch of solar radiation and the demands for energy. Very important parameter for thermal storage system is the required storage temperature.

Currently, only a few engineering offices and research institutes have experience with installations of solar thermal systems in industry. Guidelines and tools for typical industrial use should be available to a wider circle of engineers with experience. That would mean that the costs of system design will fall and that a broader experience would increase the efficiency of the systems. Wider development of the market of thermal solar systems it requires appropriate financing solutions, whose lack of it is currently an important barrier to growth. Financial incentives and widespread demonstration projects funded from public funds are necessity. Applied research are needed in a number of areas, including: behavior and management of stagnation of systems with large collector fields, development of methodology of system optimization, integration of solar system and conventional energy sources in various industrial processes.

The current costs of industrial solar thermal systems are determined by a relatively small number of suppliers of these highly sophisticated technologies which are generally too costly for the global market. Equipment manufactured locally can reduce capital costs and create local business opportunities. The IEA (2009) suggests that costs can be reduced by as much as 20% when a country's total installed capacity doubles. Large-scale applications can benefit from economies of scale and lowered investment costs, thus increasing the project's economic viability. IEA estimates that there will be a reduction in the costs in using solar thermal energy in the range of 35-50% for solar heating and 35-45% for solar cooling by 2030, and predicts that investment costs between 2007 and 2050 can be reduced by 60% by 2050 [4]. Key factors for cost reductions are automation of production processes, modular designs for easier installation, optimised tracking systems, standardisation and certification, and material replacement of copper and steel with aluminium and polymers.

Europe is leader in nearly all sectors of solar thermal technology, which explains why the manufacturing capacity in Europe is growing significantly, notably in relatively high-technological developed countries, such as Austria, Germany, Denmark and the UK. As is the case with other renewable energy industries, solar thermal can become a job motor. The solar thermal sector in Europe in 2016. provided about 35000 full-time positions in a range of sectors [15], including manufacturing, marketing, system design and engineering, installation and after sale services. Provided that Europe is able to rapidly increase its share of the global market and expand its domestic market, in optimistic prediction of ESTTP [1], this figure is expected to increase to 220,000 by 2030. The report [16] estimates that solar and wind jobs are growing at a rate 12 times as fast as the rest of the US economy and suggests that 46% of large firms have hired additional workers to address issues of sustainability over the past two years.

The key drivers for application solar heating and cooling technologies in industrial processes are: reducing risks associated with increasingly unstable and rising prices for fosil fuels; reducing energy costs; reducing carbon emissions and meeting energy needs by localised production.

The main barriers in the future to increased application of solar thermal systems in process industy are follows: high investment costs and lack of finance options; fossil fuel pricing (in many countries energy prices for industrial users are subsidised); lack of information and lack of social awareness; lack of suitable design guidelines; the availability of space for the installation of solar systems.

6 Conclusions

The process industry is a very perspective area for the application of solar thermal technology, since it has a large share of total final energy consumption. In addition, this industry uses about 75% of its energy consumption as a heat. This heat is needed in several industry sectors at low and medium temperatures, that is the major requirement for the utilization of solar thermal energy. Some industry sectors like food products and beverages and textiles are particularly suitable and offer various options for the integration of solar process heat. This article were analysed the temperature ranges for the usual processes in industrial applications that use process heat. It was given an overview of the actual state in the global market in terms of the number and capacity of installed solar systems, types of solar collectors, industrial sectors and countries of application. It was attempted to identify areas and processes with potential for the application of solar thermal energy and to point to technological and other challenges and perspectives for future development.

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