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APPLICATION OF SOLAR THERMAL ENERGY IN INDUSTRY

Richard Law[1], Peter Kew[1], Ahmad Mustaffar[1], Chris Underwood[1], David Reay[1]*

[1] David Reay & Associates, PO Box 25, Whitley Bay, Tyne & Wear NE26 1QT, UK

ABSTRACT

Solar energy has been utilized for industrial applications in Europe for many years, with most regions providing adequate insolation for hot water generation or electricity generation via photovoltaics. However, several technical challenges exist to application to higher temperature processes, with few proven cases delivering process heat at greater than 200 ºC. As industry, and society in general, drives towards net zero, new technologies are required to both deliver and store carbon-free process heat in this higher temperature range.

This paper introduces the challenges of this and some of the potential solutions being delivered by the ASTEP Horizon Europe project. Within ASTEP two demonstrations of the technology are being implemented. One project, at a Greek dairy, uses the solar thermal energy, via a phase change material (PCM) store to provide heat for unit operations and to drive absorption chillers. The second installation is at a steelworks in Romania, at a relatively high latitude of 47.1N, where preheating of tubes in a coating line will be practiced.

1. INTRODUCTION

The use of solar heat in industrial processes (sometimes abbreviated as SHIP) has been practiced for many years in climates where the solar insolation, measured typically in kWh/m^2/day is high. Within Europe the yearly average figure is 5.61, with major cities in Spain, Italy and Greece all averaging above 4. In the UK London manages a relatively poor 2.61 and even the Norwegian city of Oslo beats Edinburgh by 0.01 with a value of 2.27 kWh/m^2/day. Thus while most regions can provide adequate solar energy for PV or for low grade water heating, the demands of processes, particularly where higher temperature heat is needed, cannot easily be met in much of Europe, and in some parts of the world the preference for electrical energy is encouraging solar thermal power generation linked to large batteries, for example in Australia.

Several attempts have been made to improve the scale of take-up of solar heating in processes on a global scale, and the International Energy Agency (IEA) Solar Heating and Cooling Programme, in particular three Tasks [1], [2], and [3], has been at the forefront of world-wide activity in promoting solar thermal energy in industrial processes, for cooling as well as heating. In order to assist in overcoming the challenges in getting better acceptance in industry of solar thermal energy, particularly at temperatures above those of hot water, one approach is to improve the performance of the essential components. These are primarily the solar collector/concentrator, the thermal stores, the heat exchangers needed to serve the process needs, and the control systems. In addition to technical improvements brought about by normal development routes, one can introduce process integration and process intensification technologies to minimise losses and, in the second case, to improve heat and mass transfer, [2].

The development of high temperature thermal stores is crucial if solar energy is to be widely applied in industrial processes. Currently molten salt Phase Change Materials (PCMs) are the favoured option, but there are heat transfer problems with PCMs in larger units. To improve internal heat transfer, novel extended surface designs enabled using additive manufacturing [5], have resulted in the design and manufacture of ʻtailored ʼfins that optimize convective heat transfer to the PCM as a function of their position in the container, [6]. New materials, including Miscibility Gap Alloys (MGAs) [4], show

*Corresponding Author: DAReay@aol.com

considerable promise for heat storage, particularly associated with high temperature uses, and comprise material pairs of a high melting point matrix encapsulating grains of an immiscible low melting point metal. With a high energy density and high thermal conductivity, benefitting from both latent and sensible heat storage, MGAs could be one solution to alleviate current problems with thermal stores. in particular overcoming heat transfer problems within large thermal stores. Examples of concrete as a thermal store at temperatures of up to 500ºC are given [8] including a 400kWh thermal unit tested at Almeria, Spain. The very low thermal conductivity is compensated for by the low cost (5 Euros/kWh).

For high temperature processes (in the context of the discussion >150 deg.C), the delivery of the heat to the process can necessitate innovative heat transfer equipment designs, which need to cater for heat inputs either directly from the solar collectors or, when the collectors cannot deliver, from a thermal store. The challenges are considerable and are being addressed in a major European Commission-funded project – ASTEP.

2. THE ASTEP PROJECT

Application of Solar Thermal Energy to Processes (ASTEP) will create a new innovative Solar Heating for Industrial Processes (SHIP) concept focused on overcoming the current limitations of these systems. SHIP is becoming increasingly relevant as one of the ways to meet the high thermal energy demand required for industry.

ASTEP will demonstrate its capability to cover a substantial part of the heat demand of the process industry at temperatures in the range of 175-220 ºC and for latitudes where current designs are not able to supply itThis solution is based on modular and flexible integration of two innovative designs for the solar collector (SunDial) and the Thermal Energy Storage (TES), based on Phase Change Materials (PCM), integrated via a control system which will allow flexible operation to maintain continuous service against the unpredictable nature of the solar source and partially during night operation. These aspects will provide a very competitive solution to substitute fossil fuel consumption. Its modularity and compactness will also enable easy installation and repair with reduced space requirements, while most of the components can be sourced locally. Finally, another characteristic of the solar collector that is proposed is that it can be adapted to different industrial processes demanding heat at different temperatures.

The successful completion of ASTEP will provide guidelines for planning, installation and operation of thermal solar systems in industrial companies and will quantify the performance of the developed innovative technology considering several technical and economic parameters.

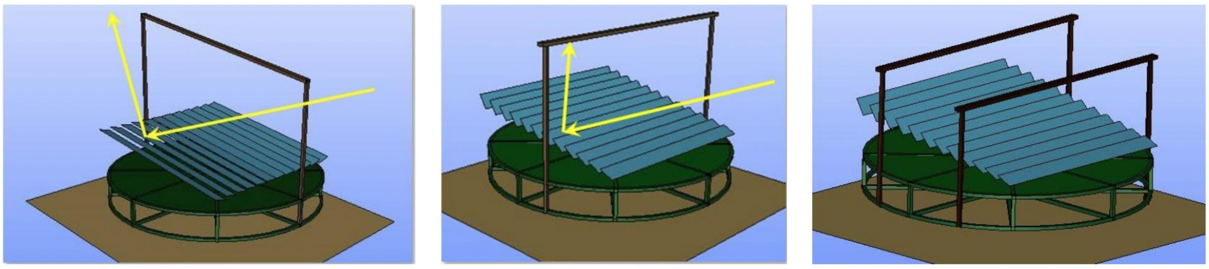
This new EU-funded Research & Innovation Action, is coordinated by Professor Antonio Rovira, representing the Universidad Nacional de Educación a Distancia (UNED), in Madrid, Spain, where additionally much of the solar collector technology brought to the project resides. David Reay & Associates provide the Scientific & Innovation Manager and Chair the Scientific and Technical Committee of the project. DRA is also responsible for the on-site commissioning and operation of the two demonstrations (steel plant and dairy).

3. KEY TECHNOLOGIES IN THE ASTEP PROJECT

ASTEP aims to investigate key technologies that will make it possible to provide solar thermal energy of up to 220 ºC at a high latitude, in a case study explained in section 4 (AMTP). The pilot-scale demonstration will also reach up to 135 kWh of thermal energy per day, and 25 MWh annual thermal energy. This will avoid 5.7 tonnes of CO_2 emissions whilst demonstrating the industrial feasibility of the ASTEP solution, the SunDial solar collector

3.1 The solar collector

The SunDial is a rotary Fresnel-like solar collector which consists of an array of Linear Fresnel Collectors (LFC) or mirrors field, and linear receivers, which can be single-tube or multi-tubes. The unique feature of SunDial is that both mirrors and receivers rotate on a platform following the sun's trajectory in the sky. There are two movement modes: longitudinal and transversal. In the longitudinal mode (Fig. 1(a)), the sun is in the longitudinal plane of the receiver. The mirrors stay fixed while the platform rotates according to the sun's trajectory, therefore only a single-axis solar tracking system is required, which is a simpler, compact and cheaper system. However, due to its inherent design, major optical losses occur in the mornings and late afternoons, where most of the reflected solar beam does not concentrate on the receiver. Fig. 1(b) shows the transversal mode, where the sun is in the transversal plane of the receiver. There are two axes of the solar tracking system, as both the platform and the mirrors rotate. This mode mitigates the optical losses at the expense of the costs associated with a more complex system. Fig. 1(c) shows another mode whereby two (or more) receivers are installed, each one with its respective mirror field, but are in the same platform. The options for the receiver design are in-line with typical LFC receivers: single-tube evacuated receivers or multi-tube bare receivers. These parameters were investigated to find the optimized design parameters to suit each case study needs [7].



a) Longitudinal mode. Beams are not focusing on the receiver at certain periods of the day.

b) Transversal mode. Beams keep focusing on the receiver throughout the day.

c) Transversal mode with 2 mirror fields, each with its own receiver

Figure 1. The SunDial solar collector designs [7].

3.2. Thermal energy storage (TES) system

The TES system is important as a thermal energy buffer during periods of weak or no solar radiation. Conventionally, energy storage technologies can be categorised into sensible, latent (phase change material) and thermochemical types. Sensible media store energy based on their temperature variations. It is being used in many concentrated solar power (CSP) plants. One example is the "Solar Two" plant, using two-tank molten salt sensible technology with a maximum storage temperature of 565ºC at 110MWh capacity. Latent heat stores employ the enthalpy change of a substance passing through a phase change (usually solid to liquid) to store energy. Some major advantages over sensible storage include narrow temperature range, higher energy density and hence, smaller size. The narrow operating temperature range allowing energy to be stored at a temperature close to the plant requirement is particularly important in solar applications, since the collector efficiency reduces with temperature. Thermochemical energy storage utilises the enthalpy change of a reversible chemical reaction. Its development is motivated by its capabilities in storing energy at higher densities than other technologies, and at ambient temperatures with negligible thermal losses. It has a huge potential in the future but is currently in an earlier stage of technological maturity [8].

Latent heat storage i.e. phase change material (PCM) was selected for the ASTEP project to meet the buffering thermal demands with cost-effectiveness. A mixed molten salt based on potassium and sodium was selected as the PCM to provide in excess of 60 kWh capacity at 190-220ºC minimum operating temperatures. There are many technical aspects of the store that require detailed investigation such as heat transfer fluids, material compatibilities, insulation and the means to overcome PCMs' inherent low thermal conductivities (Fig. 2). The usage of high conductivity extended surfaces is common, as well as micro-encapsulation. The aforementioned MGAs form new classes of advancing development. All these technological aspects surrounding the latent store enable the development of a fully-functioning, relatively light and compact thermal store unit (<1.5 m at its longest axial length) to be used in the ASTEP project.

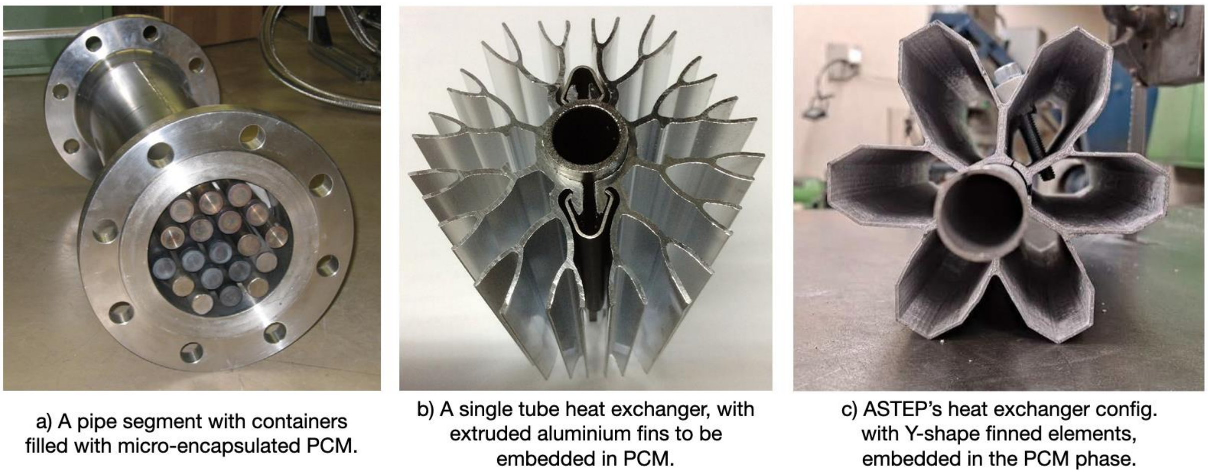


Figure 2. Some methods to increase effective thermal conductivity in PCMs for large-scale operations [7-8].

4. SOLAR THERMAL ENERGY CASE STUDIES

The two selected industries being examined in ASTEP, one in the dairy sector and one in metals (steel), rely on the integration of solar energy into the industrial process in a manner that demands careful integration of the solar collector, the heat store, and appropriate parts of the product production lines, be they batch or continuous. ASTEP will introduce into them reliable solar heat, since the current energy demand in both cases is covered with non-renewable energy sources. The expected advance is to achieve temperatures that other systems cannot reach at the specific latitude and in a reasonable cost.

4.1. Metals Production

ArcelorMittal is the world's leading steel and mining company. In particular, AM Iasi, which belongs to Europe Division ArcelorMittal Tubular Products (AMTP), is engaged in the manufacturing of welded steel tubes for many diverse applications. This industry is located at a relatively high latitude location Iasi, Romania (latitude 47.1 N). One of the key finishing for the AM Iasi's products is colour coating, consisting of a thin layer of, for example, epoxy, water-based, thermoplastic, coloured protective/decorative material covering the whole tube external surface. In order to apply this colour coating to tubes, they need to be pre-heated to a temperature of 220 ºC.

The SunDial rotary Fresnel solar collector proposed for the two trial sites, , should be able to meet the thermal demand in terms of temperature level and heat input for a proportion of the tube heating to achieve the 220ºC. The heat will be transferred via a hot thermal oil to a heat exchanger in the pre-heating line (see Fig. 3 for one concept being examined).

The ability of an industrial process partially reliant on solar energy to operate when the sun is not available is critical to continuous, and in some cases batch, production. To overcome this difficulty a high temperature thermal store must be incorporated in the system. This will operate to heat the thermal oil as needed, while being 'charge 'by the SunDial during periods when the sun is shining. There are a number of innovations in the store, including the use of additive manufacturing to provide the template for the production of extended surfaces to aid oil-PCM heat transfer.

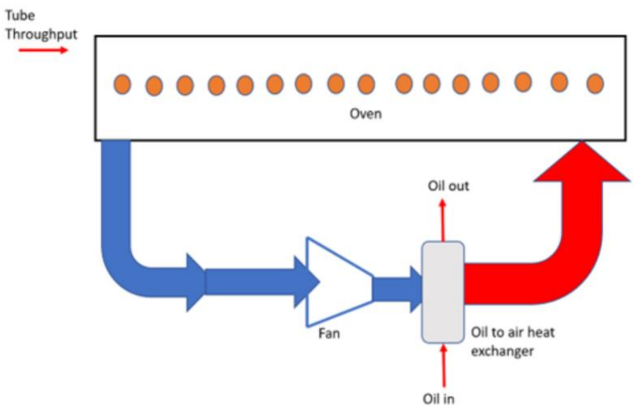


Figure 3: Delivery of heat from the thermal oil to heat the coated steel tubes – the hot thermal oil will be sourced directly from the SunDial or from the molten salt thermal store.

4.2. Dairy Industry

The second case study provides process steam (at 175 °C, 9 bar) and chilled propylene glycol (via an adsorption chiller) to a dairy processing plant in Greece. The pilot-scale prototype system will provide approximately 5% of the plants energy demands, providing proof of concept for further scale up.

Figure 4 shows how the ASTEP system integrates with the existing steam system of the plant, allowing seem less integration without major changes to plant pipework. As with the metals processing case study, the thermal storage system is optimized to provide process heating across the full shift pattern of the plant. This has been confirmed via extensive transient modelling studies [9], [11] which will be experimentally validated in 2023.

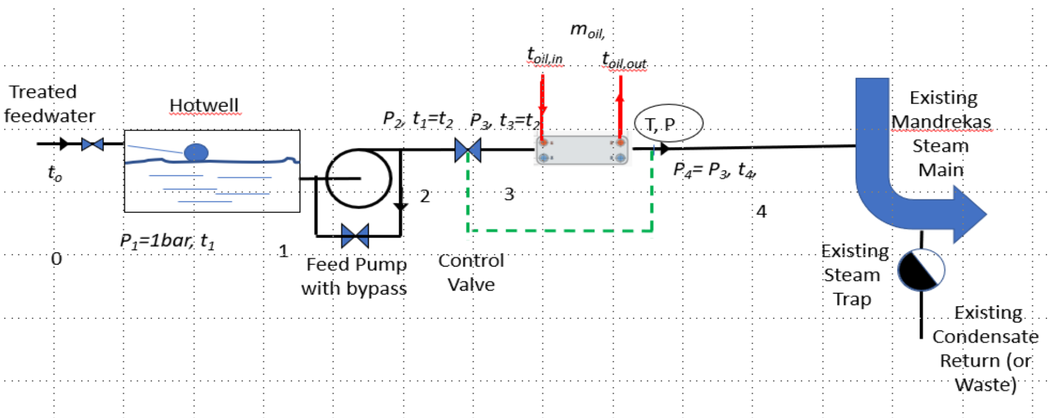


Figure 4: Integration of solar energy from ASTEP system with main steam line in Greek dairy case study.

3. CONCLUSIONS

The ASTEP project is one of many directed at using renewables to reduce carbon dioxide emissions. While solar thermal energy is well-established in areas where it can provide comfort conditions, the demands of the process industries are more difficult to meet. The European Commission is funding this initiative as part of its efforts to show that solar thermal can be a realistic option for some process applications.

The pilot scale demonstration in the ASTEP project provides a framework for future solar integration in industry, providing heat at 175-220 ºC with storage allowing 24 hour continuous supply. To date this has been demonstrated via a comprehensive modelling study with on-site tests to commence in 2023.

ACKNOWLEDGEMENTS

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