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# Optimization of solar assisted heating system for electro-winning process in the copper complex

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ABSTRACT

Through various solar assisted heating systems installed worldwide, large industrial scale applications include a very small fraction and further research is still needed in this area. Electrowinning in the copper complex is an industrial scale process that needs thermal energy for electrolyte heating. In this work, for the first time, the techno-economical assessment of using solar energy for this application is performed. Sarcheshmeh copper mine, Kerman, Iran is selected as the case study. System components are modeled and the annual performance is evaluated. To economically optimize the collector arrangement and sizes of storage tank and solar farm, a single-objective as well as a multi-objective genetic algorithm is used. Then, the effects of type and orientation of collector and heat transfer fluid on the system performance are studied. Results demonstrated that a system of 5000–6000 square meters of collectors (depending on the selected collector), facing south, 150–250 cubic meters of stratified storage tank with a height to diameter ratio of three can supply 40–78% of the total heat demanded. This leads to around a 970 tonnes reduction in carbon dioxide emissions each year, which is quite significant, especially in terms of reducing global warming. Payback period varies between 6 and 10 years.



## 1. Introduction

Renewable energy resources play a key role in improving public health and environment quality, reducing global warming and assuring sustainable development. Among different renewable sources, solar energy is the most widespread. One way of harvesting this energy is extraction of thermal energy in solar collectors.

Substantial progress has been made to promote different components of solar thermal systems. For providing temperatures from 80 °C to 250 °C, a wide choice of collectors is available like flat plate collectors, stationary compound parabolic concentrator collectors, evacuated tube collectors, small parabolic trough collectors and linear concentrating Fresnel collectors. DNI fraction is an important criterion for choosing adequate collector type [1]. Among all medium temperature collectors, evacuated tube ones showed a reliable performance, as well as having shorter payback period times and were predicted to be more economic in the near future [2]. Heat transfer fluid is the next important part of a solar-assisted integrated system. For heat transferring between collectors and plants, different heat transfer fluids are developed [3]. Another important component is storage tank. It is coupled to solar systems so as to tackle the variable nature of solar energy. Storage unit will store the unused solar energy collected during the operating-breaks (week-ends, short break of operation, …) and will restore this energy during the working process periods [4]. Results demonstrated that storage by thermocline solutions is globally more attractive, since they exhibit similar thermal performance at a low cost [5]. Moreover, the techno-economic study demonstrated that utilizing a thermal energy storage system decreases the fuel consumption in auxiliary heater [6]. However, complete replacement of auxiliary heater by thermal storage system is not reasonable. Stratified storage tanks are more economic compared to two tank storage systems. Using phase change materials in such tanks is under investigation to improve their performance, however, more effort is needed to compete economically with existing systems [7]. The demanded tank temperature and load profile influence the viability of the whole system. The energy delivered to the tank decreases by increasing the demanded temperatures and non-uniform demand profile (focused on the end of the day)

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**Nomenclature**

*Abbreviations*

| | |
|---|---|
| HTF | Heat Transfer Fluid |
| GA | Genetic Algorithm |
| NSGA | Non-dominated Sorting Genetic Algorithm |
| LCS | Life Cycle Savings |

*Symbols*

| | |
|---|---|
| $A_{collector}$ | Gross aperture area of collectors |
| $A_c$ | Collector area |
| $a_0, a_1, a_2$ | Efficiency equation coefficients |
| $C_a$ | Collector cost per unit area |
| $C_f$ | Fixed costs |
| $C_{p,HTF}$ | Specific capacity of heat transfer fluid (J/kg. °C) |
| $C_l$ | land cost per unit of land area |
| $C_p$ | Specific heat (J/kg. °C) |
| $C_s$ | Total initial investment cost |
| $C_v$ | Thermal storage cost per unit volume |
| $I$ | Global horizontal irradiance |
| $I_b$ | Direct normal irradiance |
| $I_d$ | Diffuse horizontal irradiance |
| $I_T$ | Total solar radiation incident on a tilted surface |
| $K_{\tau\alpha}$ : | Incidence angle modifier |
| $L$ | Land area |
| $\dot{m}$ | Mass flow rate (kg s$^{-1}$) |
| $Q_{collector}$ | Heat produced by the collector |
| $R_b$ | Geometric factor |
| $S$ | Total solar radiation incident on a tilted surface |
| $T_a$ | Ambient temperature |
| $T_c$ | Collector output temperature |
| $T_{elctorlyte,i}$ | Inlet temperature of electrolyte(°C) |
| $T_{electorlyte,out}$ | Desired temperature of electrolyte(°C) |
| $T_i$ | Collector inlet temperature |
| $T_{T,t}$ | Temperature of flow returning to the tank |
| $T_{T,t}$ | Temperature of top of the tank |
| $V$ | Thermal storage volume |

*Greek Symbols*

| | |
|---|---|
| $\rho_g$ | Ground reflectivity |
| $\tau$ | Transmittance |
| $\alpha$ : | Absorptance |
| $\eta$ | Collector efficiency |

*Subscript*

| | |
|---|---|
| $a$ | Ambient |
| $c$ | Collector |
| $d$ | Diffuse |
| $g$ | Ground |
| $i$ | Inlet |
| $l$ | Load, land |
| $r$ | returning to the tank |
| $t$ | top of the tank |
| $T$ | Tank |

decreases the profitability [8]. Moreover, when the demand temperature increases, the number of collectors increases as well.

In the design process for integrating the solar systems with existing plants, optimization step plays a key role to achieve an economical plan. Usually the size [9] and the position [10] of different components are adjusted in the optimization process. For optimizing performance and cost of a solar thermal system, proposing adequate criterion is a vital step [11]. Moreover, presentation of a model to simulate the effect of size, number and operational temperature of different components is very important. Commercial software packages like TRNSYS and Dymola are developed for this purpose [12]. High latitude solar heating system including seasonal storage was optimized using TRNSYS software and a genetic algorithm by considering the renewable energy fraction as a performance indicator [13]. In a distinct study [14], collector field, storage tank and industrial process components were modeled using the Dymola software. To minimize the economic costs a memetic algorithm as well as a genetic algorithm was used for supposed industrial demand profiles. For each optimization step, annual simulation was performed in Dymola software and then information was transferred to Matlab/Simulink. Since data transferring between different software packages is a time-consuming process, it is more efficient for the simulating and optimization processes to execute in the same environment. A comparison was made between Matlab and Modelica (Dymola software is coded with this language) modeling procedures [15]. Online heating model for a multi-floor building was proposed in both environments. Accuracy of both models was estimated to be similar while Modelica model was more complex and robust. However, Matlab model was faster as it could be employed independently [15]. Having considered all the advantages and disadvantages of the available software, Matlab was chosen to model the system.

Based on the technology developments and system optimization, a major part of heat demand in small and medium size applications could be covered by the solar thermal technologies. Utilization of a system of solar collectors to supply thermal load in absorption chillers [16,17], combined cooling, heating and power systems [18], livestock processing plants [19] and heat pumps [20] is designed and economically analysed. The techno-economic analysis indicates that the incentive actions are essential to develop the system in the market [21].

In addition, some studies have been done to evaluate the ability of solar technologies to supply the thermal energy demand in large scale industries. Application areas include organic Rankine cycle power plants [22], oil and gas plants [23], bio-oil production [24], desalination [25], carbon black [26], food [27], automotive [28] and Ceramic manufacturing [29] industries. Results in industrial scale reveal that poly-generation solar systems can have acceptable economic characteristics in comparison with common solar systems [30].

One group of industries that requires significant thermal energy is metal-extraction industries. Among them, is the copper extraction industry. The copper electro winning is one of the processes in this industry in which a high purity copper is extracted from an aqueous pregnant liquor acid electrolyte. Electrolyte includes a high concentration of sulfuric acid and copper, accompanied by other metals and additives [31]. To increase copper purity, the electrolyte is heated. Nowadays, two mines in Chile have integrated a solar system with existing heaters to preheat the electrolyte before entering the electro-winning cells [32]. One of them implements parabolic trough collector system. The other one uses flat plate collector system. However, thermos-economic simulation and optimization of the systems is not reported in the literature.

Although some studies have been conducted in the field of using solar thermal systems, the operating capacity of solar industrial