Journal of Applied Mechanics Research
Vol. 4, No.2, pp 13-20, Autumn, 2012
Received 20 July. 2012, Accepted 23 Sept.., 2012

Feasibility Study of Utilizing Solar Furnace Technology in Steel Making Industry

K. abbaspoursani, Ass. Prof., the Faculty of Mechanical Engineering, Takestan Islamic Azad University
A.A. Tofigh and B. Farahmandpour, Department of Energy, Materials and Energy Research Center
S. NahangToudeshki and A. Hadadian, Ms. Dept. of Energy, Materials and Energy Research Center

E-mail: k.abbaspour@tiau.ac.ir

Abstract: The casting industry in Iran is one the most energy consumer industries. According to the national statistics it consumes 33.6% of the produced electricity where 50-80 percent of that contributes in melting process. Therefore if we could able to preheat scrap to a suitable temperature, then the energy saving can be achieved in melting furnaces. The results of recent studies show that the preheating of scrap up to 400-500$^{\circ C}$ reduces the energy demand by 30-60 KW per each ton produced steel. In this paper after reviewing the current methods of preheating scrap in arc electric furnaces (AEFs), an emerging technology of solar furnace called tower reflector (TR), is described. Here, the results of feasibility study of the purposed technology for implementation in the Iran Alloy Steel Company (IASC),as a case study briefly is discussed. The results show that the preheating of scrap to a temperature of 500 $^{\circ C}$ leads to an energy saving of 400 GJ/ hour. Along the same lines, regarding capital and running cost, it would last less than five years to pay back the investment.

Keywords: **Solar** Energy, solar furnace, techno-economical assessment, and EAF

امکان‌سنجی بکارگیری فناوری کوره خورشیدی در صنایع فولادسازی

کمال عباسپورثانی– استادیار گروه تبدیل انرژی، دانشکده مهندسی مکانیک، دانشگاه آزاد اسلامی واحد تاکستان
علی‌اصغر توفیق و بهاره فرهمند پور– پژوهشکده انرژی- پژوهشگاه مواد و انرژی
سارا نهنگ‌تودشکی و آرش حدادیان- دانشجوی کارشناسی ارشد ، – پژوهشکده انرژی- پژوهشگاه مواد و انرژی

چکیده: ذوب فولاد فرآیندی انرژی‌بر و کوره بزرگترین منبع مصرف کننده انرژی الکتریکی می‌باشد. پیش گرمایش قراضه قبل از ورود به کوره باعث حفظ میزان قابل توجهی از انرژی و توان می‌گردد. توان مورد نیاز جهت پیشگرمایش قراضه تا دمای ^{o}C ۶۰۰-۵۰۰ در شرکت فولاد آلیاژی ایران (یزد) با توجه به شرایط کار و سطح تولید کارخانه حدوداً MW ۵ است. در صورت استفاده از فناوری کوره خورشیدی برای تامین این انرژی با در نظرگرفتن راندمان اپتیکی ردیاب (۰/۶) و راندمان گیرنده مرکزی (حدود ۰/۸) توان قابل جذب از انرژی خورشیدی معادل ۱۰/۵MW خواهد بود که برای تامین آن با احتساب میزان متوسط تابش خورشیدی ۶۰۰W/m^2 حدود ۱۳۰۰۰m^2 سطح مفید ردیاب خورشیدی مورد نیاز می‌باشد. در این فناوری خورشیدی، میدان‌نوری شامل ۲۹۰ ردیاب خورشیدی که سطح هر کدام ۳۶m^2 می‌باشد، در منطقه‌ای به وسعت ۱/۲ هکتار آرایش یافته‌اند. ارتفاع برج ۷۱/۵m است که در بالای آن یک آینه محدب با سطح منعکس‌کننده ۶۱m^2 طرح ریزی شده است. به منظور بهره‌برداری بیشتر و حداقل توان اتلاف در تجمع پرتوهای‌نوری و ایجاد گرمای یکنواخت، پاتیل قراضه از ۸ قسمت خوشه‌ای شکل ساخته شده است. هزینه تقریبی ساخت این تاسیسات خورشیدی شامل ردیاب، گیرنده مرکزی، پاتیل، سکوی‌نگدارنده و قطعات یدکی بالغ بر ۴۲ میلیاردریال پیش بینی می‌شود.

واژه‌های کلیدی: برگشت‌فنری، نورد عمیق، طراحی قالب و رفتار ارتجاعی- پلاستیک.

1. Introduction

Nowadays, EAFs are the common technology for producing the steel which plays a key role in the world's production. Between the1970s and1990s, the world steel production was 175 million tons in which 75% of that was produced by EAFs[1]. There are many factors which have involved in this production such as; innovation in technology, traditional cost of scrap, energy cost, the demand for production of low quality steel for manufacturing and construction[2]. It is predicted that EAFs even until 2020 will provide 60% of the world's steel production.

In comparison with the other furnaces, the process of production in an EAF has a few stages. Raw materials such as coke should be prepared and iron plate should be produced before an operator starts to charge the furnace. The EAFs convert the raw charge into molten steel by using an adequate amount of electricity. Isolated slag and molten steel is transferred into the bucket and then, good quality steel alloys are produced by adding some materials. During this process, steel is entered into the bloom billet and could be converted to the final product by hot rolling. Figure (1) shows a typical EAF

2. Common technology for scrap preheating in EAFs

Many tasks have been taken in order to increase the efficiency of EAFs, decrease the energy consumption, and also increasing the productivity. Experiences show that more than 60% of total energy is used to deliver the steel to its melting point (1150$^{\circ C}$). From previously conducted studies, it is evident that when the scrap is preheated to 500$^{\circ C}$it leads to a considerable amount of energy saving [3].

By developing the preheating scrap furnaces of BOC Gaser Company, an energy saving of 4.5 KWh/m^3 of the consumed Oxygen is achieved in an EAF[4]. Furnace is working with the flue gases from the EAF as illustrated in Fig.(2).

In the Consteel preheating scrap furnaces, as illustrated in Fig.(3) the scrap is passed through a channel by conveyor belt and after being heated by flue gases is entered to the EAF. Jones showed that by using this preheating furnace, not only an energy saving is achieved but also 40% of emissions and 33% of electrode consumption are decreased [5]. Moreover, a study claimed that by applying this preheating method, the consumed electricity is declined by 300 to 350 KWh per each tone of steel production [6].

Developing the Fuchs axial furnaces have caused that the electricity consumption decreased 90 to 110 KWh per each ton of steel production. In addition, electrode consumption and emissions declined by 20% and 25%, respectively [7]. Axial furnaces have been one of the advanced technologies for scrap preheating. Generally, this type of preheating furnace as illustrated in Fig. (4), is installed at the top of EAF in which the flue gases flowing from molten region to up and pass from the scrap for next charge of EAF.

One of the common methods to preheat scrap which have been recently invented is the double shell preheating furnace [8]. In this furnace as indicated in Fig. 5, steel is produced in one part of the furnace while the other part is charged by scrap. In the shell, flue gases released from the melting process go through the scrap to recharge the furnace. According to the report of Nippon industry [8], by using this furnace at a preheating temperature of 900 $^{\circ C}$, energy consumption could be decreased by 260 KWh per each ton of produced steel

Ignoring the source of supplying the energy need for preheating, all the common technologies at a normal preheating temperature of 250 and 500 $^{\circ C}$, they need an extra energy and as a result they need high capital cost. Despite, the low preheating temperature without extra energy and using an environmental friendly way, preheating of scrap is possible by utilizing a solar technology. In this paper for achievement of an optimum preheating temperature, a feasibility study is carried out to utilizing a solar preheating furnace at IASC.

3. Solar technology to preheat scrap in EAFs

Till yet, none effective task has been made for utilizing solar energy as a heat source to preheat scrap in EAFs. Perhaps, the main reason may be related to the low efficiency of energy conversion in solar technologies. Solar concentrators and heliostats in solar power plants with central receiver are the key factors affected the energy conversion efficiency. Generally, these optical equipment cause an energy loss about40%to 60% and their cost is about 30% to 50% of the capital cost of solar system.

Improving the concentrators and modification of the production process are one of the approaches to decrease the cost of solar energy. Despite to reduction of the manufacturing cost of heliostats, the cost of energy production has not considerably decreased. The other approach is increasing the solar system efficiency by optimizing the radiant power on the surface of heliostats. The Visaman Research Center by using the recent approach has made more attempts to develop a solar conversion system with high efficiency [9].

More serious efforts have been done at the Dead Sea Works Ltd in the 1995 [10]. This company by utilizing the solar energy proceeded direct melting of Potassium and producing electricity, simultaneously. In the 1999, the PSI Research Center constructed a 400 KW solar furnace in order to use in the thermo-chemical researches. This furnace consists of a heliostat with single axis of rotation and an incidence area of 120 $m^2$and a concentrator with an aperture diameter of 8.5 m [11].

4. Solar radiation in Yazd

Yazd (Latitude 32˚N and longitude 54˚E) is located in the southeast of Iran. Yazd has a dry and desert climate. This city is sunny in most days of year and average daily insolation is more than 6 KWh/m^2on a horizontal surface. The day light hours in this city varies between 10 and 14 hours in a day. Average daily insolation varies between 4.4 and 9.6 KWh/m^2. Therefore, yazd has a high potential for capturing of solar energy appreciate for high temperature applications.

Average daily and monthly solar irradiation on a horizontal surface is shown in the Table 1. Monthly solar insolation in this city is also shown in Fig.(6) in terms of MWh/m^2. In order to determine the solar insolation on the surface of heliostats, solar irradiation in different tracking modes is estimated and results plotted in Fig.(7). A careful examination of Fig. 7 it reveals that the maximum insolation is nearly 3.5 Mwh/m^2 and achieved for tracking mode 5 (a tracking mode with two perpendicular axes of rotation).

5. Iran Alloy Steel Company (IASC)

IASC has been operated since 2000 in Yazd. This company is one of the major exporters of alloy steel in various sections. The nominal annual capacity of production is 0.2 million tons of steel while, the scrap’s consumption is 0.25 million tons. Melting unit of this company is comprised two EAFs with a capacity of 20 tons and a power rate 36 MW for each. The characteristics of EAFs used in this company are summarized in Table (2).

6. Basic Solar Technology Proposed for Preheating Scrap

Proposed approach for preheating scrap named tower reflector which is shown in Fig. (8). Main idea came from the innovations of the Dead Sea Work Ltd and experiences of the [9] with regarding to the design of the solar power plant with central receiver. The main components of this preheating durance are the fields of heliostats around a solar tower, a convex reflector, as a secondary concentrator which is located on the top of the scrap bucket. Reflector can be a mirror or a light filter that in later it transmits a part of solar light and the remains is reflected at the solar spectrum.

In the proposed system, the process of preheating is designed on the base of direct solar radiation. Preheating the scrap by this way has two advantages; firstly, it is provided from a free and clean source of energy. Secondly, it prevents environmental pollution. Therefore, the proposed technology has a high potential for producing thermal energy at a relatively high capacity. It is planned, the preheating capacity has been set at 0.25 million tons of scrap (annual consumption of IASC). The average preheating capacity is 75 ton/h and the thermal capacity of pre-heaters is 9 MW. Because of variations of daily solar insolation in Yazd, the rate of scrap preheating varies in the range of 30 to 80 ton/h.

As illustrated in Fig.(8), bucket of scrap is made of carbon steel and consists of a hydraulic door for discharging of hot scrap. The capacity of the bucket is about 50 tons of scrap. The preheating process is only done in the sunny hours of the day (almost 4600 hours a year in the city of Yazd). During this process, scrap continuously flow into the next step of production process with a rate of 57 ton/h.

In the proposed technology, light field consists of 290 heliostats with a surface area of 36 m^2 for each and they are arranged in a terrain with an area of 1.2 hectare. Tower height is about 71.5 m and a convex mirror with an aperture area of 61 m^2 is located on the top of the tower. Square meter of reflection is put on the top of it. In order to increase the solar absorption and decrease the radiation dispersion, the bucket is constructed from 8 cluster shape that could provide a uniform heat for scrap preheating.

7. Optimization of Design and Characteristics of the Final Proposed System

Solar preheating scrap which has been described above includes the heliostats that are located in the northern region of the field, while, other system components are located in the southern region of the field. Some arrangements are predicted for controlling the sun tracking of heliostats and a water fall system is provided for cleaning the dust from heliostats' surface since Yazd is located in a desert region.

The estimated cost was attained from the available internal and external resources after completing the calculation and designing the system's components. Then, all the calculation should be repeated and thereafter the technical and economic plan should be designed. The results for scrap preheating at a conventional temperature of $500^{\circ C}$are given in Table 4.Optimization is based on minimizing the cost and increasing the solar efficiency (Segal and Epstein, 2000).

8. Techno-economic Assessment of the Plan

The finical estimation for construction based on materials and optical equipment cost was performed in October of 2009. The results are summarized in Table (5). All the costs are estimated based on the vendors and contractors offers and the cost value for electricity production according to the national report assumed to be 2 cent/KW. Employ engineering and manpower cost are 15% of the total cost and unpredictable cost is assumed to be 15%. Exchange rate based on a rate of 11000 Rials/US$. Total cost of the plan as shown in Table (5), is estimated 3.8 MUS$. A summary of techno-economic indexes for the optimum design of proposed system are given Table (6).

9. Conclusion

In this study for reduction of energy consumption and environmental impacts, a solar preheating technology by using a reflector tower was proposed. This preheating system is designed for obtaining temperature of $500^{\circ C}$with a capacity of 0.25 million tons of scrap per year. The results show that for implementation of technology in melting unit of IASC need a capital cost of 3.8 MUS$. By applying this method energy consumption is decreased by 40 GWh/per year and as a result annually almost 0.8 MUS$ would be saved in energy cost. It is estimated that after five years the investment plan cost will be repaid.

10.References

[1].Gooday, p. and Labson,B.S., Electric Arc Furnace Technology and Its Impact on Iron Ore and Coal Use, in Steel in East Asia in the 1990s, towards an East Asian Steel Agreement, *The Minerals and Energy Forum of the Pacific Economic Cooperation*, 30April to1may, Perth, Western Australia,1993.

[2].Branett, D. F. and Crandali, R. W, Up from the Ashes: The Rise of Steel Mini-mill in the United State, Washington, DC: *The Bookings Inst.,1986.*

[3].Environmental Technology Program for Industry, (ETPI) Environmental Report of Steel Melting Sector, Karachi, Pakistan,April,2001.

[4].Abbaspoursani, K., Farahmandpour, B., Haghgou, H. R., Halek, F. S., and Hejazi, G., Solar Scrap Preheating, Final Report, Iran Alloy Steel Company and MERC mutual Project, Contract No. 12461,MERC, 9in FARSi), 2007.

[5].Isenberg, O.J. Ironing It Out, 33 Metal Producing, May: 35-40. Knoerzer, Jerome J., Charles E.Ellis, and C. Wayne Pruit(1992), Start up and Operation of Jewell's Nonrecovery Coke Battery, Iron and *Steel Enginner 69(3): 50-3, March*.1995.

[6].Jones J. A. T., Electric Arc Furnace Evolution: In Search of the Optimal Design. *Bechtel Corporation*, 1997 b.

[7].Herin, H. H. and Busbee, T., The Consteel Process in Operation at Florida Steel, *Iron & Steelmaker Vol. 23, No,2,* pp 43-46, 1996.

[8].Hofer, L., Electric Steelmaking with FUCHS Shaft Furnace Technology, Linz, Austria: Voest Alpine, *Indusrtieanlagenbau Gmbh, VAI,* 1996.

[9].BCS, Incorporated, Advanced Melting Technologies: Energy Saving Concepts and Opportunities for the Metal Casting Industry, *Technical Report prepared for ITP Metal Casting*, Nov. 2005.

[10]. Jones, J. A. T., New Steel Melting Technologies: Part X, New EAF Melting Processes, *Iron and Steelmaker, Vol 24 (January):* 45-46, 1997a.

[11]. Segal, A., and Epstein, M.,The Optics of the Solar Tower Reflector, *Solar Energy J., Vol. 96 (Suppl.), Nos. 1-6*, pp 229-241, 2000.

[12]. Kirbus, A., Zabil, R., Carey, D., Segal, A., and Karni, J., A Solar Drien Combined Cycle Power Plant, *J. of Solar Energy, Vol. 62, issue 2*, Feb. 1998.

[13]. Kraupl, S. and Steinfeld, A. , Operational Performance of a 5-KW solar Chemical Reactor

for Co-Production of Zinc Syngas, , Solar Energy Vol. 125, No. 1, pp124-127, 2003.

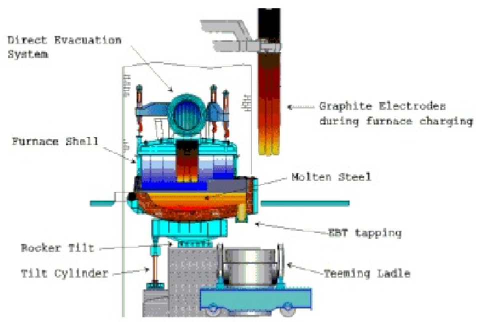

Fig.(1): A typical electric arc furnace

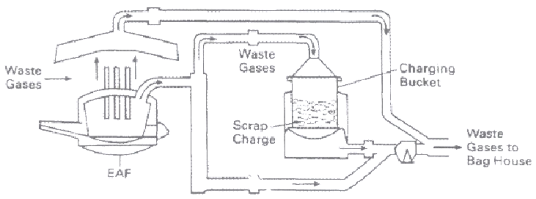

Fig.(2): Schematic of a BOC Gaser preating furnace

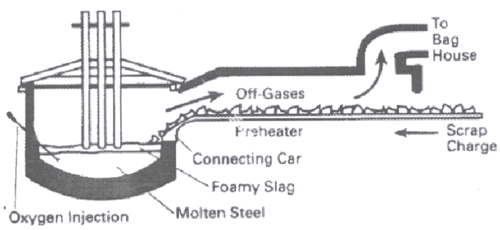

Fig.(3): Consteel Preheating furnace

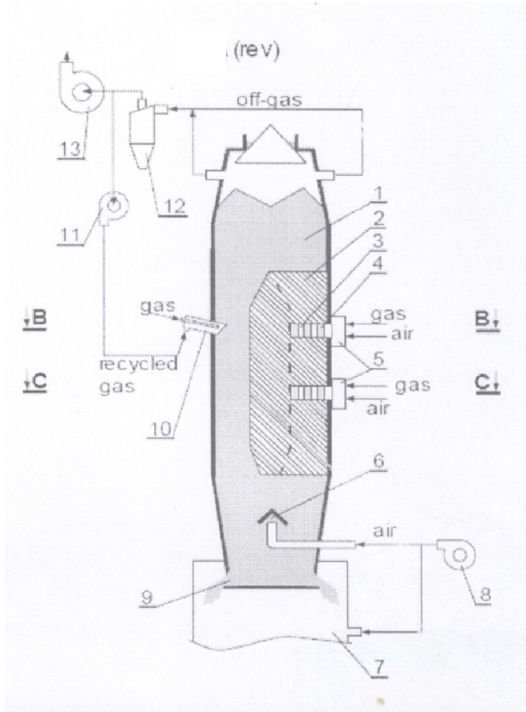

Fig.(4): A view of an axial Fuchs preheating furnace

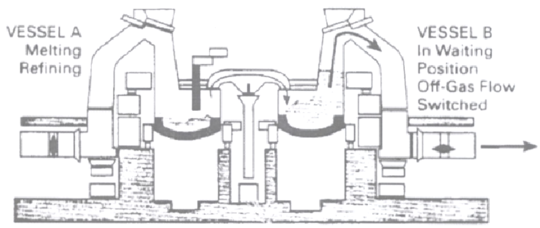

Fig.(5): view of double shell preheating furnace

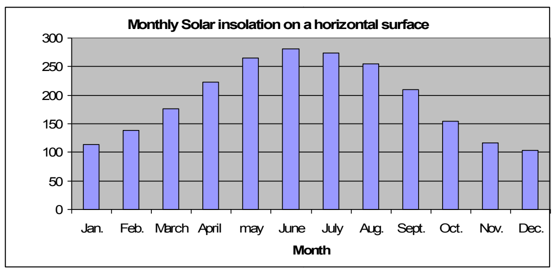

Fig.(6): Monthly solar insolation in Yazd (KWh/m^2)

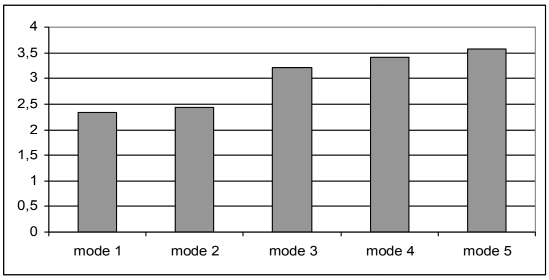

Fig.(7): Annual solar insolation for various tracking modes (MWh/m^2) in Yazd

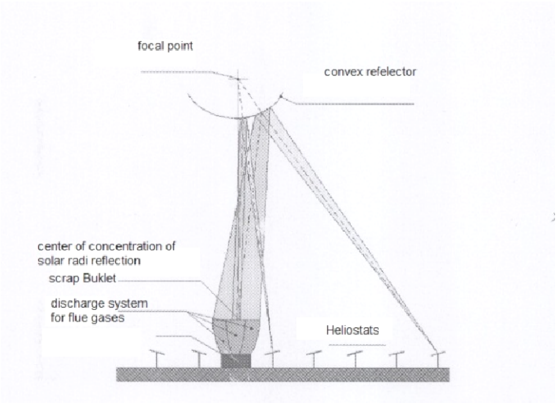

Fig.(8): A schematic of tower reflector

Table 1: Solar data for Yazd [4]

Month of year	Average daily solar irradiation (W/m^2)	Monthly solar insolation (MJ/m^2)
Jan.	318.4	371.4
Feb.	404.2	456.9
March	408.8	548.9
April	485.8	680.3
May	548.2	838.7
June	601.1	913.2
July	594.3	920.0
Aug.	587.8	865.5
Sept.	569.3	756.3
Oct.	473.2	603.0
Nov.	357.1	408.8
Dec.	313.6	357.9

Table (2): Characteristics of EAFs used in IASC

a) Furnace	
Type	EA
Capacity	40 tons
No. of charges	15 per day
Energy consumption	25.5 MWh per charge
Total Energy consumption	607 MWh/ton of product
b) Scrap	
Consumption	741 tons per day 49.4 per charge
c) Melting unit	
Daily steel production	630 tons
daily Energy consumption	382.5 MWh

Table (3): The characteristics of optimum plan for scrap preheating up to $500^{°C}$

Design Parameters:	Value
Annual Capacity of scrap for preheating:	0.25 million ton/year
Preheating rate	57 ton/h
Input electrical power	8MW
Optical Characteristics:	
Surface area of heliostats	10440 m^2
Array and density of heliostats field:	0.42 N
Aperture area of reflector	61 m^2
Effective diameter of reflector:	4.3 m
Height of the reflector	71.5 m above ground level
Focal length of tower reflector:	75
Reflected radiation power of reflector	10MW
Maximum irradiation on reflector	164KW/m^2
Total optical efficiency	95%

Table (4): Construction cost for solar scrap preheating up to 500 °C

Item no.	Cost details	Cost (1000US$)
1	Optical equipment	
	Heliostats	1280
	Refelector	25
	Tower	875
	Sum	2180
	Operational cost	
	Construction	810
2	Control devices	Included in item No. 1
	Insulation	7
	Electrical engineering	13
	sum	830
3	Employ engineering and manpower	300
4	Unpredictable cost	500
5	Total cost	3810

Table (5): Indexes for techno-economic assessment estimation of the solar scrap preheating

Parameter	Value
Specific energy consumption(per each kg of the Production)	
required Energy for preheating up to melting point	814 Kj/Kg
energy required for melting	280 Kj/Kg
Energy required for super heating the melt	41 Kj/Kg
Total	1135 Kj/Kg
Energy conversion efficiency	
Melting unit	51.9%
EAF	16.6%
Preheating the scrap	
Preheating temperature	500°C
Sensible heat of the preheated scrap	252 Kj/Kg
Net energy saving for preheating	119Kj/Kg
Energy saving in percentage	31%
Economic assessment	
Cost value of produced electricity	2 Cent/KW
Specific energy saving	188 KWh/ton
Annual electricity saving	39720 MWh/year
Daily benefit value	2345 US$/day
Annual energy reserved	0.79 MUS$/year
Investment Payback period	Less than 5 years