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Application of Solar Energy Heating System in Some Oil Industry Units and its Economy

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Abstract

Energy is one of the building blocks of modern society. Once an exporter of oil and gas, Egypt is now struggling to meet its own energy needs. In oil industry there is an energy problem due to fuel and electricity consumption and refinery losses in a way that reduces the net profit of the industry. There are also environmental problems due to carbon dioxide emissions which is a major source of the global warming problem. As Egypt is blessed with geographic location in the Sun Belt area with 325 days of sun in a year, solar energy can be used as a source of energy that reduces fuel consumption and CO_2 emissions. The current study presents solar energy heating system that can be used for heating applications in some oil industry units. The study has been divided in two parts, the first one concerned with choosing the most appropriate solar system that can be used in such applications. Four different mathematical models for prediction of optical efficiency and thermal losses for the chosen system have been analyzed and then computerized using excel sheet program. Numerical comparison and also practical validation of the selected model have been done. For that paper under title of "Evaluation of Mathematical Models for Solar Thermal System" was published in October, 2016, American Journal of Energy Science. Visual basic program is then done for the validated model for good and friendly user interface. For the second part of the study, this paper concerned with performing an economic evaluation for providing feasibility and reliability conception about using the proposed system in some oil industry applications in number of Egyptian companies as preheating of crude oil for desalting in oil production (Khalda petroleum company), preheating of viscous oil for transportation enhancing and preheating of boiler feed water (Cairo oil refining company). The results show that payback period for crude preheating before desalting is 20 years and for fuel oil and boiler feed water preheating are 7 years.

Keywords: Solar energy; Parabolic trough solar collector; Crude oil heating; Steam production

Introduction

In Oil Industry there is an energy problem due to energy losses in a way that reduces the net profit of the industry. Energy Losses are due to fuel consumption, refinery losses and electricity consumption. For example Heating viscous oil for transportation enhancing and heating crude oil for preliminary treatment consume a great amount of fuel. In refinery also for 100 kbpd crude needs approximately 120 MW to be preheated up to 350°C [1]. A rule of thumb used by some refiners is that it takes 1 barrel of oil-equivalent energy to process 10 barrels of crude oil [2]. Petroleum refining in the United States is the largest in the world, refineries spend typically 50% of the cash operating costs [3]. Oil refining, petrochemicals, ammonia, paper, cement, and steel production consume about 18% of the primary energy in the European Union (EU).

So there is a great interest towards the technologies for increasing the energy efficiency by reduction of the energy consumption. The most productive energy-conserving measures appear to be in the areas of improved combustion, the recovery of low-grade heat, and the use of process modifications. Concerning these solutions Romulo, Lima S et al. made a comparison between energy efficiency in Brazilian and United States crude oil refinery and concluded that increasing the refinery complexity which means more heat integration inside the plant will lead to reduction of the energy consumption [4]. To meet the energy challenges faced by Chinese petroleum refiners. Liu X et al. indicated that upgrading process heaters is identified as apriority to enable short term energy optimization [5]. Refineries may be also able to use other sources of energy, and otherwise wasted heat, to reduce the combustion of gaseous and liquid fuels. So fuel substitution (such as the use of coal in refineries) is an important goal [6].

In addition to energy problems, there are also environmental problems as in 2008 around 81.3% of the world's primary energy was supplied from oil, gas, and coal products; resulting in around 29,381 million ton of CO_2 which is a major source of the global warming problem [7]. Renewable energies including solar, wind, hydropower and biomass are considered to be attractive alternatives that are highly abundant, sustainable and environmentally friendly resources, most countries have initiated programs to develop energy sources based on renewable resources.

To overcome economical and environment problems, solar energy is introduced in this paper for heating applications in oil industry. For the applications of solar energy in oil industry, researchers studied using solar thermal energy in heating viscous fuel oil to about 50°C and stored at that temperature [8,9], heating crude oil to maintain flow ability during transportation [10-13] and thermal treatment of crude oil by heating water in the collector to 85-90°C then heated water exchanges heat with crude which is heated to 55-60°C [14].

Reference to the first part of the study [15] parabolic trough collector (Figure 1) presents the most appropriate type of collector to be used in the discussed solar thermal system for usage in the oil

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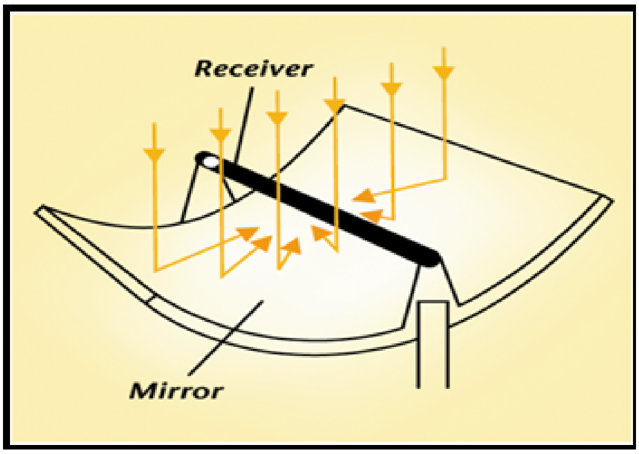


Figure 1: Parabolic trough collector.

industry.

For developing an economic study for any process unit, the process designer must be aware of selection of a basic process route, equipment used in the process and also details incorporated into the equipment. From a first draft flow sheet, a preliminary cost estimate can be prepared by the "factoring" or equivalent method. With more comprehensive and better information regarding the process, estimating engineers can prepare detailed estimates, which are often quite accurate, usually ±10% for the best [16].

Methodology

Cost estimation

For preliminary cost estimation of any process unit the following steps to be done:

1. Preparing a flow sheet for the process.
2. Preparing heat and material balances around each piece of equipment.
3. Sizing all of the equipment for cost estimation (the material cost of equipment often represents 20-40% of the total project cost for process plants).

Equipment cost prediction in the present study is done using the following methods:

a) Estimating Charts (Chemical Engineering Economics).

b) Matches (licensed Engineering Company) software.

c) Online cost estimator (McGraw-Hill Education).

d) Equipment cost V.1 software (University of Porto).

e) Actual commercial costs from Egyptian oil sector.

4. Analyzing the process carefully to determine what plant cost factors that should be used for calculation of (Electrical, Instrumentation, Utilities, Foundation, Installation, etc.) costs, and then calculation of total plant cost.
5. Finally investment decisions are taken often based upon several criteria such as payback period that is usually measured as the time from the start of production to recovery of the capital investment.

The above mentioned steps for cost estimation are done for each of the discussed applications (Figure 2).

Proposed solar system

Heat transfer fluid (HTF) is designed to transfer heat from parabolic trough collector (PTC) to the fluid needed to be heated through heat exchanger. HTF must combines heat stability and low viscosity for efficient, dependable and uniform performance in a wide optimum use range of 120°C to 400°C.

Basis of design:

1. Configuration of the solar system is based on Kuraymat Plant (solar power project 100 km south of Cairo).
2. Design solar incident radiation=600 W/m².
3. Operating temperature range of HTF= (120-400°C).
4. Ambient temperature=20°C.
5. No over design is considered.

Process description: HTF is transferred by a transfer pump to be heated through PTC, and then directed to heat exchanger for heat transfer to the fluid to be heated. HTF is finally directed to surge tank to be pumped again (Figure 3).

Scope of work: This study scope of work in each application is to perform detailed engineering for the solar package in order to provide cost estimation for each project through the following steps:

a) Hysys simulation for the hot oil system to optimize the design of plant (Figure 4).

b) Hydraulic calculation for pump and piping is to provide piping size, system pressure drop (Figure 5) using HCALC (full pipe flow hydraulic calculator) and then pump required power.

Then commercial pump selection based on Tahoe Design Software's Pump Base (Figure 6).

c) Heat exchanger thermal design using HTRI (Figure 7) (Heat

Plant Cost Estimating Factors

Component	*Plant Cost Factor, Fraction of Total Purchased Equipment Cost*	
Purchased equipment	1.00	
Piping	0.15–0.70	
Electrical	0.10–0.15	
Instrumentation	0.10–0.35	
Utilities	0.30–0.75	
Foundations	0.07–0.12	
Insulation	0.02–0.08	
Painting, fireproofing, safety	0.02–0.10	
Yard improvements	0.05–0.15	Optional Estimating
Environmental	0.10–0.30	Factors, Fraction
Buildings	0.05–1.00	of (Subtotal)
Land	0–0.10	Plant Costs
	Subtotal	1.96–4.80
Construction, engineering	0.30–0.75	0.10–0.40
Contractors fee	0.10–0.45	0.03–0.10
Contingency	0.15–0.80	0.05–0.20
Total	2.51–6.80	2.31–8.16
Usual limits for total factor		*Lang Factor*
Minimum (solids processing)	3.00	3.4
Average (mixed processing)	4.00	
Maximum (fluid processing)	5.50	5.2
	Additional Factor,	
Other capital requirements	*% of Total Plant Cost*	
Off-site facilities	0–30	
Plant start-up	5–10	
Working capital	10–20, or 10–35% of mfg. cost	

Figure 2: Plant cost estimating factor.

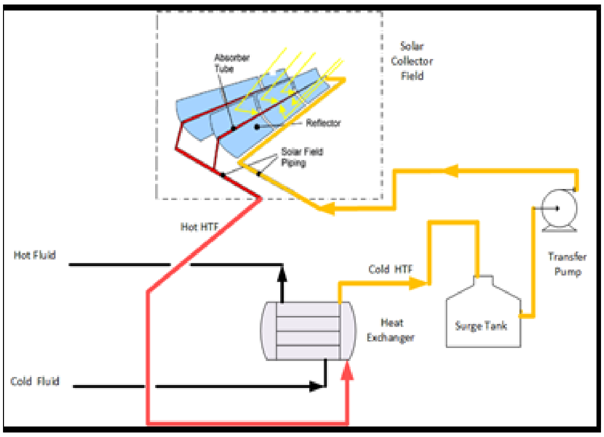


Figure 3: Solar package.

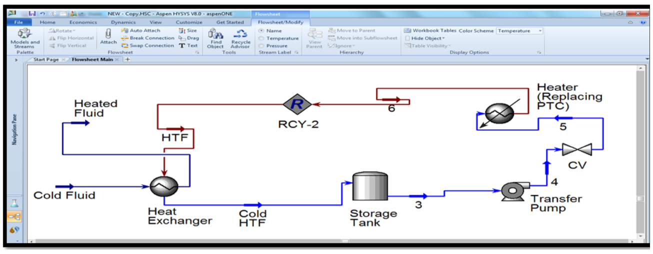


Figure 4: Hysys simulation for the proposed solar package.

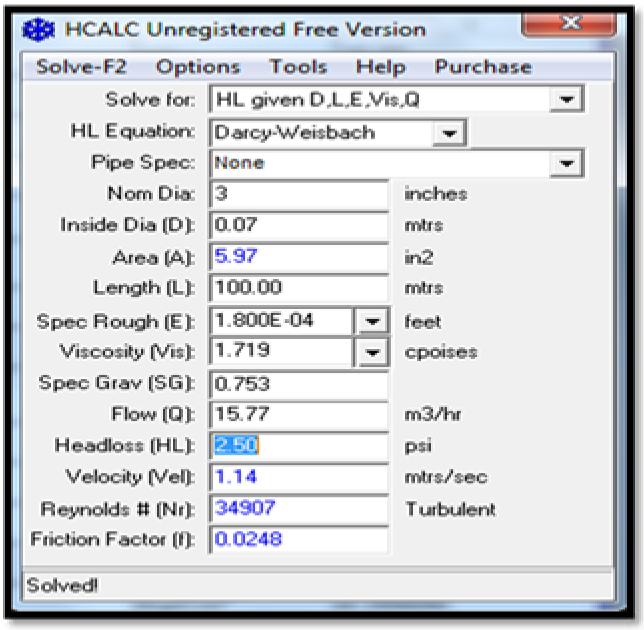


Figure 5: HCALC line sizing.

Transfer Research Institute) the global leader in process heat transfer to calculate heat transfer area and pressure drop across heat exchanger.

d) Solar thermal system design using PTC calculation (Figure 8) (software developed in first part) to calculate solar collector required area.

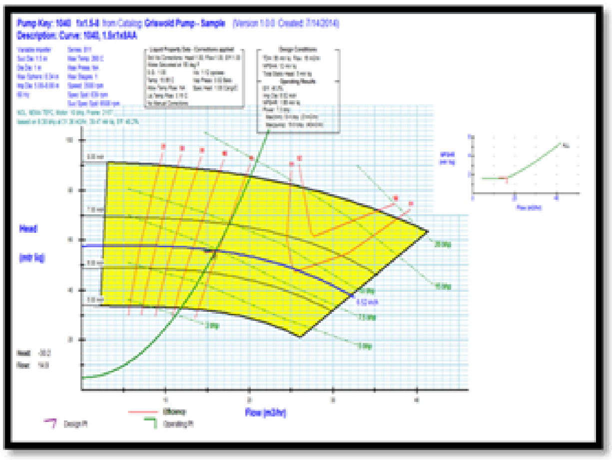
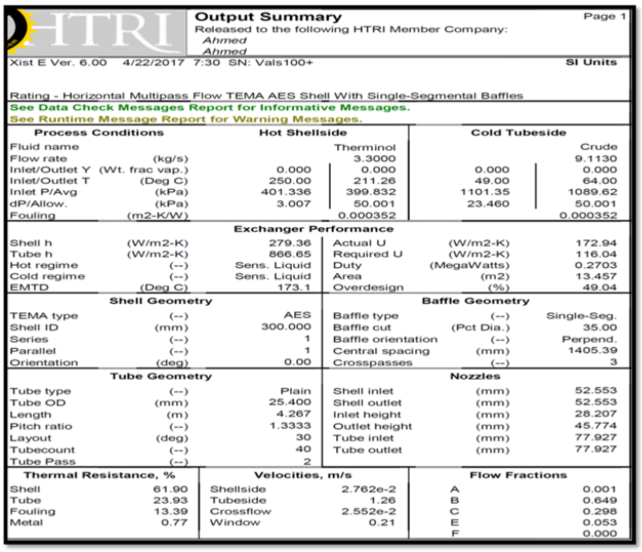


Figure 6: Q and H curve for Kalabsha.



HTRI Output Summary Page 1
Released to the following HTRI Member Company:
Ahmed
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Xist E Ver. 6.00 4/22/2017 7:30 SN: Vals100+ SI Units

Rating - Horizontal Multipass Flow TEMA AES Shell With Single-Segmental Baffles
See Data Check Messages Report for Informative Messages.
See Runtime Message Report for Warning Messages.

Process Conditions		Hot Shellside		Cold Tubeside	
Fluid name			Therminol		Crude
Flow rate	(kg/s)		3.3000		9.1130
Inlet/Outlet Y	(Wt. frac vap.)	0.000	0.000	0.000	0.000
Inlet/Outlet T	(Deg C)	250.00	211.26	49.00	64.00
Inlet P/Avg	(kPa)	401.336	399.832	1101.35	1089.62
dP/Allow.	(kPa)	3.007	50.001	23.460	50.001
Fouling	(m2-K/W)		0.000352		0.000352

Exchanger Performance					
Shell h	(W/m2-K)	279.36	Actual U	(W/m2-K)	172.94
Tube h	(W/m2-K)	866.65	Required U	(W/m2-K)	116.04
Hot regime	(--)	Sens. Liquid	Duty	(MegaWatts)	0.2703
Cold regime	(--)	Sens. Liquid	Area	(m2)	13.457
EMTD	(Deg C)	173.1	Overdesign	(%)	49.04

Shell Geometry			Baffle Geometry		
TEMA type	(--)	AES	Baffle type	(--)	Single-Seg.
Shell ID	(mm)	300.000	Baffle cut	(Pct Dia.)	35.00
Series	(--)	1	Baffle orientation	(--)	Perpend.
Parallel	(--)	1	Central spacing	(mm)	1405.39
Orientation	(deg)	0.00	Crosspasses	(--)	3

Tube Geometry			Nozzles		
Tube type	(--)	Plain	Shell inlet	(mm)	52.553
Tube OD	(mm)	25.400	Shell outlet	(mm)	52.553
Length	(m)	4.267	Inlet height	(mm)	28.207
Pitch ratio	(--)	1.3333	Outlet height	(mm)	45.774
Layout	(deg)	30	Tube inlet	(mm)	77.927
Tubecount	(--)	40	Tube outlet	(mm)	77.927
Tube Pass	(--)	2			

Thermal Resistance, %		Velocities, m/s		Flow Fractions	
Shell	61.90	Shellside	2.762e-2	A	0.001
Tube	23.93	Tubeside	1.26	B	0.649
Fouling	13.39	Crossflow	2.552e-2	C	0.298
Metal	0.77	Window	0.21	E	0.053
				F	0.000

Figure 7: HTRI output summary.

One module area=12 × 5.76=69.12 m^2

e) Separator and tank sizing (if any).

f) Cost estimation of the total solar package.

g) Payback period calculation.

Cases process description and study scope of work

Case 1: Preheating of crude oil for desalting in oil production facilities KALABSHA (Khalda Petroleum Company):

Process description: The facility is located at KALABSHA field, Western Desert Egypt. Oil (Figure 9) is distributed to the six trains to separate the emulsion water in the oil to eventually achieve the product specifications through the following equipment for each train:

i. Indirect forced heater.

ii. Production separator.

iii. Heater treater.

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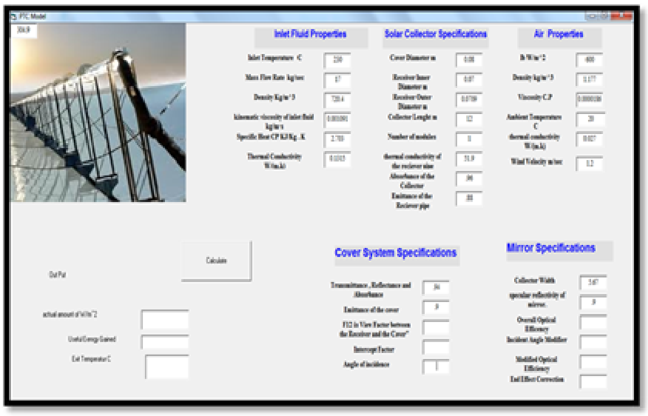

Figure 8: PTC calculations.

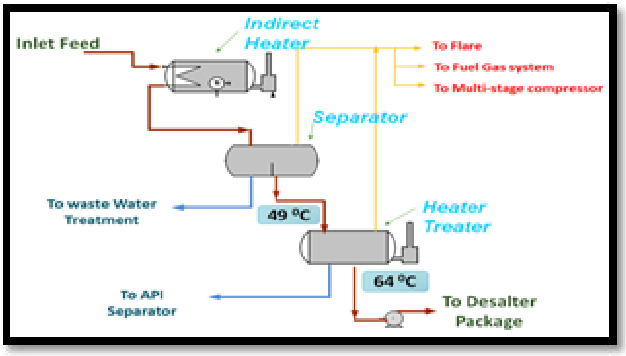

Figure 9: KALABSHA plant process description.

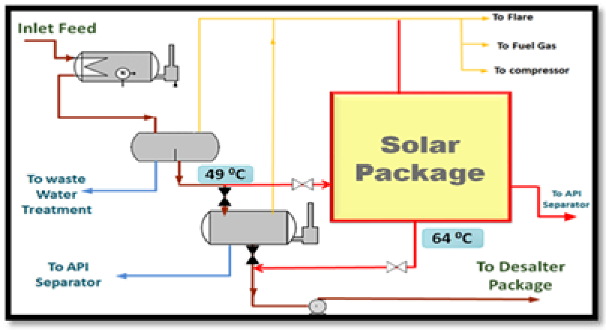

Figure 10: KALABSHA plant after introducing proposed solar package.

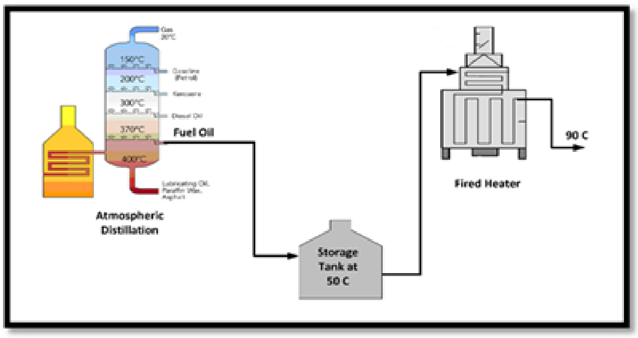

Figure 11: Fuel oil system process description.

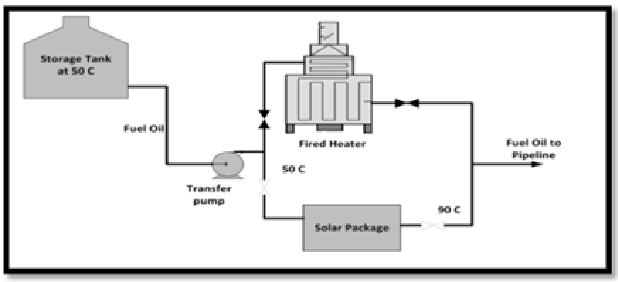

Figure 12: CORC fuel oil heating plant after introducing solar package.

iv. Oil feed pump.

Oil feed is heated in the indirect forced heater to 55°C to separate the emulsion water in the three phase separator. Flashed gases is directed to existing fuel gas system, separated water is directed to the waste water treatment facility and the oil is directed to the heater treater to further separate the emulsion water in oil. The outlet oil is pumped through oil feed pump to two desalter packages.

Scope of work: Produced crude oil is heated from about 49°C to 64°C in heater treater using fuel gas. Our scope of work is to bypass the heater (Figure 10) during day only (6 hours) with the proposed solar system and making a comparison between the existing and the proposed system.

Case 2: Preheating of viscous oil for transportation enhancing Cairo Oil Refining Company (CORC):

Process description: The Facility is located at CORC (the biggest refinery in Egypt). Its capacity represents about 30% of Egypt's refining capacity. Fuel oil is produced from atmospheric distillation unit, stored at 50°C in storage tanks, and then heated in fired heater to about 90°C for transportation enhancing through overcoming pour point and viscosity problems (Figure 11).

Scope of work (fired heater): Produced fuel oil (Figure 12) is heated from about 50°C to 90°C in fired heater using diesel oil as heating fuel. Our scope of work is to bypass the heater during day hours (hours) with the proposed solar system and making a comparison between the existing and the proposed system.

Case 3: Preheating of boiler feed Water Cairo Oil Refining Company (CORC):

Process description: The facility is located at CORC. In boiler (Figure 13), water is preheated firstly in the deaerator by steam. Burner mixes fuel and oxygen together and, with the assistance of an ignition device, provides a platform for combustion in the combustion chamber, and heat generated is then transferred to the water for steam production.

Scope of work (deaerator): Water is preheated in the deaerator from 25°C to about 110°C. Our scope of work is to preheat water before the deaerator from 25°C to 60°C in a way that the consumed steam in the deaerator is reduced. So for production of the same net amount of steam, the amount of consumed fuel in the boiler is reduced (Figure 14).

Results and Discussion

- **Summary of solar package design for the three cases** (Table 1).

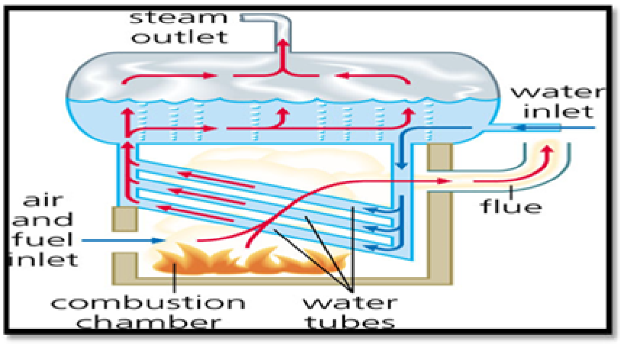

Figure 13: Boiler system description.

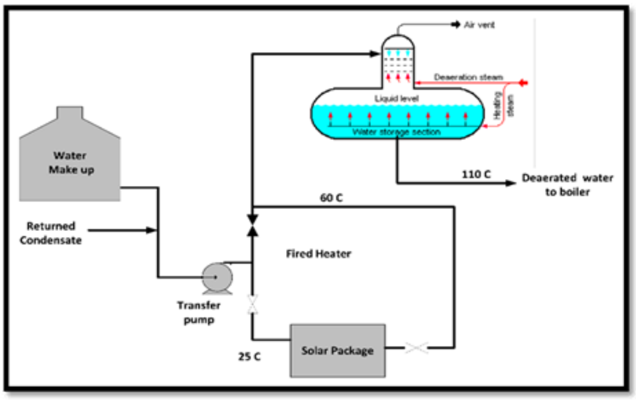

Figure 14: CORC boiler feed water preheating after introducing solar package.

- **Total Project Cost**

HTF system equipment cost

For total project cost calculation firstly HTF system equipment cost is estimated using the above mentioned five methods. Then the total HTF system cost is calculated using plant cost estimating factor.

Case 1: KALBSHA total project cost: In Table 2, it is shown that costs from charts, excel sheet and commercial data are approximately equal. So the HTF system total equipment cost=115000$.

Case 2: CORC fuel oil preheating: In Table 3, it is shown that costs from charts and also data from actual commercial plant are approximately equal. So the HTF system total equipment cost=112000$.

Case 3: CORC boiler feed water: In Table 4, it is shown that costs from charts and commercial data are approximately equal. So the HTF system total equipment cost=29800$.

PTC cost

PTC cost estimation is done (Table 5) according to updates to Solar Advisor Model (SAM) initiated by NREL (National Renewable energy Laboratory) which states that:

Solar plant Cost per m^2=170$

Installation and Site Improvements per m^2=200$

Total Cost of Solar Plant per m^2=370$

	Case 1	Case 2	Case 3
Hydraulic Calculation			
Piping size in	3	3	3.5
Line pressure drop bar	1.2	1.5	4.6
Heat exchanger pressure drop bar	0.5	0.5	0.5
Total pressure drop bar	1.7	2	5.1
Pump discharge pressure kg/cm²	8	8	Booster pump 7 Main Pump 9
Heat Exchanger Thermal Design			
Heat exchanger surface area m²	15	83	71
PTC Design			
Number of required modules module	25	33	79
Total required area m²	1800	2281	5461

Table 1: Solar package design results.

Equipment	Chart Cost $	Matches software $	Cost Estimator $	Excel Sheet $	commercial data $
Heat Exchanger	12180	16700	8200	12409	9000
Pump	31000	12900	12500	7488	17000
Surge Tank	1740	1236	10615	1284	12000
Vessel	69700	84872	21229	69749	40000
Total Cost $	114620	115708	52544	90930	78000

Table 2: Case 1 total HTF system equipment cost.

Equipment	Chart Cost $	Matches software $	Cost Estimator $	Excel Sheet $	commercial data $
Heat Exchanger	40020	44200	18000	32000	50000
Pump	70000	44000	13000	30000	50000
Surge Tank	1740	1236	1500	1284	12000
Total Cost $	111760	89436	32500	63284	112000

Table 3: Case 2 Total HTF system equipment cost.

Equipment	Chart Cost $	Matches software $	Cost Estimator $	Excel Sheet $	commercial data $
Heat Exchanger	34800	41000	16000	29700	42000
Booster Pump	87000	50000	14000	36000	122000
Main Pump	87000	50000	15000	36000	122000
Surge Tank	1740	1236	1500	1284	12000
Total Cost $	210540	142236	46500	102984	298000

Table 4: Case 3 total HTF system equipment cost.

Total project cost summary: After calculation of HTF system cost and PTC solar plant, the total project cost for the three cases is then calculated in Table 6.

Comparison with the existing fuel consumption and payback period calculation

The purpose of this section is to calculate the payback period for each case and this can be done through the following steps:

	Case 1	Case 2	Case 3
Required Area m²	1800	2281	5461
Cost $	666,000	843, 970	2, 020, 570

Table 5: PTC cost estimation for the three cases.

	Case 1	Case 2	Case 3
HTF Equipment Cost $	115, 000	112, 000	298, 000
Plant Estimating Factor	1.95	1.95	1.95
HTF System CPost $	224, 250	219, 000	581, 100
PTC Cost $	666, 000	843, 970	2, 020, 570
Total Project Cost with 10 % margin $	980, 0000	1, 170, 000	2, 862, 000

Table 6: Total project cost for the three cases.

	Case 1	Case 2	Case 3
Heat consumption for the existing heaters	3200 MMBTU/ HR	1126 KW	2640 KW
Existing fuel consumption / day	0.5 MMSCFD	2376 Lit	5520 Lit
Amount of fuel Saved / 6 hrs.	0.125 MMSCF	591 Lit	1385 Lit
Fuel Saved / year*	41.25 MMSCF	194809	456746
$ Saved /year	50, 000	176000	412000
Total Project Cost $	980, 0000	1, 170, 000	2, 862, 000
Payback Period year	**20**	**7**	**7**

Table 7: Comparison with existing plant and payback period calculation.

*For Case 1 exiting heater uses natural gas as a fuel while for Cases 2 and 3 Diesel is used as fuel

1. Calculation of the amount of fuel saved after implementing the new design.

2. $$\text{Calculation of payback period}=\frac{\text{Total project cost}}{\text{Money saved due to fuel reduction per year}}$$

(Table 7).

Through (Table 7), the payback period for each application is calculated and after this period the annual profit for each case shall be the money saved for fuel consumption reduction. For example for Case 3 the payback period is 7 years and after these years the annual profit due to fuel saving shall be 412000$.

Conclusion

The aim of this paper work is to provide economic study about using solar thermal system in some oil industry applications. For developing such study and through survey of different solar thermal systems, parabolic trough collector presents the most appropriate type to be used. Then evaluation of four available mathematical models for PTC was introduced for choosing the reasonable one that provides simulation of this collector under different operating conditions. For that paper under title of "Evaluation of Mathematical Models for Solar Thermal System" was published in October, 2016, American Journal of Energy Science. Finally steps and results of study using PTC solar heating system in some oil industry units are presented.

The study steps included design of all equipment and overall plant cost estimation for payback period prediction. The results showed that payback period for crude preheating before desalting was 20 years, fuel oil preheating was 7 years, water preheating 7 years. Fuel used in Case 1 was natural gas while for the other two cases was diesel fuel, and this is the most important factor that resulted in higher pay back period for Case 1.

Recommendations

1. Solar field presents about 50% of the total proposed system cost in each application so optimization of solar system design affects greatly the total cost.
2. Selection of PTC type with high efficiency and minor optical and thermal losses is essential for more economic application.
3. Plant location is one of the main factors that affect collector performance so location with high direct radiation intensity is recommended.
4. Heat exchanger optimum design is important as it presents about 25% of the HTF system cost.
5. The oil industry application that the proposed system can replace in day hours is recommended to have fuel oil as a heating medium not fuel gas because of higher costs of fuel oil than fuel gas for generation of the same duty.
6. The utilization of renewable energy in EGYPT should be increased, as there is a global concern that the developing nations could be faced with energy crisis and global warming. It is expected that more damage and pollution of the environment will continue. Parabolic trough solar collector is one of the options for renewable energy and this technology should be adopted in industries that utilize fossil fuel for heating and steam generation.
7. The government has to support further research works in this area financially and allocating large area to test large grids of the parabolic trough system for heating applications and also power production.

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