Journal of Energy in Southern Africa 19(1): 70–76
DOI: http://dx.doi.org/10.17159/2413-3051/2008/v19i1a3316

Experimental results of using a parabolic trough solar collector for thermal treatment of crude oil

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Abstract
At present, there are economic, ecological and energy efficiency problems in dealing with the oil industry. We have tried to solve this problem through a solar thermal application. Thus, parabolic-trough solar plant utilization in the oil industry is a relatively new application in the area of solar energy usage. In Azerbaijan (Baki), such an application has firstly been realized in the crude oil treatment process by us. We must mention that a solar energy application has a great advantage for the oil industry to be economical with fossil fuels partly, to improve safety measures and ecology, and to also reduce additional financial expenses. Besides the ecological and economical facets, the obtained results from the experiments, which have been carried out in the Absheron Peninsula (Baki), are useful from an energy efficiency point of view in the field of solar thermal applications by using parabolic troughs. These experimental results are significant on account of economic, energy efficient and ecological advantages.

Keywords: parabolic trough solar plant, solar reactor, initial crude oil treatment, ecological situation, energy efficiency

1. Introduction

In the Azerbaijan Republic, the oil industry has a great role to play. Because of economic difficulties, ecological problems including global warming, and oil depletion at present, the oil industry needs to have ecologically clean and economically favourable energy sources to reduce atmospheric pollution.

In the context of the oil fields, much natural gas, mazut is utilized for the purpose of crude oil treatment (in Azerbaijan, on average, 1.6 tons of mazut is used in 24 hours, and 400 tons of crude oil is used in the Binegedi Oil and Gas Production Department, but 20m^3 of natural gas for each one tone crude oil is used in the Balachani Oil and Gas Production Department). Much of the fuel utilization in the oil fields deals with that of plants that are old, which were given for exploitation in the middle of the former century. At a result of fossil fuels burn, atmospheric pollution by CO_2, CO, C_xH_y, N_2O and $N\hat{I}_x$ forms a gradual greenhouse effect, which leads to global warming of the Earth (Samadova, 2006). It must be mentioned that the amount of CO_2 is getting to be more year by year because of various fuels' ignition (oil, gas, pit coal) into the atmosphere.

The traditional crude oil treatment causes additional financial expenses, air pollution, on the one hand and, on the other, overindulgence from an energy efficiency point of view. Taking into consideration all three aspects (ecological, economic and energy efficiency), parabolic trough solar plant utilization has been realized in the crude oil treatment process in the Azerbaijan oil industry.

For the dehydration process of crude oil, an experimental solar plant with double modular parabolic trough collectors and corresponding technological demands was applied and important experimental results have been obtained. A Principle scheme, general view of the plant and some experimental results have been given here (Mammadov, 2006).

2. Experimental procedure and results

Because of the geographical location of Baki (latitude 40^0, 26′ N and longitude 49^0, 46′ E), climatic

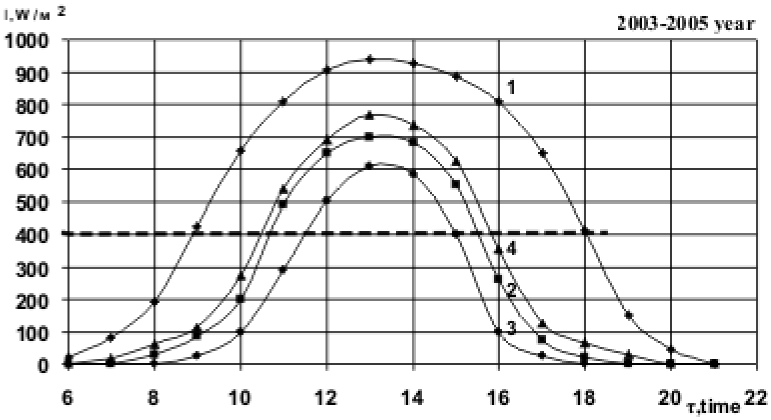

Figure 1: The changing curves of direct solar radiation's average value depending on the time during a day; 1- Summer; 2- Autumn, 3-Winter; 4-Spring

conditions are very favourable for the experiment on both sides including oil and solar potential. Therefore, the dependence of annual mean solar potential on time has been developed, due to the long-term results of a weather station (Salamov *et al.*, 2005).

Based on the above mentioned, theoretical calculations of a parabolic trough collector and a solar reactor were carried out. As a result, heat-and-power engineering annual and seasonal mean values have been obtained.

Before realizing the crude oil treatment process, the next parameters have been determined: 1.Direct solar radiation; 2. Wind speed; 3. Air temperature; 4. Temperature of the reactor surface; 5. Temperature of heat transfer and oil; 6. Molybdenum glass pipe's surface temperature; and 7. Flow rate of heat transfer and crude oil.

For checking up on the plant's fidelity, we have carried out initial experiments in a water-water system, so here, cold water is heated by warm water when direct irradiance is more than 400 W/m^2 and wind speed 3-5.5 m/sec. During the experiment on the water-water system, heat transfer was heated to 68-98°C and the temperature of the reagent was increased from 57°C to 92°C (Mammadov *et. al.*, 2004). After test experiments, the expenditure of the heat transfer was calculated in several permanent regimes of the direct irradiance.

While summarizing the different experiments on a water-water system, we have come to the conclusion that a parabolic trough solar plant is advisable to realize the crude oil treatment process in oil fields.

As for oil extraction, some details of the process should be clarified that, besides gases, there are a few percent mechanical mixtures such as sand, clay, salt crystals and water in a crude oil container which can be extracted. Generally, mechanical mixtures are no more than 1.5% in an un-cleaned crude oil container. But water percentage changes through several scenarios. When the oil well exploitation is longer in this case, there may be more water in the crude oil container. It should be taken into consideration that if more oil is extracted from the old well, such oil has about 90-95% water in its container. Actually, water must not be more than 1% in oil, which is pumped into the pipeline and 0.3% for oil

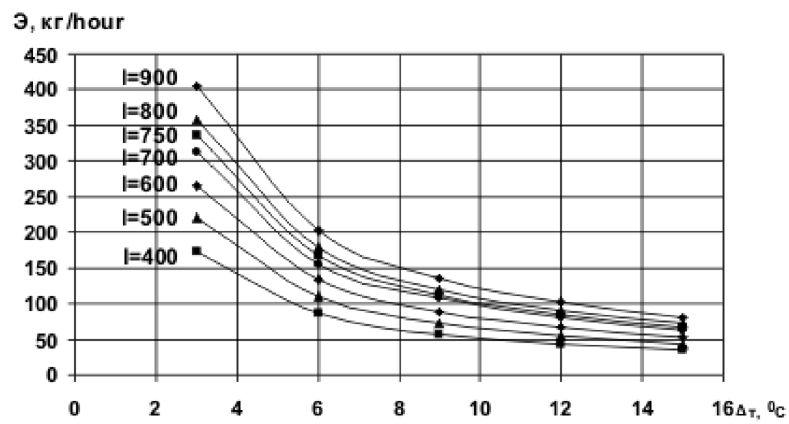

Figure 2: The dependence of the heat transfer expenditure (G,kq/hour) on temperature drop (Δt, °C) in a solar reactor at several direct radiations

Table 1: The obtained results from the calculation on seasonal and average annual means of power engineering parameters of a parabolic trough collector and solar reactor

Characteristics	*Summer*	*Spring-Autumn*	*Winter*	*Average annual*
N_s.hour	824.0	897.0	297.0	2018.0
N_e.hour	129.0	247.0	121.0	497.0
N_{gen}.hour	953.0	1144.0	418.0	2515.0
æ. unit	0.865	0.784	0.71	0.802
P_{ad}^{pt}.KW·hour	16.0	5.22	1.76	7.06
P_{ad}^{sr}.KW·hour	11.52	3.76	1.27	5.08
$P_{s.aa}^{pt}$.KW·hour	1472.0	956.0	158.4	2585.0
$P_{s.aa}^{sr}$.KW·hour	1060.0	688.3	113.8	1861.2
P_{gen}^{pt}.KW·hour	3297.5	3072.0	915.3	7284.8
η_{pt}. unit	0.446	0.311	0.173	0.355
η_{sr}. unit	0.321	0.224	0.124	0.255
η_{p}. unit	0.72	0.72	0.72	0.72

Notes:

Ns amount of real hours of service (effective usable duration of the sun shining hours), hour;

N_e amount of excluded hours (unusable duration of the sun shining hours), hour;

N_{gen} general amount of the sun shining hours, hour;

æ use factor of the sun shining hours (æ=100 N_s / N_{gen}), unit;

P_{ad}^{pt} average daily amount of solar radiation on the parabolic trough collector surface when the direct radiation is more than 400 W/m^2 KW·hour;

P_{ad}^{sr} average daily amount of effective usable part of the radiation concentrated in the solar reactor when the direct solar radiation is more than 400 W/m^2, KW·hour;

$P_{s.aa}^{pt}$ seasonal and average annual amount of the radiation on the parabolic trough collector surface when the direct radiation is more than 400 W/m^2, KW·hour;

$P_{s.aa}^{sr}$ seasonal and average annual amount of solar rays' energy concentrated in the solar reactor which is effectively used at more than 400 W/m^2 of the direct irradiance- KW·hour;

P_{gen}^{pt} general amount of solar flux on the parabolic trough collector surface when solar radiation is more than 200 W/m^2, KW·hour;

η_{pt} use factor of general radiation on the parabolic trough collector surface during service hours of sun shining time (η_{pt} = P_{as}^{pt} / P_{gen}^{pt}), unit;

η_{sr} use factor of general radiation concentrated in the reactor during service hours of sun shining time (η_{sr} = P_{as}^{sr} / P_{gen}^{pt}), unit;

η_p the plant's specific efficiency in different parts after the solar reactor not taking into consideration the heat loss, unit;

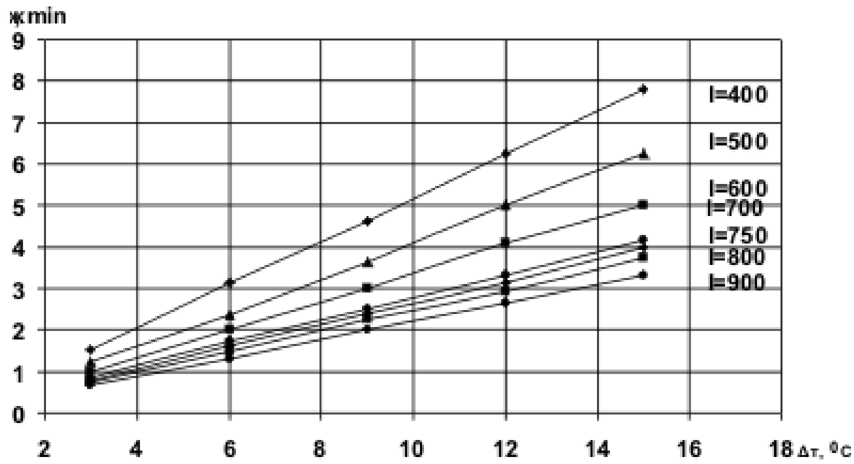

Figure 3: Dependence of contact duration (j,min) between heat transfer and the solar reactor's inner wall on temperature drop (Δt, °C) at several direct solar radiations

to the Oil Refining Plant (ORP).

To carry out the crude oil treatment by a solar thermal application after the parabolic trough solar plant has been prepared for the treatment process, heat transfer is heated to 85-90°C by solar rays which are reflected from the collectors' surfaces. Because at present, Azerbaijan oil is heated to 55-60°C during its treatment process and physical-chemical properties (Safarov *et.al,* 2006).Water goes out from the hot solar reactor and circles in a solar reactor-heat exchanger-expansion tank system. When stationary regime is, at that time crude oil comes into the system and, in this way, demulsifier is added to it (80-100g/tone), it then enters a coil pipe in the heat exchanger. Here, the heat exchanging process happens between crude oil and water, and oil is heated to the demanded temperature (60°C), and then the heated oil leaves the heat exchanger and flows into the sedimentation tank. Approximately during 24 hours, separated water goes out the sedimentation tank and treated oil is sent to the ORP through special pipes.

While summarizing the different experiments on a water-crude oil system, we have come to the conclusion that not depending on the physical-chemical properties, any type of oil can be treated by this method in a parabolic trough solar plant. Such treatment has a great advantage from energy efficiency, economical and ecological facets.

After the experiments, temperature dependence of the density and kinematical viscosity coefficients of the treated oil have been determined. For this purpose by using scales method we have measured density (ρ) by densimeter and defined kinematical viscosity (ν) by the Engler viscosimeter method at several temperatures (19,5 – 72°C) at the lab (Naziyev, 2001).

Table 2: Measurements and the amount of water, salt and mechanical mixtures in the oil container – before and after treatment

Oil	*Amount of water in the container, %*	*Amount of salt in the container (as NaCl)*	*Amount of mechanical impurities in the container*
Before	22	120 mg/l	9.8g/100g
After	0,8	14 mg/l	1.27g/100g

On the basis of the obtained results to calculate the temperature of the solar reactor surface and heat transfer in various intervals of the direct radiation on a large scale, the following equations may be applied (Mammadov *et al.,* 2005).

$$t_{s.r} = a + bI^s \quad (1)$$

and

$$t_{h,r} = a + dI^e \quad (2)$$

Here, à=20 is constant and equals to the temperature of the solar reactor surface and heat transfer when the experiment is begun – I-direct solar radiation W/m^2. b and d constants are determined by Table 3.

$$b = \frac{1gt_{s.r}}{1gI} \quad (3)$$

$$d = \frac{1gt_{h.t}}{1gI} \quad (4)$$

Here, $t_{s.r}$ - temperature of the solar reactor surface, °C. $t_{h.t}$ - temperature of heat transfer, °C.

But *s* and *e* constants are analogically determined as follows:

$$s = \frac{\lg t_{s.r} - (\lg a + \lg b)}{\lg I} = \frac{\lg t_{s.r} - \lg ab}{\lg I} \quad (5)$$

and

$$e = \frac{\lg t_{h.r} - (\lg a + \lg b)}{\lg I} = \frac{\lg t_{h.r} - \lg ab}{\lg I} \quad (6)$$

Values of these constants have been revealed due to the experiments: B = 0,26; s = 0,9; d = 0,21; e= 0,87.

These equations may be used to determine temperatures of heat transfer and a solar reactor with different diameters.

To supply the plant's continuous work throughout the year, especially at nights and in cloudy weather, a technological scheme of a combined solar-fuel energy plant has been developed.

A combined solar-fuel energy plant consists of: 1. An untreated crude oil tank; 2. A demulgator tank; 3. Heat exchanger; 4. Sedimentation tank 5. A commercial oil tank; 6. A heater; 7. A parabolic trough concentrator; 8. A solar reactor 9. Sun-tracking systems; 10. A water-metering system; 11. An expanding tank; 12. A gravitation tank; 13. A ball valve; 14. A gage; 15. A control panel and instrumentation; 16. A pump (P1P3) 17. A flow meter (F1F5); 18. A thermometer (Ò1Ò5); 19. A manometer (Ì1Ì3); 20. A valve (V1V11); and 21. A monitor cable.

The working principle of the combined solar-fuel power plant is as traditional like in the oil fields, but it consists of and additional concentrators' system and other interior pieces.

Heat transfer enters the solar reactor (8) when the solar flux is more than 400 W/m^2 and circulates in the general system. In this case, valves (V4, V5) of the entrance and the exit of the furnace (6) are closed and valves (V6, V7) of the entrance, and the exit of the collector (7) are open. Heat transfer is heated to 85-90°C by solar thermal. Heat transfer goes out from the solar reactor and enters the heat exchanger via the pump (P3). Giving its heat to the

Table 3: Showings of temperature of the solar reactor surface and heat transfer at several solar radiations

$I, W/m^2$	500	550	600	650	700	750	800	850	900
$t_{s.r,}$ °C	88	95	100	104	110	115	125	132	140
$t_{h.t,}$ °C	68	71	74	77	80	84	88	94	98

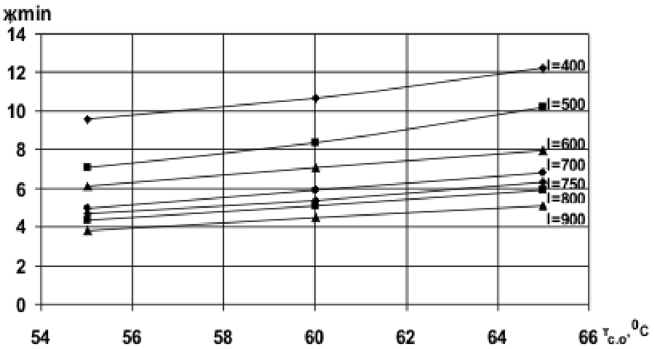

Figure 4: Dependence of contact duration (j,min) between crude oil and inner wall of heat exchanger pipe on its temperature ($t_{c.o,}$ °C)at several direct solar radiations

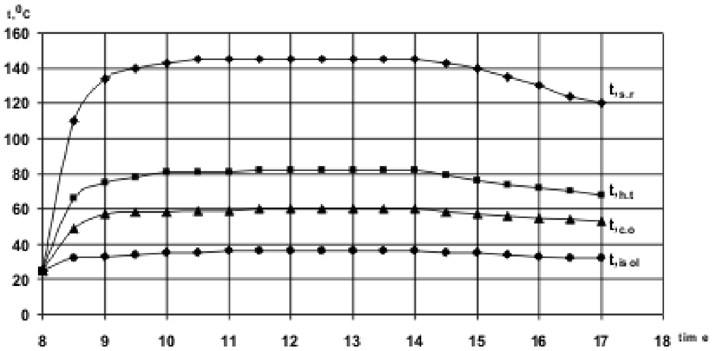

Figure 5: Experimental result on temperature dependence of solar reactor surface ($t_{,s.r}$), heat transfer ($t_{,h.t}$), heated crude oil ($t_{,c.o}$) and solar reactor isolation's surface ($t_{,isol}$) on time

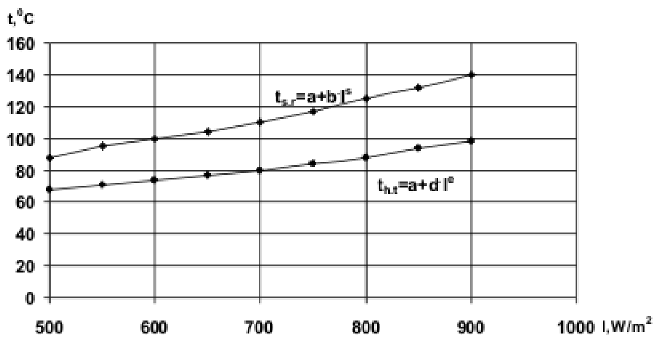

Figure 6: Temperature dependence of the solar reactor surface and heat transfer on solar radiations

crude oil, here heat transfer becomes cool and comes into the system again and circulates. The oil which comes from the untreated crude oil tank enters the heat exchanger via the pump (P1). Demulsifier is added to the unheated crude oil by the pump (P2) from the demulsifier tank. (2).

A heat exchanging process happens between heat transfer and crude oil in the heat exchanger, and crude oil is heated to the required temperature and then the oil leaves the heat exchanger and begins to move to the sedimentation tank. Here, the heated oil has been kept for some time, and during this time, the separated water is taken out from the sedimentation tank via the valve (V2) due to the level meter's showing (14), and the treated oil is pumped to the commercial oil tank.

As mentioned above, for the plant's continuous work valves (V4-V5) of the furnace that are opened, and valves (V6-V7) of the collector that are closed, the process goes on in this cycle.

The operating panel and instrumentation (15) are controlling measurement and conservation of a stable temperature of the collector, oil, and heat transfer (water) which circulates in the furnace along the system.

If a combined solar-fuel energy plant is applied in the process, then the permanent crude oil treatment process over 24 hours might have been supplied.

Conclusion

This paper has attempted to highlight the following issues:

- A new method of a solar energy application has been highlighted;
- New technical and technological opportunities of a solar energy application in crude •
  oil treatment in oil fields has been established;
- Improve practical engineering on a solar thermal application;
- Opening of new plants for parabolic troughs production in Azerbaijan;
- Economic advantage of a solar thermal application in crude oil treatment by:
  - Decreasing of additional expenses for the oil industry;
  - Development of a solar energy market for Azerbaijan;
  - Reduction of the production cost of commercial oil;
- There is an energy efficiency advantage of the solar energy application;

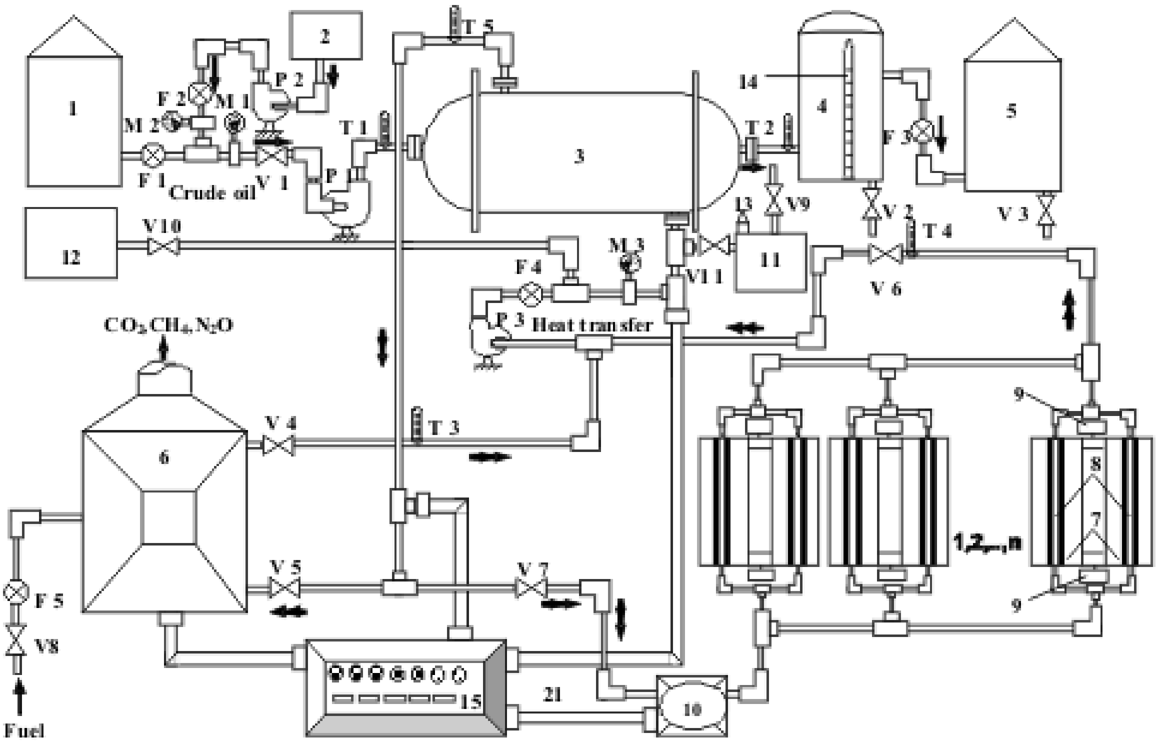

Figure 7: Technological scheme of a combined solar-fuel energy plant

Table 4: Showings which characterize solar energy application's profitability level and exploitation expenses of the furnace, solar energy plant

Showings	*On the heaters*	*On the parabolic trough solar plant*	*Comparative defe-rence of the expense on the plants ((-) shows the funds econ-omy in solar plant)*
Annual treatment productivity of the energy plants (tone)	200 000	200 000	–
Well-grounded investment (US$)	138 000	460 000	322 000
Fuel expenses, 1ì^{3}-0,04 (US) dollar (0,04•4000000ì^{3})	160 000	–	-160 000
Fines on the hazardous gases to atmosphere (US$)	300	–	-300
Expenses spent to each one tone crude oil treatment (US$)	0.98	0.32	-0.66
Total expenses of ecological pollution (US$)	11 200	10 900	-300
Total expenses of production (US$)	183 920	52 800	-131 120
Production expenses of each one tonne crude oil (US$)	0.92	0.27	0.66
Specific weight of the fuel expenses (%)	78	–	–
Payment duration of the well-grounded investment (to economy) (year)	–	2.8	–
Profitability level of the investment (%)	–	35	–
Profitability degree of the exploitation expenses (time)		2.56	–

- There is an ecological advantage of this solar energy application which includes:
  - Preventing the atmosphere from being polluted by hazardous wastes;
  - Escaping partly from greenhouse gases – CO_2, CO, C_xH_y, N_2O and NÎ$_x$.

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Received 27 March 2007; revised 22 December 2007