Exploiting Solar Thermal Energy in Ammonia Synthesis Plant

M. Dmarany, **M. H. M. Hassanien, Alaa-Eldin Adris**

Abstract: Energy Is Always Becoming A Key Factor In The Process Of Achieving Any Sort Of Sustainable Development, With Respect To The Drastic Increase In The Global Energy Consumption Throughout The Past Few Decades, Accompanied With The Well-Established Relation Between The Technological Advancement And The Patterns Of Energy Consumption (1). Abundant As Well As Cheap Energy Resources Have Always Fueled The Growth And Development Of Modern Societies. Furthermore, Maintaining A Sustainable Yet Secured Source Of Energy Is Always A Crucial Challenge Nowadays In Order To Achieve Sustainability On All Levels, Economic, Social And Environmental. Medium Temperatures Applications Of Solar Thermal Practices Have Undergone A Remarkable Interest Recently In Various Industrial Sectors. Solar Concentrating Systems Could Properly Serve In Applications And Practices With Temperature Ranges From 85 To 250°C, Taking Their Sun Light Focusing Characteristic And High Thermal And Optical Performance As An Advantage(2). This Research Paper Introduces A

System For Solar Energy Heating That Could Be Utilized For Heating Applications And Practices Inside The Oil And Gas Industry. First, The Proper Selection Of The Appropriate Solar System That Could Be Used In Such Applications Was Performed. A Full Analysis Has Been Held On Four Different Mathematical Models In Order To Predict The Optical Efficacy And Thermal Losses For The Selected System, Afterwards The Predictions Are Modeled Using Computer Software For A Comparison With Respect To These Prediction And Numerical Data, Also A Practical Comparison Took Place Using Real Input Data From Experimental And Actual Solar Plants. After That, We Took The Approach To Make Good Use Of Solar Thermal Applications, After Selecting The Most Appropriate Solar Thermal Concentrators, Which Is Parabolic Trough Collectors (Ptc), To Increase The Process Gas Feed Temperature Before Entering The Primary Reformer Reactor In Ammonia Synthesis Plant. The Energy Assessment For The Ammonia Plant, The Engineering, Sizing And Simulation Cases And The Economic Study For The Project Showed A Remarkable Return On Investment.

Keywords: Solar Energy, Parabolic Trough Collectors, Solar Thermal Applications, Ammonia Synthesis, Energy Saving, Methane Steam Reforming.

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I.   INTRODUCTION:

Inside the Oil and gas Industry there is a crystal-clear energy crisis due to the losses of energy in fuel consumption especially in heating systems. Refineries, Petrochemicals and Fertilizers plants have fuel and electricity losses that reduce Fig. (1) Illustrates that the increase of the global energy consumption over the last two decades (illustrated in black bars), with the increase in consumption in the upcoming couple of decades (illustrated in grey bars). As shown, the global energy consumption has raised from ~8,108 Mtoe in 1990 to 12,002 Mtoe in 2010 with a projected increase up to 16,631 Mtoe in 2030. By 2040, the world's GDP is expected to be doubled with respect to the transition

scenario, driven by raise in prosperity inside the emerging fast-growing economies, as nearly 2.5 billion people or even more are moved from low incomes levels. This raise in prosperity will definitely lead to an increase in the global energy demand; nevertheless, the extent of this growth is recompensed by accelerating gains in energy efficacy: energy demand will raise by only around one third within the upcoming 25 years. However, the renewable energy seems to be the fastest-growing source, which is accountable for 40% of the raise in the primary energy. By 2040, the energy mix will be the most diversified the world would ever see (4). Based on the (IEA), the International Energy Agency, the raising demand in the consumption of energy over the upcoming 25 years, will require about twenty two trillion US Dollars for new investments in the energy sector (5). Oil shares by nearly two-thirds of the growth or increase in the non-combusted exploitation of energy, while the natural gas represents the remainder. Although being accountable for only a small fraction of current oil and gas demand, which is , the non-combusted use of oil and gas is the largest contributor of their growth combined together (6). Undoubtedly the consumption of energy inside the oil industry leads to a reduction in the final net profit. This energy consumption is due to fuel combustion and also electricity generation. For example; in refineries, 100 kbpd of crude oil needs approximately 120 MW to be preheated to reach 350°C (7). A fundamental rule in all down-stream plants that undoubtedly the consumption of energy inside the oil industry leads to a reduction in the final net profit. This energy consumption is due to fuel combustion and also electricity generation. For example; in refineries, 100 kbpd of crude oil needs approximately 120 MW to be preheated to reach 350°C (7).

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A fundamental rule in all down-stream plants states that for processing 10 barrels of crude oil one barrel of oil-equivalent energy is consumed (8). It's declared that petroleum refining, petrochemicals, cementing, ammonia, and steel production consume about 26% of the energy. So consequently, a great interest is taking place towards technologies aiming for increasing the energy efficacy by reducing the energy consumption (9). Methods of solving this problem appear to be focusing and targeting the areas of improved combustion, waste heat recovery, and process modifications. Concerning these solutions, a comparison was held between energy efficacy of crude oil refineries in Brazil and the United States of America, the conclusion was that the more the complexity of the refinery, such as more heat integration inside the plant will straightforward lead to a reduction in the consumption of energy (10). In order to face the energy challenges in Chinese petroleum refiners Xiaoyu Liu (11) pointed out that the upgrade of process heaters is as a priority for enabling a sort of short-term energy optimization. The results shows that
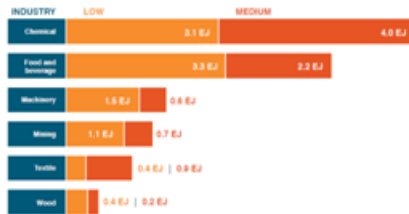

Figure (1) Total world energy consumption in (Mtoe)

the process heaters upgrade have been a priority during recent years, but on the other hand, heat recovery and advanced process control systems will begin to dominate gradually the technological marketplace in the long term. By 2020, current policies of technology will approximately result in 2.7 x 108 GJ of energy savings, while keeping the average energy consumption of the refineries within 57 kg oil equivalent (kgoe)/t-feed. In the past, the main priorities of the research in the solar heat process field were mainly focusing on the following three points, collector developments, identifying suitable industries and processes, in addition to the implementation of case studies and initiation of pilot and demonstration plants. Approaches towards simplification the integration of solar heat within the industrial processes are rarely found. A clear indication for the growing interests in developing solar thermal applications was the agreement signed between Chevron and Bright Source Energy (a company specialized in solar thermal power); they started constructing a demonstration plant in California. This plant is working on generating steam for the extraction of oil from a field that Chevron owns. The generated steam from this plant in California is of a capacity 29 MWth. The methodology of generating this steam is reflecting sunlight by the aid of 7000 flat mirrors to the boiler located at the top of a tower of 98 meters height. (12). This project enabled Chevron in to reduce of its reliance on natural gas as the main source of steam generation or direct injection, and no need to mention that this project has helped in the reduction of the company's carbon footprint, in addition to saving the money spent on volatile natural gas used. Solar thermal technology can produce high-pressure steam with temperatures reaching as

high as 550 ºC. The main drivers for solar energy usage in EOR is steam in the range of 115 to 300 ºC (13). An important barrier for the market development is the large effort to carry out a feasibility assessment including the predimensioning of a suitable solar process heat system. Especially to facilitate the identification of suitable integration points for solar heat in Industry, tools and guidelines are required (14). To reduce the effort for identification of a suitable integration point within industry Fig. (2), comprehensive research on the food and beverages sector was performed to highlight the possibilities for integrating solar heat. The analysis shows that the utilized process installations and especially the current equipment for heating are of particular importance for the integration of solar heat (15). Solar collectors do supply and provide heat at various range of temperatures for production processes in numerous industries. The term Solar Heat for Industrial Processes (SHIP) remains a bit far from being standardized globally, but at the same time, the market is already growing to a considerable size.
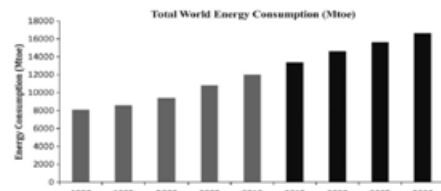

Figure (2) Solar Thermal Heat Industry Applications

The first World Map of Solar Process Heat Specialists 2017 shows 71 suppliers of turnkey SHIP systems from (Germany, China, India, Mexico) showing that the most popular type in SHIP is the parabolic trough collector type (16). The chart below Fig. (3) shows the market segments most suitable for each collector type. In addition to energy problems, there is also an environmental dilemma, based on reports, in 2008, about 81.3% of the global preliminary energy was supplied from coal products, gas, and oil, leading to the emissions of 6511 million tons of carbon dioxide equivalent, and this is a great reason behind the aggravation of the global worming issue (17). Renewable energy sources as hydropower, biomass, wind, and solar are now being contemplated as promising alternatives, as these renewable sources are environment friendly, sustainable, and abundant. This is the explanation why many countries are designing and implementing new programs to develop renewable energy resources as which can finally, reduce the net energy consumption at any industrial plant and reduce the GHG emissions (18).

Figure (3) Solar Collectors Market Segmentation

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II. METHODOLOGY:

Our scope of work concerns with selecting and developing a thermal solar energy system, which could be used in some applications in the field of oil and gas industry as a heating medium in order to reduce the net amount of consumed fuel used for heating applications. This application will consequently minimizes the overall energy consumption and so the net specific energy consumption for a unit of produced product in addition to becoming environmental friendly source of energy, which finally maximizes the companies' net profits.

The research methodology is as the following steps:

• Selecting the most appropriate solar thermal application among the medium temperature concentrators.

• Evaluation of the selected Parabolic Trough Collectors (PTC) available models (as the most appropriate solar thermal application among the medium temperature concentrators) through the below methodology;

- Description of each model steps, basis, assumptions.

- Numerical comparison and validation based on practical data which is the core of the evaluation and the most important key for choosing the best of the four models.

• Modeling the selected solar thermal application so that can be used in the integration project.

• Surveying the performance and make an energy assessment for an ammonia plant in Egypt (Capacity: 1200 ton/day) to select the most appropriate energy saving opportunity to be integrated with the selected solar thermal application in the medium temperatures range (85ºC:250ºC).

• Using a simulations programs to verify all the above steps and make an economic study for the whole project.

This comparison and validation gives correct image about the validity of using each model in the next step.

III. SOLAR THERMAL APPLICATIONS:

A standard or basic solar concentrator is constructed of one or multiple collection mirrors, piping work, supporting structure, absorption receiver, heat transfer fluid, heat exchanger, and pumps. Some of the solar concentrators are designed to comprise sun-tracking systems and/or techniques of thermal storage based on the applications and the configurations considered. The solar collector is the key component of any solar thermal system, and a reliable and efficient solar collector should be capable of the absorption of the incident radiation and its conversion into useful thermal energy that could be used in heating a working fluid with minimal both thermal and optical losses. Generally, solar collectors are classified into two main types, concentrating and non-concentrating collectors. Concentrating collectors are categorized as two major categories: line-focusing systems category and point-focusing systems category. Line-focusing systems applies a linear receiver and focusing these solar radiations along a single axis, while on the other hand point-focusing systems are focusing the radiations at a point receiver that has two-axis sun tracking. Line-focusing systems category include parabolic trough collectors or (PTCs), linear Fresnel reflectors or (LFRs) and compound parabolic concentrators or (CPCs), line-focusing system category can reach temperatures up to of 250ºC with a simple and reliable

design and operation. On the other hand, point focusing systems are able to reach a temperature exceeding 500ºC but they are more expensive as they include solar towers and solar dishes. In non-concentrating collectors category, the solar radiation collection area is considerably equal to the radiation absorption. While on the other hand, solar concentrating systems category are based on the concept of focusing solar radiation by a larger collection area onto a respectively smaller receiver absorption area. As shown in in the table of comparison above, a brief comparison between different solar collector types. For medium temperature solar thermal applications with a temperature range of 80ºC:250ºC, concentrating systems or called solar concentrators are favorable to maximize the solar thermal energy flux (19). Solar heat in industrial applications has a wide range starting below 100 °C up to 2000 °C.

Also, this high temperature (200ºC to 2000ºC) can be used for electrical and mechanical power generation, for reaching this high range of temperature, PATNODE (22) developed a simulation model both solar field and Rankin power cycle for solar electric generation systems (SEGS) built in southern California. The model's validation was held via using real actual data from the plant. A summary comparison between some types of solar concentrating collectors types are clarified in the below comparison.

In 2017 SINGIRESU S. RAO (20) developed a methodology for the estimation of the potential or the applicability of integrating solar collectors in India for process heating. This methodology include process-operating temperatures in temperatures ranging from 70 ºC to 150 ºC, in order to pick the solar collectors type suitable. The estimation of the size of the solar fields will be done taking into considerations the following factors: thermal heat loads, efficiency of the selected solar collectors, utilization of the capacity of the solar collector, the working fluid and the processes' temperatures, and the location based solar irradiance. Also, Zhang (21) proposed an experimental work proving the probability of the generation of effective hydrogen via reforming of methanol steam inside an original solar reactor/collector at temperatures ranging between 200 °C and 300 °C was demonstrated experimentally. With a 1000 W/m^2 of solar radiation, the solar reactor-collector has successfully generated hydrogen by rates reaching 68.1 g/(m^2·h), the efficiencies of solar to hydrogen reached 41.3%, and the overall energetic efficiencies calculated while

Concentrating Technology	Parabolic Trough Concentrators	Linear Fresnel Reflector	Solar Towers	Solar Dishes
Focusing Type	Line Focusing	Line Focusing	Point Focusing	Point Focusing
Optical Efficiency	70-80%	<70%	<70%	75-85%
Output heat temperature	Up to 400ºC	Up to 400ºC	Up to 500ºC	Up to 900ºC
Working Fluid	Water, Steam, Syn. Oil	Water, Steam	Water, Steam, Air	Air
Development Status	Commercially Available	Commercially Available	Semi-commercial	Prototype Demonstrations
Advantages	- Best land (specific land area 18-25 m²/kw. - Lowest Material Demand. - Hybrid concept proven &storage capability.	Lower materials needed (30:130 Kg/m²)	Hybrid operation possible operation experience of first prototype	- Hybrid operation possible. - Storage at high temperatures.
Concentrating Technology	Parabolic Trough Concentrators	Linear Fresnel Reflector	Solar Towers	Solar Dishes
Focusing Type	Line Focusing	Line Focusing	Point Focusing	Point Focusing
Optical Efficiency	70-80%	<70%	<70%	75-85%
Output heat temperature	Up to 400ºC	Up to 400ºC	Up to 500ºC	Up to 900ºC
Working Fluid	Water, Steam, Syn. Oil	Water, Steam	Water, Steam, Air	Air
Development Status	Commercially Available	Commercially Available	Semi-commercial	Prototype Demonstrations
Advantages	- Best land (specific land area 18-25 m²/kw. - Lowest Material Demand. - Hybrid concept proven &storage capability.	Lower materials needed (30:130 Kg/m²)	Hybrid operation possible operation experience of first prototype	- Hybrid operation possible. - Storage at high temperatures.

considering both inputs, solar and fuel has reached 76.6%. Which is vigorously competitive with other different forms of technologies using high temperature solar heat to produce solar fuel.

3.1 PARABOLIC TROUGH COLLECTORS PTC):
The parabolic trough systems are consisting of queues of mirror reflectors curved in a single dimension to gather and focus the rays of the sun. These mirror reflectors arrays can exceed 100 meters long, and its curved surface could be above five meters. Fig. (4).

The components of heat collectors are stainless steel pipes that perform as the absorber tubes, they are coated by a certain selective coating that are manufactures to allow the absorber tubes to absorb high amounts of solar radiations, and emitting the least amount of infrared radiations. These pipes are enveloped by a glass envelope that is evacuated. A heat transfer fluid (usually known to be oil) is running at the focal point inside the tube, this heat transfer oil absorbs this concentrated sun radiations, the temperature of this heat transfer fluid raises up to 400 °C. The receiver tube of the PTC is its key component, as the overall collector's efficacy mainly relies on the thermal and the optical characteristics of this component (e.g. thermal emittance, coefficient of thermal loss, solar absorbance, etc.).

Figure (4) Parabolic Trough Solar Collector (PTC)

In 2017, MOYA A.Z. (23) introduced Has presented the state of art of the working fluids for the parabolic troughs collectors, firstly starting with the option that is already implemented in the majority of the commercial parabolic trough plants, which is the thermal oil. Then afterwards with the other option of alternative working fluids that would definitely lead to a significant reduction in cost and/or increasing the plant's efficiency. The following three alternative working fluids has been analyzed and assessed in this chapter: (1) water/steam (or direct steam generation technology); (2) pressurized gas; and (3) molten salts.

IV. EVALUATION OF SOME AVAILABLE PARABOLIC TROUGH COLLECTORS (PTC):

4.1 Methodology

The evaluation PTC available models can be summarized in the following points
• Description of each model steps, basis, assumptions.
• Validation using practical data which is the core of the evaluation and the most important key for choosing the best of the four models.

4.2 SOME AVAILABLE MODELS FOR PARABOLIC TROUGH COLLECTORS (PTC):
Through survey of the literature review, specially studying parabolic trough collector performance, the constituents of a Parabolic Trough Collector performance simulation model are the following two parts: the reflector system's optical analysis and a the receiver's system thermal analysis.

Both optical and thermal analysis can be carried out completely independent from each other, and this with no doubts makes the performance simulation modeling less complex. Jeter (24) introduced a mathematical computation and formulation with respect to Gaussian function to compute the density of concentrated solar flux, and the PTC's optical behavior. Guven and Bannerot (25) have founded an optical model that used ray-tracing technique for the assessment of the optical performance and the determination of the optical errors via statistical analysis. With respect to the thermal model, modeling principle relied on energy balance among the fundamental components of the HCE (heat collection element) which are the receptor tube, and the HTF (heat transfer fluid). Many studies have been carried out to scrutinize and study the coupled heat transfer dilemma in the solar receiver while assuming a uniform solar flux. Dudley et al. (26) introduced a one-dimensional (1D) model to analyze the thermal behavior and performance of the LS2 SEGS collector. Foristall (27) established both a one and a two dimensional models (1D&2D) by splitting the absorber into several segments. Four different mathematical models and computations for the parabolic trough heating system have been assessed and analyzed and then modeled using computer software program for the evaluation of numerical and practical validation.

4.2.1 FIRST MODEL (ENERGY ASSESSMENT OF A PARABOLIC TROUGH COLLECTOR IN NORTH CYPRUS):

Olopade (28) presented the First Model for the Energy Assessment of a Parabolic Trough Collector located in Norther Cyprus. This Model consists of two main parts. The first part is the optical model for absorbed radiation calculation then the second part is the thermal model for the useful energy gained and exit temperature calculation. For Absorbed Radiation computations, the prediction of the performance of the collector requires data about the absorbed solar energy by the collector absorber plate. This is the actual quantity of radiation on the receiver and is calculated by eq. (1)

$$s = Ib\ Rb\ \rho\ \gamma\ \tau\ \alpha + (\tau\ \alpha\ Do)/(W - Do)$$

Where; Ib incident radiation, Rb beam radiation, ρ specular reflectance, γ intercept factor, α absorptance, W aperture width, τ transmittance, Do outer diameter. With respect to Heat Loss by Radiation calculation there are two radiation coefficients calculated for a single system with a glass covert, hr, which is the natural convection heat transfer coefficient, r-c for the enclosed annular space between a horizontal absorber tube (receiver) and a concentric cover and also radiation coefficient between the cover and the ambient air (hr, c-a). The overall coefficient of loss combines the thermal losses into one coefficient. The coefficient on a per length basis is calculated through the following eq. (2)

$$U_l = [(Do)/((hw + hr, c\text{-}a\ *Dc)) + 1/(hr, r\text{-}c)]$$

Where UL=overall loss coefficient (W/m^{2}K), hw=wind heat transfer coefficient (W/m^{2}K), Dc=cover diameter (m). The coefficient of the heat transfer fluid (h$_f$) is calculated depending on the Reynolds number of the fluid (Ref). The overall heat transfer (U$_o$) is the coefficient of transfer of heat from surroundings to the fluid, station on the outer diameter of the receiver pipe eq. (3).

$$Uo = \left[\frac{1}{Ul} + \frac{Do}{hf\ Di} + \frac{Do\ \ln(\frac{Do}{Di})}{2K} \right]$$

Where K= thermal conductivity of receiver pipe. The collector efficient factor (F) can be defined by eq. (4)

$$F = Uo/UL$$

The term FR is called the factor of collector heat-removal; it is a crucial design parameter, as it is the measure of the thermal resistance faced by the absorbed solar radiation in reaching the collector fluid eq. (5).

$$FR = \frac{mCp}{ArUl}\ x(1 - \exp(-\frac{Ar\ Ul\ F}{m\ Cp}))$$

Where Cp=Specific heat of the fluid, Ar=Area of the receiver (π Do L N), L= length of receiver per module. N=number of modules. The specific heat (Cp) depends on the HTF temperature. Because the inlet fluid temperature is usually a known quality, The following Equation is a relatively convenient expression for the computation of the useful energy gain eq. (6)

$$Qu = FR\ Aa\ (S - \frac{Ar}{Aa}\ Ul\ (Ti - Ta)$$

Where Aa= Area of the aperture (a-a0) L, a is the aperture's width, a0=is aperture's width shaded by the receiver, T=inlet fluid temperature (K). Following the energy balance the exit temperature can be determine by equating the heat gained by the fluid to the useful heat gain rate, this can be described in eq. (7)

$$T_{fo} = Ti + Qu/mCp$$

Where T$_{fo}$ is the fluid's outlet temperature and Tf is the fluid's inlet temperature.

With the same concept of evaluating the first model, the Second Model (Modeling and Experimental Investigation of Parabolic Trough Solar Collector) has been done.

Can Uckun (29) Presents a model for the proposed solar system. This model was developed for direct steam generation mathematical formulation, which means that the thermal analysis should be split into two different sections. A part of the analysis should treat and deal with the one phase flow which consists of dry steam and liquid water. The other part should treat and deal with two-phase flow where the characteristic of the flow of the heat transfer is changing. Our scope of work presents using only the first part below the saturation temperature of the working fluid as If the exit temperature reaches the saturation temperature of fluid.

With the same concept of evaluating the first and second models, the Third Model (Optical and thermal modeling of parabolic trough concentrator systems) has been done.

Tadahmun (30) presented an experimental study at Tikrit-Iraq and also theoretical study using FORTRAN 90 program that has been handled for the thermal efficacy determination of a parabolic trough solar collector. The computation of the total incident solar radiations on an exposed surface involves determination of the diffuse radiation and the beam, which are computed after the estimation of the solar time and position.

With the same concept of evaluating the first, second and third models, the Forth Model (Thermal Analysis and assessment, Design and Experimental Investigation of PTC - Parabolic Trough Solar Collector) has been held.

Yidnekachew Messele (31) introduced The HCE performance model via an energy balance between the atmosphere and the HTF, including all correlations and equations needed for the prediction of the terms in the energy balance, which relies on the optical properties, ambient conditions, HCE condition, and the collector type. The optical efficiency contains complex parameters such as reflectivity, absorption, transmission and spillage of the mirror, the glass envelope and the absorber tube. For aluminum reflective surface field test shows that the optical efficiency is above 60%.

V. COMPUTER PROGRAM AND NUMERICAL COMPARISON BETWEEN AVAILABLE MODELS:

After detailed explanation and knowing the steps of the four models for exit temperature and useful energy gained, calculation software program for each model must be built for more easy, rapid and accurate calculation of the required output using the same input for the four models.

Software used for the parabolic trough collector

Excel Sheet Program which provide easy interface with the model and also easy prediction of errors and results. There are basic steps which are approximately similar in the four models for calculation of the required output based on approximately the same input table (1).

Table (1) Four models' data input and data output

| Input data to the models	Output results from the models
Solar radiation Plant Geographical Data Air characteristics Inlet fluid characteristics PTC specifications.	Optical Efficiency Thermal Losses Useful energy gained Exit temperature of the HTF.

VI. EXPERIMENTAL VALIDATION FOR PTC MODEL:

Practical comparison between the four models in order to validate the selected model is done using actual data from experimental and actual plants. Ten Actual Cases are used from different location all over the world as shown in table (2). The comparison between models based on calculation of error% for each model in every case from the actual result as follow:

$$\text{Error\%} = \frac{\text{Model Results} - \text{Actual Results}}{\text{Actual Results}}\%$$

VII. PTC MODEL SELECTION:

From the optical and thermal performance evaluation, we can conclude that the 1st model Fig. (5) gives the best results (approximately the same as the actual data) and also the lowest average error for all cases. The 2nd model gives good results also in different cases (Case 3, Case 6 and Case 10). The 3rd model gives good results in (Case 5 and Case

8). In addition, the 4th model gives the lowest error at Case 9. So that, It can be concluded that the 1st model is the most appropriate model among the four studied models that can simulate the performance of PTC as a solar heating system to be used to represent the parabolic trough collector as a solar heating system that can be used as a tool for developing an economic study about the feasibility and reliability of using solar energy in oil and gas industry applications such as heating the process gas feed to primary reformer in ammonia synthesis plant form 32ºC to 110ºC.
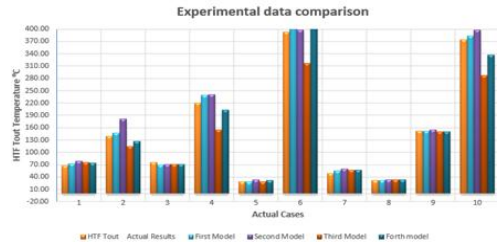
Case No.	Description	Country
Case 1	Parabolic trough solar field installed on the rooftop of a hotel using water as a heat transfer fluid.	Dead Sea area
Case 2	Experimental test have been carried out in Baghdad with climatic conditions during selected days of the months of October, November and December.	Iraq
Case 3	Experimental test from geographical location in kurukshetra.	India
Case 4	Experimental tests have been carried out in SRT.	Thailand
Case 5	Experimental tests have been carried out during the months of April and May 2010 at Shivaji University, Kolhapur.	India
Case 6	Integrated Solar Combined Cycle Power Plant (ISCC) Kuraymat is located about 87 km South of Cairo.	Egypt
Case 7	Comparison with daily results from solar parabolic trough collector for salt-water desalination during period (9.45 A.M to 15.45 P.M) at Daytona Beach, Florida on February 19, 2014.	USA
Case 8	Comparison with results from solar parabolic trough collector for salt-water desalination in arid areas of Saudi Arabia during period from (12 P.M to 17 P.M) on 8/12/2005.	KSA
Case 9	Comparison with output results from experimentally performance investigation of the parabolic trough collector of Shiraz power plant with hot oil generation system in summer period.	IRAN
Case 10	Comparison with operating data from real solar power plant in SEGS-VI in California.	USA

Figure (5) Models comparison with the actual data

VIII. AMMONIA PLANT PROCESS DESCRIPTION AND EVALUATION:

In Misr Fertilizers Production Company (MOPCO), the biggest ammonia producer in Egypt (1200 t/d), Uhde technology. After a full energy efficiency assessment for MOPCO's ammonia plant, it was obvious that there is a great opportunity in enhancing the plant's energy performance just by adjusting the process gas feed (Natural gas) temperature and raising it from 32ºC to 110ºC. The Process gas feed is introduced to the primary reformer's convection bank coil at 32ºC, and then be directed to the hydrodesulphurization reactors. The convection bank's coils, which includes the most critical plant's fluids passing through, e.g.; (Process gas, HP steam, Process Air and combustion air), so that its optimal performance is so vital in balancing the plant's energy performance throughout the continuous production process. HP steam coils temperature are so unbalanced which causes heat unbalance for the whole convection bank where; the outlet temperature of HP steam is decreased leading to increase the consumption of the turbines' HP steam, increase the temperature of the process air to its design limit 480ºC which leads to high thermal stress in the secondary reformer, and increasing the temperature of desulphurization reactor to hydrocarbon cracking limit 380ºC.

Consequently, our scope of work Fig. (6) is to raise the process gas feed temperature from 32ºC to 110ºC only (6 hours/day) with the proposed PTC solar system, that we studied in the above sections, and establishing a comparison between the proposed system and the already existing system. After that the process gas feed being introduced to its convection bank's coil to be heated again inside the coil to 370ºC then being hydro de-sulphurized, so that, the convection bank overall energy performance and temperature profile will be completely enhanced to perform more efficiently with a great impact on the convection bank temperature profile and also a significant impact on the specific energy consumption for each ton of ammonia produced.
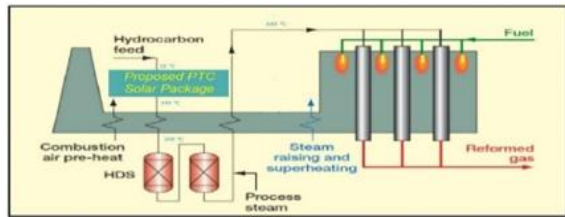

Fig. (6) Scope of work

IX. PRPOSED SOLAR SYSTEM:

The HTF or the heat transfer fluid, (Therminol VP-1), is precisely designed to transfer heat from parabolic trough collector to the fluid that required to be heated through the mounted heat exchanger. This heat transfer fluid should be having low viscosity and heat stability for and efficient, uniform and reliable performance in a wide usage range of 120°C to 400°C.

9.1 Basis of design:

1. Configuration of the solar system is based on Kuraimat solar plant (Egypt).
2. Design solar incident radiation=900 W/m^2.

9.2 Solar package process description (hot oil system):

Heat transfer fluid is transferred via a transfer pump to be heated through PTC, 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 Fig (7).
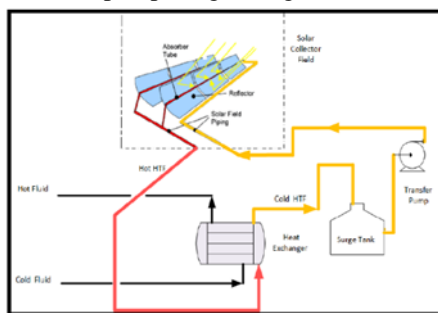

Fig. (7) HTF Process Flow

9.3 Primary Reformer and Convection bank Aspen Plus simulation:

A detailed ASPEN Plus simulation case has been done to simulate the actual ammonia synthesis process at the primary reformer reactor and so that we can evaluate the current process situation, and then asses the proposed solar package after been integrated with the ammonia plant Fig. (8).
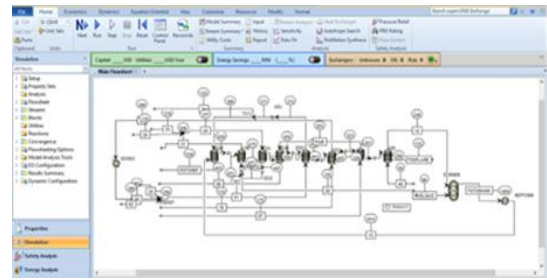

Fig. (8) Primary Reformer Simulation Case – MOPCO/Uhde Ammonia Plant – Egypt

9.4 HTF Pump Design and Commercial Selection:

HTF pump is responsible for transferring the therminol VP-1 from the storage tank to the heat exchanger, to exchange heat with the process gas feed of the primary reformer, passing through the PTC system. The design flow Rate is set to be 18.2 m3/hr and original pressure (operating pressure of storage tank) = 1 kg/cm2 a, also the NPSHA is 10.526 kg/cm2 a and the Pump discharge pressure is 8 kg/cm^2 a. Based on Tahoe Design Software's Pump Base (Academic Version), the following curve provides commercial curve with highest efficiency among number of reasonable curves to provide the required head and service Fig. (9).
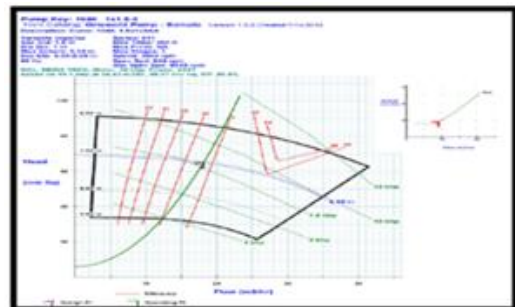

Fig. (9) Q&H curve for the proposed PTC solar system pump

9.5 Heat Exchanger design:

The following table (3) shows data input to Aspen EDR for the two fluids; Process gas (cold) and HTF (hot) Fig. (10) represents the temperature performance analysis for both streams.
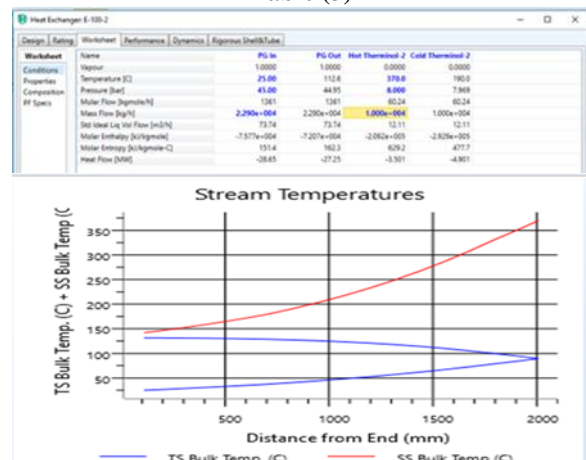
Table (3)

Fig. (10)

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9.6 Solar System Configuration Fig. (11)
• One module area = 12 * 5.76 = 69.12 m².
• Number of required modules= 43 module.
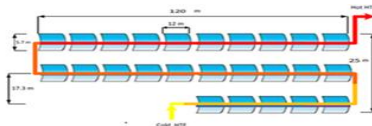• Total required area = 43* 69.12=2,950 m²

Fig. (11)

X. PROJECT ECONOMICS:

a) Total HTF system equipment cost

The following table presents a comparison between individual and total equipment costs using five methods (Charts, Matches Software, ASPEN Simulation Software, Commercial data) table (4).

Table (4)

Equipment	Chart $	Matches software $	Commercial data	ASPEN EDR
Heat Exchanger	20,731.6	29,800	35,000	30,500
Pump	56,540	27,000	45,000	-
Surge Tank	1884.69	3,800	5,500	-
Total Cost $	79,156.25	60,600	85,500	-

b) PTC cost calculation

With respect to updates to SAM (Solar Advisor Model) initiated by NREL (National Renewable Energy Laboratory)
• Solar plant cost/m2=100$•Installations+site Improvements/m²=200$ • Total cost of solar plant= 300*2950= 885,000 $.

c) Total Project Cost

= Solar plant cost + HTF system=166,725+885,000=1,051,891.72$.
Project cost with 30% margin=1,367,459.24$ table (5).

Table (5)

Primary Reformer Fuel Saving	$/year	182013.8337
HP Steam Saving	ton/3°C	2.9
HP Steam Saving	$/year	926043.9257
Total Savings	$/year	1,108,057.76

XI. RESULTS AND DISCUSSION:

After calculating the Project's Energy and Environmental Assessment for MOPCO plant before and after the proposed project it is found that; raising the process gas stream temperature from 32°C to 110°C (as declared before in the below ASPEN Plus/HYSYS simulation case) in the Solar PTC proposed system would promote the plant energy optimization, especially that heating the process gas feed stream is so vital and economically has more than a benefit, such as:

a)Increasing the temperature of the process gas stream entering the primary reformer after being heated in the convection bank section (from 537°C to 539°C) Fig. (12) in addition to increasing the combustion air temperature from 232°C to 248°C which reflects on and declare the vital impact on both sides:

1-The energy consumption side which will be obvious because of decreasing the reformer fuel gas consumption from 11,908.144 Nm3/hr to 11,790.9 Nm³/hr.
2-The environmental side which will be so obvious while decreasing the CO_2 emissions from 10,701.32 ton/year due to decreasing the NG consumed as a primary reformer fuel.
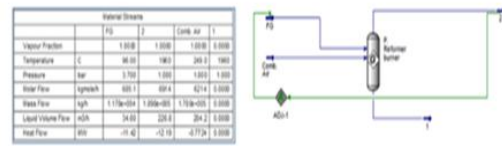

Fig. (12) Primary Reformer, HYSYS simulation case

b)Increasing the HP Steam outlet temperature from 503°C to 506°C which in return will decrease the HPS steam turbines consumption by 2.9 ton HPS steam/hr per one HPS turbine for each 3°C increase in the HPS temperature. MOPCO plant has three HPS turbines for (Syngas Compressor, Electric Generator and CO_2 Compressor).
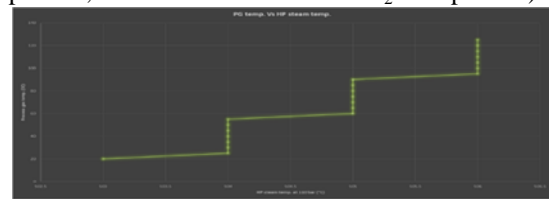

Fig. (13) HP steam temperature Vs Process gas temperature profile

XII. CONCLUSION:

The purpose of this thesis was the providence of the needed economic study about the exploitation of solar thermal system in some applications inside the oil and gas industry (Methane Steam Reforming Process). For the development of such a study and through surveying different solar thermal systems, the conclusion was that the parabolic trough collector represents the most adequate type to be used. Then afterwards an assessment for four different available mathematical PTCs models was introduced for the selection of the most reasonable model that provides simulation of this parabolic trough collector under various operating conditions. Finally, further steps and results of study using parabolic trough collector solar heating system inside MOPCO methane steam reforming process:

• Preheating of the process gas feed (Natural gas) (form 25°C to 110°C) before entering the primary reformer at methane steam reforming process (Ammonia Production Plants). The steps of the study included the design of all equipment and an overall estimation of the plant cost for the prediction of the payback period. The results revealed that payback period is 3.7 years table (6).

Table (6)

Process gas feed temperature difference (dT °C)	90
Primary Reformer fuel saved (6 hr/day) (Nm³/hr)	703.46
HP steam saved for 3 HP steam turbines (t/year)	45,938
Boiler fuel saved due to HP steam production saved (MMBTU/year)	146,321
HP steam temperature difference °C	3
Project total CAPEX ($)	1,367,459.24

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