Sustainable Solution for Crude Oil and Natural Gas Separation using Concentrated Solar Power Technology

1Piyush Choudhary*, 2Rakesh K Srivastava, 3Som Nath Mahendra & 4Saad Motahhir
1Research Scholar, Department of Electrical Engineering, Indian Institute of Technology (BHU), India
2Superintending Engineer (Electrical), Oil and Natural Gas Corporation (ONGC) India
3Professor and 4Institute Professor, Department of Electrical Engineering, Indian Institute of Technology (BHU), Varanasi, India
4Renewable Energy Research Engineer, Laboratory of Production Engineering, Energy and Sustainable Development, Smart Energy Systems and at USMBA University, Fez, Morocco
*Corresponding Author: piyush.rs.eee@iitbhu.ac.in

Abstract: In today’s scenario to combat with climate change effects, there are a lot of reasons why we all should use renewable energy sources instead of fossil fuels. Solar energy is one of the best options based on features like good for the environment, independent of electricity prices, underutilized land, grid security, sustainable growth, etc. This concept paper is oriented primarily focused on the use of Solar Energy for the crude oil heating purpose besides other many prospective industrial applications to reduce cost, carbon footprint and moving towards a sustainable and ecologically friendly Oil & Gas Industry. Concentrated Solar Power technology based prototype system is proposed to substitute the presently used system based on natural gas burning method. The hybrid system which utilizes the solar energy in the oil and gas industry would strengthen the overall field working conditions, safety measures and environmental ecology. 40% reduction on natural gas with this hybrid system is estimated. A positive implication for an environment, working conditions and safety precautions is the additive advantage. There could also decrease air venting of CO₂, CH₄ and N₂O by an average of 30-35%.

Keywords: Concentrated Solar Power, Crude Oil, Heater treater, Oil & Gas, Parabolic Dish, Solar Energy and Sustainable Development

1.INTRODUCTION

Climate change is one of the environmental threat and challenges of today. The impact of climate change on businesses is imminent with some risks - Physical, Regulatory and Brand Value threatening to affect business operations. Therefore, it is essential for businesses world over to create a detailed plan for assessment of risks from this challenge and identification of opportunities.

In today’s era when renewable energy sources are being explored exhaustibility and being used for energy security, still, Oil and Gas industry is a major producer as well as consumer of energy. Based on statistical inputs and industrial experience it is projected that oil/gas sector would have dominance to support the world energy demand for next two decades. The primary energy contribution is in the range of 60% of total energy demand and which amounts to approximately 9960 MtoE in 2035.[1] Oil and Gas industry consumes about 10% of total energy produced and this share of energy consumption would increase with time, considering other unconventional sources like Shale Gas, etc. This unique sector is energy intensive in the range of activities of the seismic survey, drilling, exploration, production, processing, refining, reinjection of water, enhanced oil recovery, electrical power production, transportation, multiple pipelines, etc.[2]. An environmental unbalance is being emerged processing device which separates the oil, gas and water and finally, sends them into separate process lines. The remaining oil, gas and water mixture goes into a heater and treating process unit. Thermal heating further supports to break up the crude mixture so that oil separates from denser water. Natural gas being less dense than oil rises to top of the chamber and extracted separately. The gas is removed
by processing and burning, and water is removed and stored for further treatment. The crude oil viscosity also plays an important role for further flow-ability.

A. Single stage / double stage/ multiple stage separation

As a global practice, the force of gravity is a universal method for the separation of oil, gas, and water. The principles and operation of production separators are based on the difference in gravity, or weight, of each fluid [9]. Production separators do the same gravity job; however, they are built to handle a continuous stream and have improved separation efficiency under flow conditions. Based on pressure zone, three general types of separators called Horizontal Separator, Vertical separator, and Spherical separator are being used in the industry.

![Fig. 1. Stage separation method (two stage separation)](image)

After oil, gas and water separation, there is a small amount of unwanted salts left in the crude, whose concentration needs to be reduced around 5-10 Pounds per Thousand Barrels. This reduction of concentration is necessary for processing of crude and gas in a refinery or stabilizer plant. Crude Oil desalting technology is utilized to remove left out salt to meet these requirements.

B. Concept of Emulsion terminology and Heater treater system

Gravity settling solution gives better results when it is used treat loose and unstable emulsions, however for strong emulsion, other treating methods called destabilizing which increases water droplet size and it finally culminates toward coalescence.

![Fig. 2. Emulsion classifications and its Photomicrographs][11]

(a) Water-in-oil emulsion, (b) Presence of solids, (c) Water-in-oil-in-water emulsion

A dispersion of any immiscible liquid into another uses the chemical which reduces the interfacial tension between the two liquids to achieve stability. In Oil and Gas industry, two types of the emulsion are used first oil-in-water emulsion, and second, water-in-oil emulsion mud[10]. The former is basically water-base mud and the latter is commonly known as an oil-base mud. Oil-field emulsions are water-in-oil macro emulsions.

Emulsions are inherently unstable and are classified based on their kinetic stability; it refers that lose their bonding from the range of few minutes to hours or days. Next process is termed as
demulsification which means breaking of a crude oil emulsion into oil and water. From a heating process point, the rate of separation, left out residual water in oil, and residual oil in water plays the significant role. The most widely used process system for separation and emulsion treating is the use of heater treater system, which includes the pre-heating of the emulsion. Heating the crude emulsions is helpful to reduce its viscosity, increases droplets, dissolves paraffin crystals, and increases density between oil and water[11]-[12]. The design parameters for the heat input depends on the temperature rise, crude specific gravity, the water content in the oil, and the crude flow rate. Heater-Treater contains three chambers, first as the heating chamber, second as degassing chamber and third as electrical chamber, shown in Fig 3.

![Fig. 3. Cross section of Horizontal Heater Treater](image)

In the heating chamber, fire tubes are extended and are in a submerged in emulsion oil. The heating of oil emulsion decreases the viscosity of oil and water, which further reduces the resistance of water movement. In continuation, the surface tension between droplets reduces and formation of bigger droplets created. This overall repeats toward in the separation of oil and water. The temperature required for breaking the emulsion is around 80-85 °C[14]. Degassing chamber is the next area where fluids flows and it allows gas to pass away and leaves the heated emulsion into next an electrical chamber. In this chamber, the gas being lesser denser leaves from top. The Instrumentation plays an important role for continuous control of the oil level in the chamber. Similarly, in electrical chamber, a water level is continuously maintained for oil washing and free water droplets are eliminated before fluid proceeds towards electric chamber. This process is called as Electrostatic coalescence[15], [16]. Several small water droplets would be dispersed in the crude emulsion and would be coalesced by a high-voltage electrical field. When this nonconductive crude oil is subject to electrostatic field, dispersion takes placed between water droplets.

Based on the heating process of crude oil and its requirement of pre-heat temperature of 80-85°C, an innovative idea is thought utilizing solar energy technology which has capability of developing high-grade temperature exchange system. Out of all possible available solar energy technology, only concentrated solar system with a modular parabolic dish could hybrid to the present system comprising of heater treater based primary crude oil heating.
Fig. 4. Typical Crude Oil Treatment system (Separation associated with Heating, dehydration, etc[17]).

C. Environmental impacts due to heater treater state of process

This section describes the research studies conducted for the emission factors for heaters–treaters in oil and gas industry. The factors which were studied to identify emissions testing and emissions estimates for heater-treater are: 1) Equipment used and their technical specification 2) Survey of oil and gas sites, 3) Examination special inventory data, 4) Policy and guidelines of environmental agency on calculating heater emissions, 5) conducted a literature review of studies, papers, and books discussing combustion emissions, and 6) boiler design and how it affects emissions [18]. As CO2 and NOx are the primary pollutants of concern, the focus of this review was to both factors of emissions.

Table I: Heater-Treater Category Emissions[18], [19]

| Pollutant | Heater treater Emissions(tpy) | 2018 Annual Emissions(tpy) |
|-----------|------------------------------|-----------------------------|
| CO₂       | 0.18                         | 4,809                       |
| NO₂       | 0.88                         | 22,901                      |
| PM₁₀      | Negligible                   | Negligible                  |
| SO₂       | Negligible                   | Negligible                  |

II. CONCENTRATING SOLAR POWER TECHNOLOGY

Concentrating Solar Power (CSP) is an emerging technology with very high potential which could cater the demand of energy shortage. CSP based system uses high concentration ratio mirrors or lenses to align sun rays to a common focal point which further heats up a fluid, e.g., water, which produces steam to drive turbines [20]. This produced heat could also be utilized for many industrial applications. Out of other solar energy base technology, only CSP has the potential to achieve the desired temperature, which is comparable to crude oil heating temperature through heat exchangers. Dishes have been used for pilot scale natural gas reforming, steam generation, using several standard states of thermodynamics called Brayton Cycles and Sterling engines, as well as for concentrating photovoltaic [6] Various studies claim that CSP technology has carbon footprint. One meta-analysis study estimated for parabolic trough CSP very less CO2 equivalent per kWh. Compared to other renewable energy sources, CSP is capable of producing energy 24X7, by storing energy during the day and releasing it to
the generator at night or in any weather. These technologies, such as point-focusing parabolic dish may extend the ability of CSP to provide the major industrial application of solar heat energy.

Parabolic dish (sterling engines) system makes use of parabolic mirrors to align solar insolation onto a receiver, which is oriented at the focal point of the dish. The working fluid in the receiver would be heated to very high temperatures of range 500-750°C[21]. This high temperature fluid is further utilized to generate electricity in a small Sterling Engine, or Brayton cycle engine, which is in tandem of the receiver. Parabolic dish based CSP systems are the most efficient and least water consuming of all solar technologies. It is estimated that Dish based CSP system are 25% more effective, compared to other solar thermal technologies[22]

![Diagram](image)

**Fig. 5. Typical Gas Gathering System(GGS) layout in oil and gas sector[23]**

Concentrated Solar Power electrical power systems have the potential to replace fossil fuels. They will also help mitigate the possible effects of climate change. The proposed prototype will be in hybrid combination with existing natural gas fired crude oil heating facility. The focus are where this concept utilization be done is shown in Fig. 5 for typical Gas Gathering System(GGS). The utilization of CSP technology was conceptualized to utilize the concentrated heat for heating up of the emulsion to the temp of 80-85 ºC. Further, Emulsion breaks by an action of demulsified & some part of water is separated which is then drained. Based on the reliability of sun, the hybrid system is best suited. In the absence of sun/ cloud, the original system of natural gas heating would maintain the oil and gas production[25]. The variation of concentrated solar heat would further be supported by the natural gas heating system.

### III. PILOT-SCALE PROTOTYPE & SOLUTIONS

The routine temperature required to heat the crude is 80ºC (considering initial temperature is 30ºC) through three-phase heater treater system. The natural gas is fuel for the heater treater and helpful to achieve the required temperature. The proposed schematic for the CSP based heater treater hybrid system is shown in the Fig. 6
Fig. 6. General Schematic view of the prototype dish CSP crude oil heating system.

With the help of a by-pass valve, a system is proposed to heat the crude oil by solar energy through the heat exchanger. Solar incoming rays being reflected from the concentrator's surfaces on the receiver and through heat exchange with running water, crude emulsion is heated up to required temperature in the range of 85-90°C [17]. Heat exchanged water circulates in the solar thermal receiver-heat exchanger expansion tank system. During a definite initial time period of around 30-60 minutes it comes into the coiling pipe in the heat exchanger, further demulsifier is added to make the emulsion more clean. Here, the heat exchanging process is happening between oil and water oil and is heated to demanded temperature (80°C) then leaving, and heat exchanger oil begins to go to the sedimentation tank[25]. The oil mixture with demulsifier flows into the sedimentation tank. After having kept it approximately 24 hours, the separated water goes out the tank, and treated oil is sent to flow line.

The prototype will be Hybrid with existing Natural Gas Fired Crude Oil heating facility at the site. The utilization of solar heat from the sterling engine would further support build 1-5 MW solar thermal crude heater. The electrical power generated would be utilized for captive use of the oil and gas facility. Based on current present gas values it has been estimated that a 1 MW proposed solar heating system would result in approximately $220,000 per annum saving in Fuel cost and 500 Ton per annum of CO2 equivalent emissions reduction. The payback period of the proposed system is estimated to be six years.

Based on heat requirement at one of oil and gas facility, it is estimated that the modular of 20KW Solar Thermal system would suffice to build a prototype system. Further based on power and heat requirement three situations are explored:

- Option1- 760KW (Thermal): Thermal + Moderate storage
- Option 2 - 400KW (Thermal): Only thermal heating
- Option 3 - 2000KW (Thermal): Full thermal & storage.
TABLE II: Design parameters for prototype system as per Indian Oil and Gas Sector[26]

| Parameter                                      | Value          |
|------------------------------------------------|----------------|
| Total flow of crude                            | 10 m³/hr       |
| Pressure of Crude                              | 4 Kg/sqcm      |
| Use of Natural Gas for crude heating           | 70 m³/hr       |
| Specific heat of crude                         | 0.5            |
| Specific gravity of crude at 15° C             | 0.85           |
| Desired temperature of crude                   | 80°C           |
| Natural gas density into calculation           | 0.8 kg/m³      |
| 1 kg of Natural Gas will generate              | 13.5 KWh       |

The novel solar assisted crude heater installation at one of the Indian oil fields has the potential to reduce Natural Gas consumption in the crude heating process by 432 Million Standard Cubic feet when applied across the further 200-250 oil and gas installation, leading to a cost saving of 76 Million Dollars. Based on the 80-KW prototype installation and demonstration a design will be developed for the 1-5MW system.

IV. SCOPE OF RESEARCH & SYSTEM DESIGN

The prototype is proposed to be the hybrid solution with existing natural gas fired crude oil heating facility due to the uncertainty of sun and other climatic reasons. The performance of the prototype is extensively evaluated, and it is estimated that the prototype would provide the benchmark data on building solar thermal crude heater. Based on current gas values it could be estimated the total power (Electricity & Heat) in the solar heating system that could result in annum saving in fuel cost and CO2 equivalent emissions reduction[27]. During the prototype estimation, the parameters which were further are considered which includes:

1. Geometric concentration ratio for solar dish
2. Optical Efficiency of the solar collectors
3. Direct solar radiation and wind speed;
4. Overall Heat Loss Coefficient
5. Overall Heat Transfer Coefficient and Factors
6. Air temperature and temperature of skin of dish;
7. Thermal Efficiency of a parabolic solar dish
8. The temperature of heat transfer of oil and
9. Flow rate of heat and crude oil.
10. Thermal storage options/ methods

TABLE III: Design parameters of prototype system as per Indian Oil and Gas Sector[28]

| Specifications                  | Unit  | 1 PSC | 4 PSC  | 10 PSC |
|---------------------------------|-------|-------|--------|--------|
| Aperture Area                   | M²    | 8     | 32     | 80     |
| Heat Delivery Rate/day          | KW    | 15 to 35 | 60 to 140 | 150 to 350 |
| Daily Energy Produced           | kcal  | 12900 to 30,000 | 51600 to 120000 | 129000 to 300000 |
| Annual Sunshine (8hrs / day)    | days  | 300   | 2400   | 2400   | 2400   |
| Annual Fuel                     | kg    | 395 to 920 | 1580 to 3680 | 3950 to 9200 |


| (Furnace oil, kerosene, diesel) Savings | Kg/day | 20 to 40 | 80 to 160 | 300 to 400 |
|----------------------------------------|--------|----------|-----------|------------|
| Steam Generation                       |        |          |           |            |
| Unshaded Space Requirement             | M²     | 20       | 80        | 220        |
| Aperture Area                          | M²     | 8        | 32        | 80         |
| Heat Delivery Rate/day                 | KW     | 15 to 35 | 60 to 140 | 150 to 350 |

The performance of solar concentrator is dependent upon solar radiation insolation, site condition, sunshine hours and other parameters. Above figures are indicative and based on specific solar radiation and approximate average values. Performance may be lower or higher than indicated above.

The thermal energy generated by a CSP system is being tested through various thermal storage systems. Thermal energy can be stored much more efficiently than electrical energy, typically in the form of molten salt, which are being tested at several demonstration plants in USA. Thermal Storage gives CSP technology several considerable advantages[29]:

- Reliable operations during cloudy or night time conditions;
- Near instantaneous dispatchable power to meet expected and unexpected peak demand.
- The ability to shift electrical production from the natural peak of insolation to higher-priced peak demand, thereby increasing profitability and investment Returns.
- The ability of the solar field to be oversized about turbine capacity, thereby decreasing turbine costs, increasing the capacity factor and reducing the payback Period.

Fig. 7. Flow diagram for developing the Hybrid Prototype system
V. SUMMARY / CONCLUSION

The proposed prototype hybrid system with existing natural gas fired crude oil heating facility would be an innovative sustainable solution for oil and gas industry globally, with an additional benefit of reducing the carbon footprint and enhance the energy security. This would also be in support of carbon neutrality mission, strive to reduce carbon-dioxide emissions for some industrial sectors. There is also decreasing air venting of CO2, CH4 and N2O by an average of 30-35%[30]. It is judged that there would be 40% reduction in Natural Gas consumption with this hybrid system. A positive implication for an environment, working conditions and safety precautions is the additive advantage.

The estimation and computations for the conceptualized model shows that by the utilization of the proposed solar collector based on a parabolic dish double modular concentrator; it is possible to achieve the temperature of the water that reaches the vaporization temperature, which supports the various technical purposes. The payback period of the proposed system is estimated to be six years. The further benefits and these solutions could be game changes due to following add-ons in following areas:

- Social and environmental importance for reduced pollution & dependency on fossil fuels
- The importance of the project from climate change mitigation aspect.
- Vision statement emphasizes for growth through sustainable development
- Unique and first of a kind-prototype can be patented
- Can accrue the Clean Development Mechanism (CDM) benefits.

ACKNOWLEDGMENT

The authors gratefully acknowledge the support from Oil and Natural Gas Corporation Limited and Indian Institute of Technology (BHU) Varanasi India for the access of facilities and laboratories respectively.

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Piyush Choudhary has obtained his B.Tech. (Electrical Engineering), with Honors in the year 1998, from G. B Pant University of Agriculture and Technology, Pantnagar Uttarakhand, India. Presently he is pursuing his PhD in Solar Energy from Indian Institute of Technology, Banaras Hindu University, Varanasi India. He is corresponding author of this paper.

He is professionally employed at Indian National Oil Company, Oil and Natural Gas Corporation (ONGC) for last 16 years. He had worked in different capacities of engineering, management and environmental sustainability. He has multi-functional experience viz. Core Electrical Engineering, Electrical Operation & Maintenance, Project Management, Project Engineering, Multilateral assignment & government policies, Carbon Management & Sustainable Development, R & D projects on Low Carbon initiatives, Corporate Social Responsibility(CSR), Environmental Protection, Project conceptualization on Renewable Energy, Electrical Design,
Captive Power generation and many more. He has worked for several Sustainable Development projects in association with many countries including USA, Canada, Finland, Australia etc.

Dr. Rakesh Kumar Srivastava is senior Professor in Electrical Engineering in IIT(BHU), Varanasi (India). He obtained his B.Tech. (Electrical Engineering), M.Tech. (Electrical Machines & Drives) and Ph.D. (Linear Induction Motors) from IIT(BHU), Varanasi in years 1983, 1985 and 2000 respectively. His areas of interests are Special Electrical Machines, Linear Induction Machines and Electromagnetic Fields. He is Senior Member IEEE, Member IE(I), Life Member ISTE, Advisor IEEE IAS Student Chapter at IIT(BHU), Varanasi.

Dr. Som Nath Mahendra is an Institute Professor at Indian Institute of Technology Varanasi. His areas of Interest are Electrical Machines, Linear Induction Machines, Electromagnetic Fields and Development of Low Cost LIM Propelled Rail Metro

Saad Motahhir received the technical University degree in Electrical & Electronic Industry from the high school of technology of Fez, Morocco, in June 2011, and he received Embedded System and industrial computer engineering diploma from the national school of applied science of Fez, Morocco in June 2014. He is one of a search team SESIT (Smart Energy systems and information treatment) in Laboratory of Production engineering, Energy and Sustainable Development. His researches are based