

# The Possibility of using Flared Gas to Generate Electricity using Combined Power Cycle

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Received: 09 Jul 2023,

Receive in revised form: 10 Aug 2023,

Accepted: 18 Aug 2023,

Available online: 27 Aug 2023

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**Keywords**— *Exergy, Power Cycle, Power, Rankine, Brayton, Gas Turbine, Steam Turbine*

**Abstract**— *This work evaluated the possibility of generating electricity from flared gases through the application of combined power cycle (Organic Rankine and Brayton cycle) which was simulated using Aspen Hysys. The data for the stimulation was obtained from literature in terms of the process plant operating conditions. The results obtained from the simulation were presented in terms of material balance, energy balance, costing, sensitivity analysis and exergy analysis, which is otherwise known as energy availability. The major equipment in the plants were: pump, heat exchanger, compressor, combustion chamber (conversion reactor), and an expander modeled as a gas and steam turbine respectively in Aspen Hysys simulation. The condenser was modeled as a cooler. The material and balance results were in agreement with the principles of conservation of mass and energy for a steady state process. The costing of the plant in terms of total capital cost, total operating cost, total utility cost, equipment cost and total installation cost were: \$16,762,100.00, \$70,661,490.00, \$4,745,230.00, \$11,323,700.00 and \$12,359,400.00 correspondingly. The sensitivity analysis results revealed that efficiency of the gas turbine increase with an increase in exhaust gas pressure (kPa), signifying that the efficiency increased from 81.5% to 85% when the exhaust gas pressure was raised from 100 kPa to 500 kPa. The efficiency of the steam turbine increased from 72.6% to 74.2% when the outlet pressure was raised from 100 kPa to 900 kPa. Finally, the exergy result for gas turbine in terms of total exergy inlet and outlet are 14187 kW and 3710 kW respectively. This indicates an exergy efficiency of 26.15% or 10,477 kW exergy destruction. Similarly, the exergy result for steam turbine in terms of total exergy inlet and outlet are 1,856 kW and 1,357 kW respectively. This indicates an exergy efficiency of 73.12% or 498kW exergy destruction*

## I. INTRODUCTION

A great deal of gas flaring at many oil and gas production sites has nothing to do with protection against the dangers of over-pressuring industrial plant equipment (Rahimpour *et al.*, 2012). When petroleum crude oil is extracted and

produced from onshore or offshore oil wells, raw natural gas associated with the oil is transported to the surface, as well. Mostly in the developing countries of the world where pipelines and other gas transportation infrastructure is not developed, vast amounts of such associated gases are commonly flared as waste or unusable gas.

Gas flaring flow measurement applications present several unique challenges to the Plant, Process and Instrument engineers when selecting a flow meter system. According to (Mohammad et al., 2015), there are many challenges, when trying to measure the gas flared, including diameters of large pipe, high flow velocities over wide measuring ranges, changing gas composition, low pressure, including dirt, wax and condensate. The procedure of flared gas measurement are uniquely challenged by two various and critically important flow conditions: very low flow under normal conditions and sudden very high flows during an upset blow-down conditions. Additionally, several other important criteria must be considered when selecting constraints and considering a flow meter for flared gas applications, such as: plant Operators, Managers, Process and Instrument engineers.

According to Orimoogunje & Odiong (2010), when petroleum crude oil is extracted and produced from oil wells, raw natural gas associated with the oil is brought to the surface as well. Especially in areas of the world lacking pipelines and other gas transportation infrastructure, vast amounts of such associated gas are commonly flared as waste or unusable gas. The flaring of associated gas may occur at the top of a vertical flare stack or it may occur at a ground-level flare in an earthen pit. The other option is gas re-injection into the reservoir, which saves it for future use while maintaining higher well pressure and crude oil productivity.

Eman (2015), defined gas flaring as the process of burning-off associated gas from wells, hydrocarbon processing plants or refineries, either as a means of disposal or as a safety measure to relieve pressure. It is now recognized as a major environmental problem. It contributes an amount of about 150 billion m<sup>3</sup> of natural gas flared around the world, with the consequences of contaminating the environment with about 400 metric tons CO<sub>2</sub> per year.

Jones & Samuel (2021), stated that between 1990 to 2017 period, oil supply which formed a key part of the energy generation process in Ghana has increased from about 1,000 ktoe (kiloton of oil equivalent) to more than 3,000 ktoe.

Gas supply has also witnessed a steady growth since 2008, that is, over 1000 ktoe in 2017.

Saheed & Ezaina (2012) considered the impact of gas flaring is of local and global concern. Gas flaring is one of the most challenging energy and environmental problems facing the world today whether regionally or globally. It is a multi-billion dollar waste, a local environmental catastrophe and a global energy and environmental problem which has persisted for decades.

Azeez (2017), alluded that gas flaring is one of the major environmental problems in the world now. It consumes useful natural resources and produces harmful wastes, which have negative impacts on the society. It is one of the most tedious energy and environmental problems facing the world today.

Francis et al., (2022), lamented that Nigeria is a country blessed with vast oil and natural gas resources, but due to inadequate management of resources most of the natural gas is flared. One of the most pressing challenges today is global warming. Gas flaring has been known to produce carbon dioxide and other ozone depleting substances, which ultimately cause global weather changes.

## II. PROCESS DESCRIPTION

Figures 1 and 2 depict process flow diagrams of the base case obtained from literature and the simulation case from Aspen Hysys software. In Figure 2, air is compressed in a compressor and the outlet of the compressor was reacted with flared gas inside a combustion reactor, where the reaction between air and flared gases takes place to produce carbon dioxide and water. The outlet product from the combustion reactor is fed to a steam turbine. The outlet of the steam turbine is then fed to a heat exchanger to complete the first circle known as Brayton circle. The next circle which is known as Rankine circle starts with the working fluid pumped into the heat exchanger where it is to be heated with the exhaust stream from the gas turbine. The (outlet) - the hot fluid from the heat exchanger is fed to the steam turbine where its outlet is cooled in a condenser and recycled back into the pump to complete the circle.

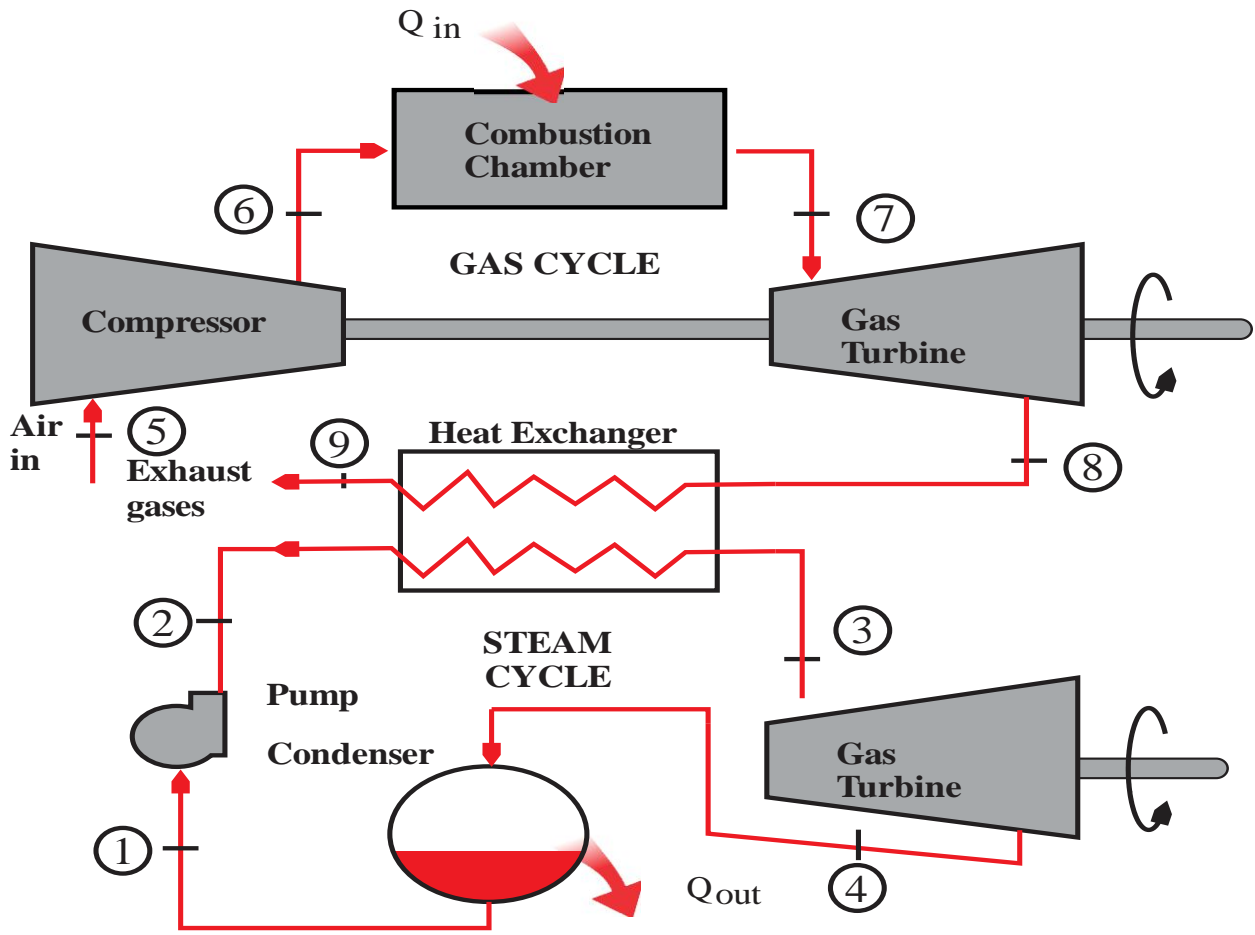


Fig.1. Base Case Combined Gas-Steam Plant (Yunus & Michael, 2006)

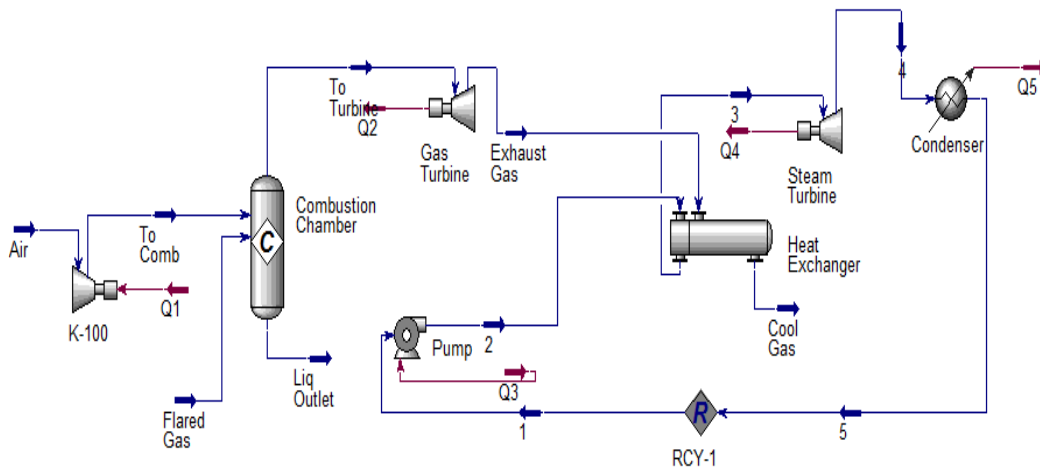


Fig.2. The Aspen Hysys Simulation Case of Combined Gas-Steam Plant

### III. RESULTS AND DISCUSSION

The results obtained from the simulation of combined power plants (steam turbine and gas turbine are presented in Figures 3 to 8)

#### 3.1 Effect of Gas Turbine Efficiency Changing with Outlet Pressure of Turbine

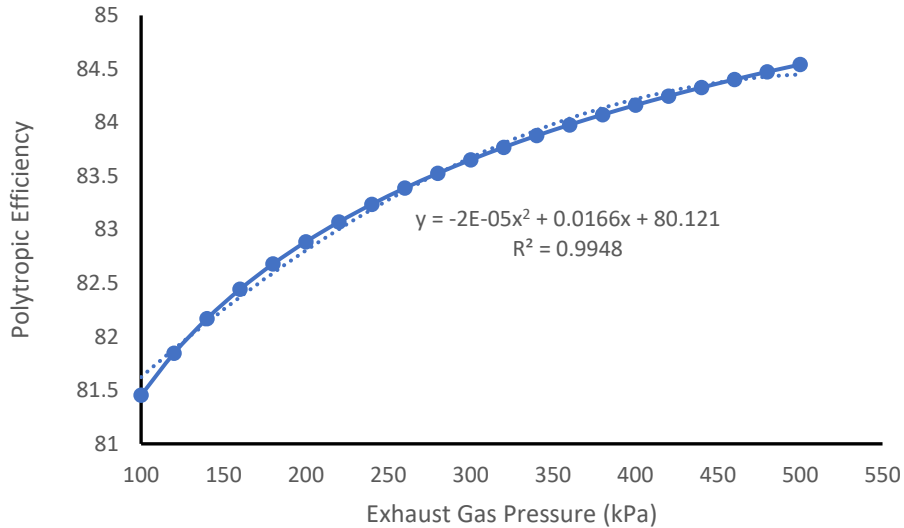


Fig.3: Profile Plot of Polytropic Efficiency of Gas Turbine versus Outlet Pressure of Turbine

Figure 3 shows how the increase in the outlet pressure of the turbine causes a corresponding increase its outlet pressure. Hence, from Figure 3, an increase in turbine’s outlet pressure from 100 kPa to 500 kPa causes its polytropic efficiency to increase from 81.5% to 85%. This means that, if optimization of the turbine efficiency is desired then the outlet pressure of the turbine should be increased until the desired efficiency is achieved. Care must be taken when increasing the outlet pressure of the turbine, because it might get out of range to achieve the desired

efficiency. Therefore, an alternative solution to this problem is to make use of the Adjust Function Tool (AFT) in Aspen Hysys, which is applied in sensitivity analysis. The technique to study the effect of change in input variables on the output of a process model. The results obtained from the sensitivity analysis can be used further to carry out process optimization.

**3.2 The Effect of Gas Turbine Power Changing with Outlet Pressure of Turbine**

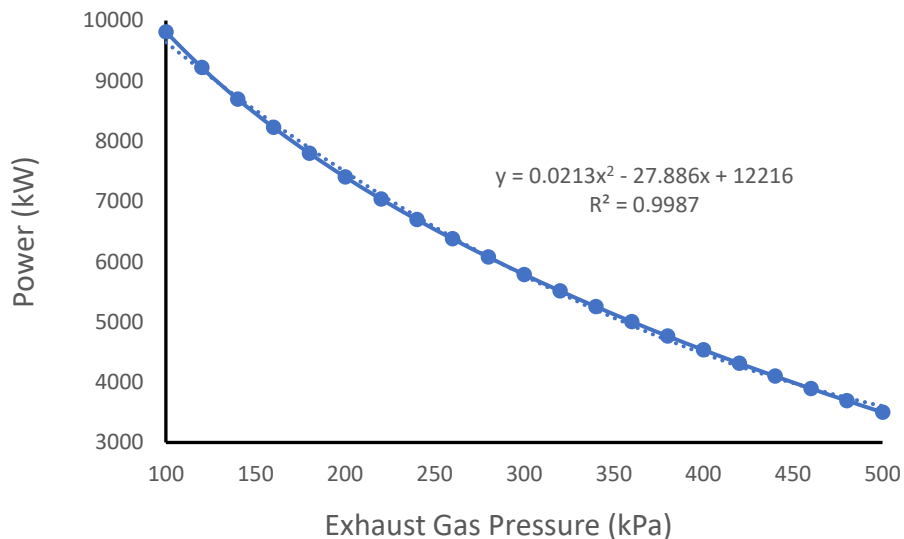


Fig.4. The Profile Plot of Polytropic Efficiency of Gas Turbine versus Outlet Pressure of Turbine

Figure 4 shows how the increase in the outlet pressure of the turbine causes a corresponding increase its power. Hence, from Figure 4, an increase in turbine’s outlet pressure from 100 kPa to 500 kPa causes its power to

decrease from 9000 kW to about 3000 kW. This means that, if optimization of the turbine power is desired, then the outlet pressure of the turbine should be decreased until the desired efficiency is achieved. Care must be taken when

decreasing the outlet pressure of the turbine, because it might get out of the range to achieve the desired efficiency. Therefore, an alternative solution to this problem is to make use of the AFT in Aspen Hysys which is applied in sensitivity analysis (the technique to study the effect of change in input variables on the output of a process model).

The results obtained from the sensitivity analysis can be used further to carry out process optimization.

**3.3. The Effect of Gas Turbine Polytropic Head Changing with Air Mass Flow Rate**

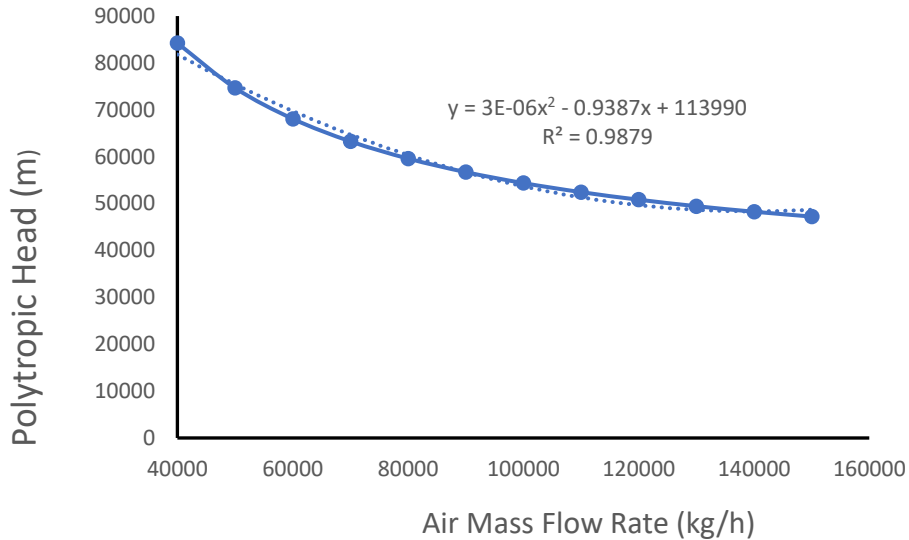


Fig.5. Profile Plot of Polytropic Head of Gas Turbine versus Air Mass Flow Rate

Figure 5 shows how the increase in the mass flow rate of air of the gas turbine causes a corresponding decrease its polytropic head. Hence from Figure 5, an increase in gas turbines air mass flow rate from 40,000 kg/h to 150,000 kg/h causes its polytropic head to decrease from 84,230 to 47,230 meters. This means that, if optimization of the gas turbine polytropic head is desired, then the air mass flow rate of the turbine should be adjusted until the desired efficiency is achieved. Care must be taken when adjusting the air mass flow rate of the gas turbine because it might get out of range to achieve the desired efficiency, therefore an AFT is used as an alternative solution to this problem as described above. The results obtained from the sensitivity analysis can be used further to carry out process optimization.

**3.4. The Effect of Gas Turbine Polytropic Efficiency Changing with Air Mass Flow Rate**

Figure 6 shows how the increase in the mass flow rate of air of the gas turbine causes a corresponding decrease its polytropic efficiency. Hence, from Figure 6, an increase in gas turbine’s air mass flow rate from 40,000kg/h to 150,000 kg/h causes its polytropic efficiency to decrease from 87.1% to 81.2% This means that, if optimization of the gas turbine’s polytropic efficiency is desired then the air mass flow rate of the turbine should be adjusted until the desired efficiency is achieved. Care must be taken when adjusting

the air mass flow rate of the gas turbine, because it might get out of range to achieve the desired efficiency, therefore an alternative solution is to use the AFT, ditto. The results obtained from the sensitivity analysis can be used further to carry out process optimization.

**3.5. The Effect of Steam Turbine Efficiency Changing with Outlet Pressure of Turbine**

Figure 7 shows how the increase in the outlet pressure of the steam turbine causes a corresponding increase its outlet pressure. Hence, from Figure 7 an increase in turbine’s outlet pressure from 100 kPa to 900 kPa causes its polytropic efficiency to increase from 72.6% to 74.2%. Which means that, if optimization of the steam turbine efficiency is desired then the outlet pressure of the turbine should be increased until the desired efficiency is achieved. Care must be taken when increasing the outlet pressure of the turbine, because it might get out of range to achieve the desired efficiency. As such, an alternative solution to this problem is to make use of the AFT, ditto. The results obtained from the sensitivity analysis can used further to carry out process optimization.

**3.6 The Effect of Steam Turbine Power Changing with Outlet Pressure of Turbine**

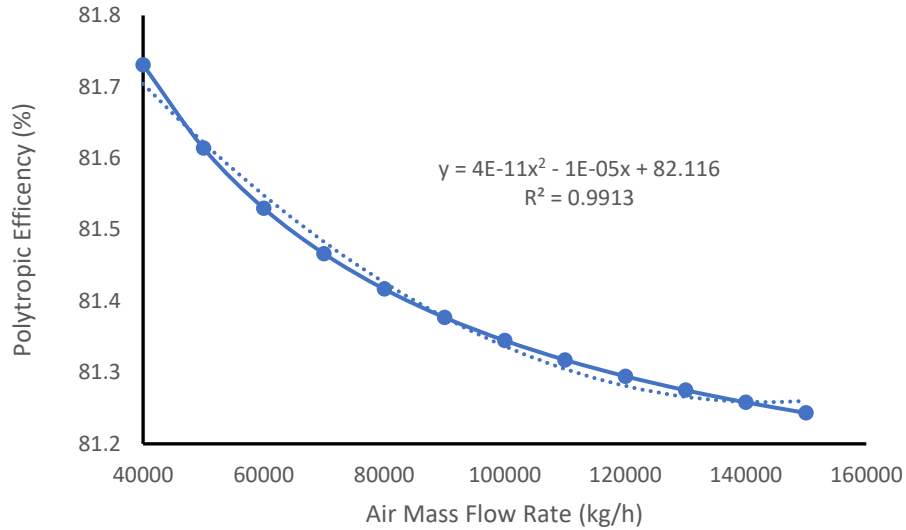


Fig.6. The Profile Plot of Polytropic Efficiency of Gas Turbine versus Air Mass Flow Rate

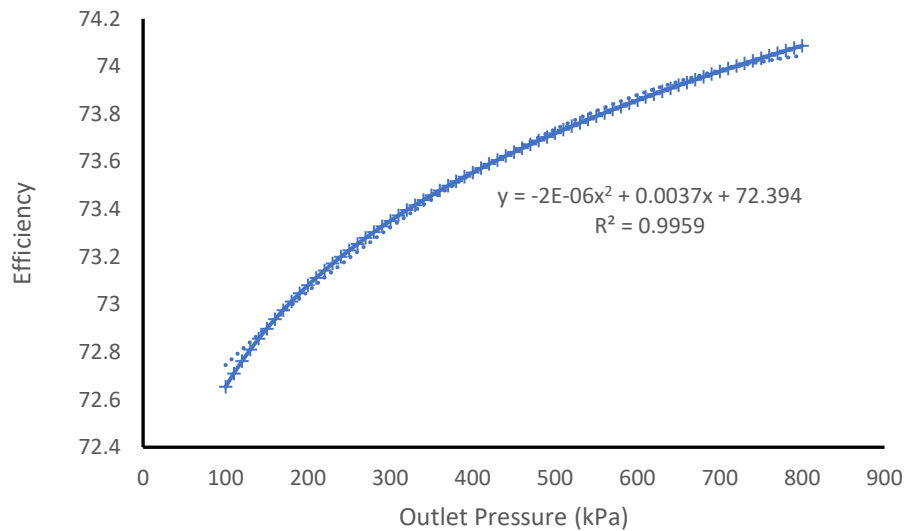


Fig.7. The Profile Plot of Polytropic Efficiency of Steam Turbine versus Outlet Pressure of Turbine

Figure 8 shows how the increase in the outlet pressure of the turbine causes a corresponding increase its power. Hence, from Figure 8, an increase in turbines’ outlet pressure from 100 kPa to 900 kPa causes its power to decrease from 800 kW to about 300 kW. This means that, if optimization of the turbine power is desired, then the outlet pressure of the steam turbine should be decreased until the desired efficiency is achieved. Care must be taken when decreasing the outlet pressure of the steam turbine, because it might get out of range to achieve the desired efficiency. Therefore an alternative solution to this problem is to make use of the AFT, ditto. The results obtained from the sensitivity analysis can used further to carry out process optimization.

From Figure 8, air was compressed in a compressor and the outlet of the compressor was reacted with flared gas inside a combustion reactor where the reaction between air and flared gases takes place to produce carbon dioxide and water. The outlet product from the combustion reactor is fed to a steam turbine. The outlet of the steam turbine is then fed to a heat exchanger to complete the first circle known as Brayton circle. The next circle which is known as Rankine circle starts with the working fluid pumped into the heat exchanger where it is to be heated with the exhaust stream from the gas turbine, the outlet of the hot fluid from the heat exchanger is fed to the steam turbine where its outlet is cooled in a condenser and recycled back into the pump to complete the circle.

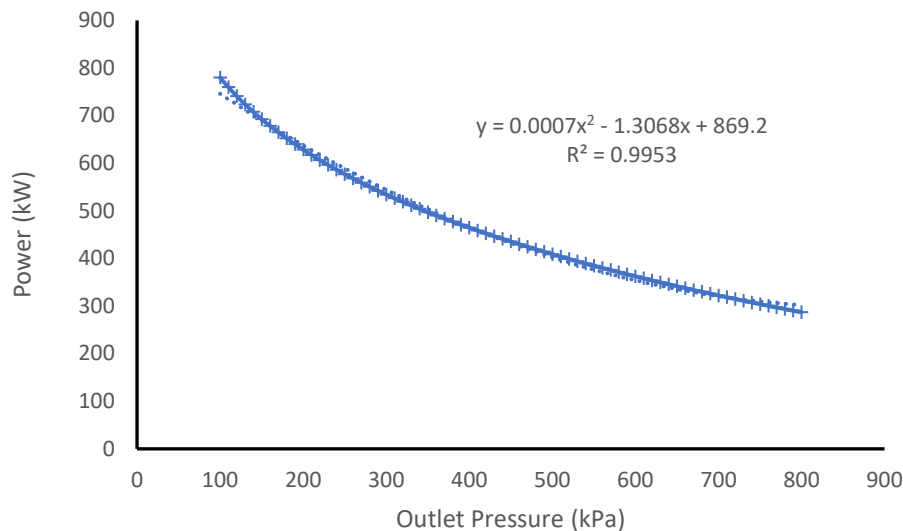


Fig.8. The Profile Plot of Polytropic Efficiency of Steam Turbine versus Outlet Pressure of Turbine

#### IV. CONCLUSION

From the foregoing, the following are the summary of the work:

- (i) The material balance results were in agreement with the principles of conservation of mass and energy for a steady state process.
- (ii) The costing of the plant in terms of total capital cost, total operating cost, total utility cost, equipment cost and total installation cost were: \$16,762,100.00, \$70,661,490.00, \$4,745,230.00, \$11,323,700.00 and \$12,359,400.00 correspondingly.
- (iii) The sensitivity analysis results revealed that efficiency of the gas turbine increased with an increase in exhaust gas pressure (kPa) signifying efficiency increase from 81.5% to 85% when exhaust gas pressure was raised from 100 kPa to 500 kPa. The efficiency of the steam turbine increased from 72.6% to 74.2% when the outlet pressure was raised from 100 kPa to 900 kPa. Finally, the exergy result for gas turbine in terms of total exergy inlet and outlet are 14,187 kW and 3,710 kW respectively. This indicates an exergy efficiency of 26.15% or 10,477 kW exergy destruction. Similarly, the exergy result for steam turbine in terms of total exergy inlet and outlet are 1856 kW and 1,357 kW respectively. This indicates an exergy efficiency of 73.12% or 498 kW exergy destruction.

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