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Evaluation and Optimization of Kodak, Harrow, Combined Cycle Gas Turbine Unit Performance.

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Abstract
With the increasing demand for energy, the growing consciousness towards the environment and the era of austerity at the doors, techniques and methods for efficient energy production are sought after. In this sense the use of CHP systems based on gas turbines based combined cycles has become more common as they present a highly efficient electricity and heat generation tool used in the 21st century. The aim of this paper is to perform an evaluation and optimization of Kodak Harrow's CHP plant, used to satisfy the energy demands of the building where the manufacturing and process of photographic paper take place. The optimization of the system is made thermodynamically initially for each major component before moving to a complete optimization of the operating parameters and conditions of the cycle. Data collection of current operating conditions is made, while climate data is also used. This data is fed to the simulation software Cycle-Tempo (TUDelft) which allows to evaluate the current situation and shows the effects on efficiency by the proposed changes.

Keywords: CCGT, CHP, Optimization, Cycle Tempo, Thermodynamic Analysis

Introduction
The emergence of CCGT technology in the United Kingdom began by the mid-1970s. Although several industrial applications had required the use of CCGT in its earliest forms, cogeneration technology was primarily used for power and electricity production. As a matter of fact, by the beginning of the 1990s, most of the power generating plants in the United Kingdom were operating using Gas Turbines based systems (Winskel, 1998). CHP plants based on the gas turbine systems are now widely utilized and distributed all over the UK. For that, the government has, through the DECC and DEFRA, looked to insure that all CHP systems employed are of good standard and are of benefit both efficiently and environmentally (Department for Environment, Food and Rural Affairs (DEFRA), 2009).
This project is based on the evaluation and optimization of the Eastman-Kodak combined heat and power unit plant in Harrow, West London. Built in 1896, the Harrow manufacturing plant was the largest photographic manufacturing factory in the British Commonwealth and is nowadays one of the Eastman-Kodak's most modern and productive plants (Kodak Limited, n.d.) The plant's main function is still to produce Ektacolor paper, Thermal Media Finishing (Harrow View, 2012) and a several types of Graphics film materials for the printing and publishing industry. It is the world's largest facility photographic paper manufacture, and supplies customers in all continents (Kodak Limited, n.d.).

Current Manufacturing Plant
The current CHP system available at the Eastman-Kodak Harrow site consists of two gas turbines feeding their exhaust gases to a Heat Recovery Steam Generator (HRSG),

from which high pressure steam is produced and sent for expansion through a back pressure steam turbine. The steam generated from the cogeneration plant is sent for the melting of emulsions and also for drying the coating which spread on the emulsion, with the second process requiring much more heat transferred from the incoming steam. For this reason, a specific agreement is made between the Utilities and Operations Department with the Ektacolor Engineering Department regarding the required standards of electricity, steam and other utilities for manufacturing and building operations. It is important to note that the main requirement is the standard level of steam and the electricity generated by the formation and expansion of the steam is used as a by-product. If the electricity does not meet the requirement, extra power is imported from the national grid. This has a negative effect on the systems energy efficiency and makes it clear that ameliorative interventions in the system are necessary to improve it.

Methodology

The present CHP plant has extensive control and monitoring systems in place. Indeed, data is collected at certain points, through installed instrumentation, is monitored and recorded at the control room of the plant. A software is readily available from which data recorded over a predefined period of time, can be saved upon and collected. The data collected over the three month period resulted in some 11,400 entries and they refer to inlet and outlet pressure, temperature and mass flow rate in every component of the CCGT. The first step carried out in the analysis of the system was to separate the different components of the cogeneration plant into gas turbines, steam turbine, HRSG and stack.

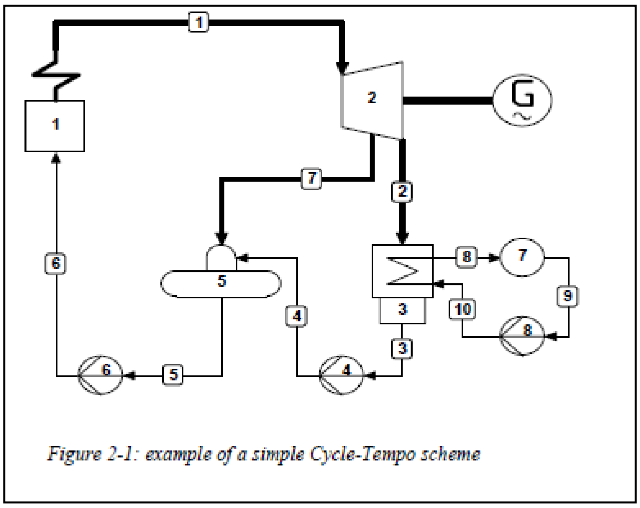

Figure 1: Example of Cycle Tempo scheme

The Evaluation and Optimization of the system was made by determining the following:

1. Thermal Efficiency of Gas Turbines.

2. Power Output from Steam Turbine.

3. Heat Recovered by HRSG.

4. Effectiveness of HE in HRSG.

4. Stack Heat Losses.

5. Exergy Analysis of all components.

Analysis of the previously mentioned quantities allowed the determination of possible areas for improvements. The optimization was done in a purely thermodynamic and heat transfer fashion by looking at compression ratio, inlet temperature and air composition for the gas turbine. As for the steam turbine, the power output was monitored as a function of changes in inlet steam flow, temperature and pressure and same procedure at exist conditions.

The HRSG was simulated in its four possible cases of unfired double gas turbine operation, fired double gas turbine operation, unfired single gas turbine operation and fired single gas turbine operation.

Finally, the stack losses were simulated simultaneously with the HRSG and the heat losses at different exit temperatures were analyzed.

The optimization was targeted as to reduce both electricity imported and natural gas consumed. Thus it was necessary to increase power output from gas turbines and the steam turbine and increase heat recovery to reduce the
It is important to mention that the calculations are made in such a way to meet criteria regarding the mass equations and medium compositions.

Results and Findings

I. Gas Turbines

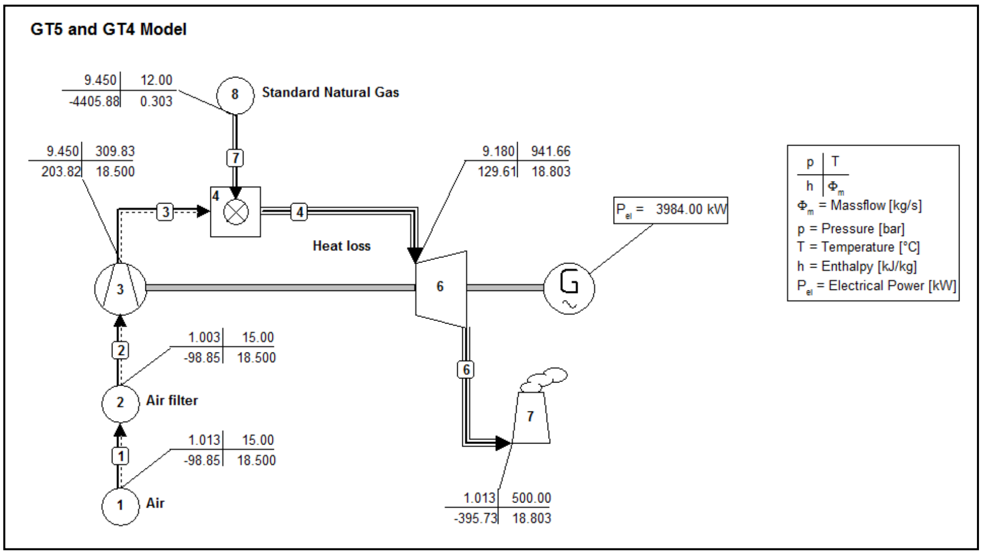

Figure 2: Gas Turbine Units Simulated in Cycle Tempo

Table 1: Input Operating Conditions for the Gas Turbines

Input Operating Conditions	
Inlet Air Mass Flow (kg/s)	18.5
Inlet Air Temperature (°C)	15
Compression Ratio	9.45
Inlet Air Pressure (bar)	1.013
Inlet Gas Mass Flow (kg/s)	7.11
Gross Calorific Value (MJ/m3)	40.1
Compressor Isentropic Efficiency	0.86
Turbine Isentropic Efficiency	0.87
Shaft Efficiency	0.98
Generator Efficiency	0.98

Table 2: System Output for the Gas Turbines

System Output	
Exhaust flow (kg/s)	18.803
Exhaust Temperature (°C)	500
First Law Analysis	
Electrical Power Generated (kW)	3984
Absorbed Power (kW)	14815.26
Thermal Efficiency	0.268912
Second Law Analysis (Exergy)	
Electrical Power Generated (kW)	3984
Absorbed Power (kW)	18000.54
Efficiency	0.221327

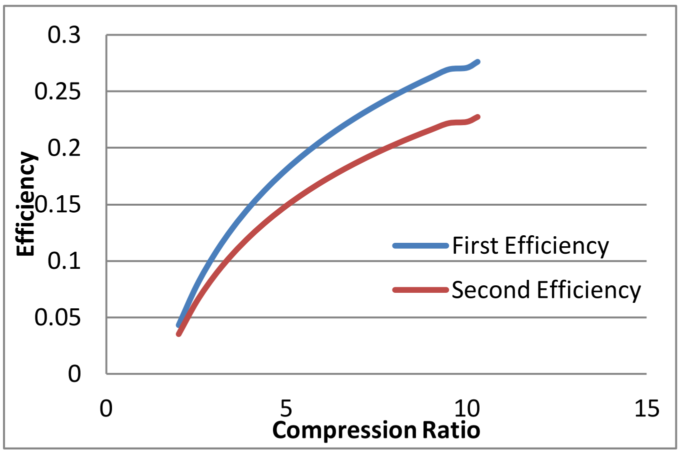

Figure 3: Effect of Compression Ratio on 1st and 2nd Efficiencies

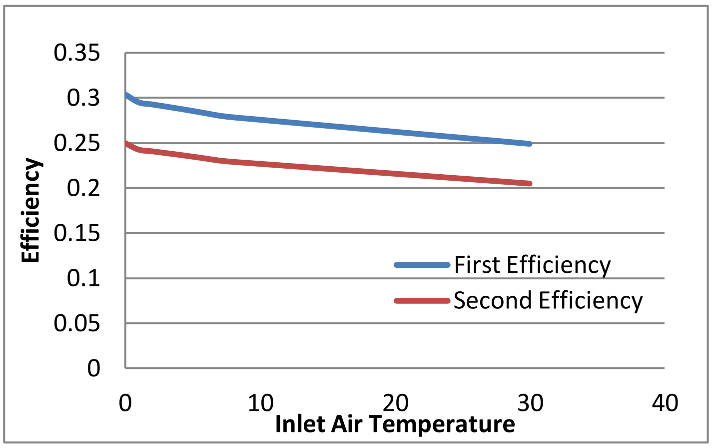

Figure 4: Effect of Inlet Air Temperature on 1st and 2nd Efficiencies

The above results show the evaluation of the current gas turbines available on site with an efficiency of about 27%. The plots show the increase in both first and second efficiencies with the increase in Compression Ratio and with Reduction in inlet Air Temperature.

II. Steam Turbine

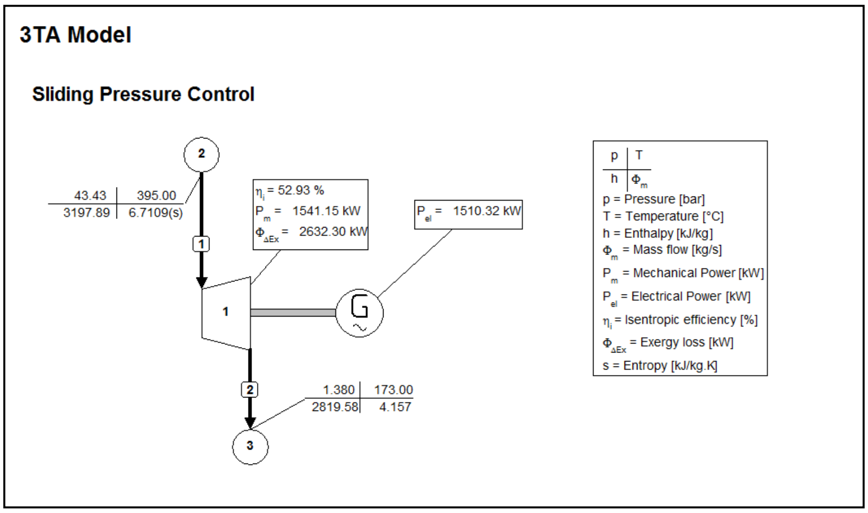

Figure 5: Steam Turbine on Cycle Tempo

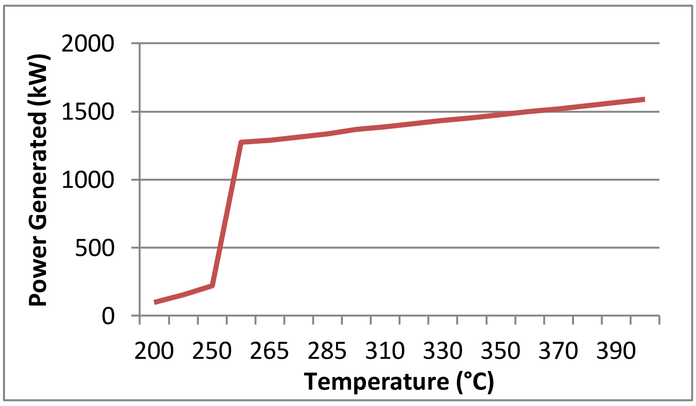

Figure 7: Effect of Inlet Temperature on Power Generated

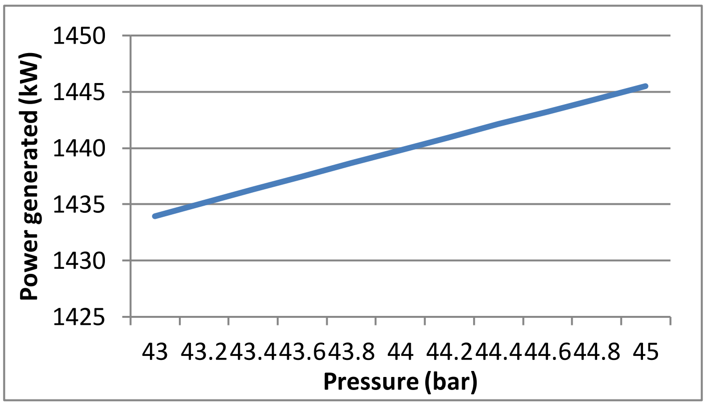

Figure 6: Effect of Inlet Pressure on Power Generated

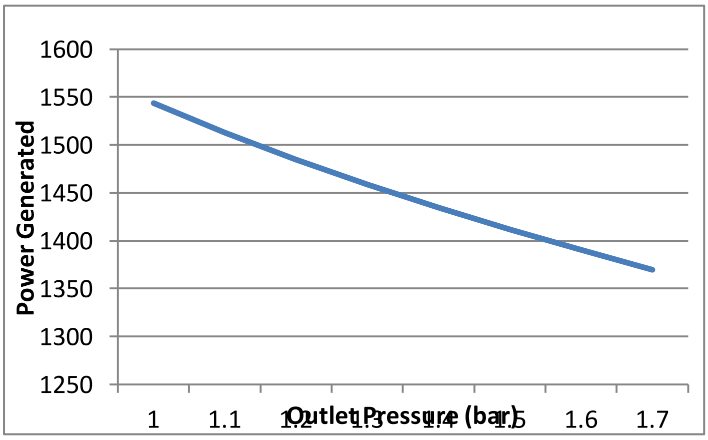

Figure 9: Effect of Outlet Pressure on Power Generated

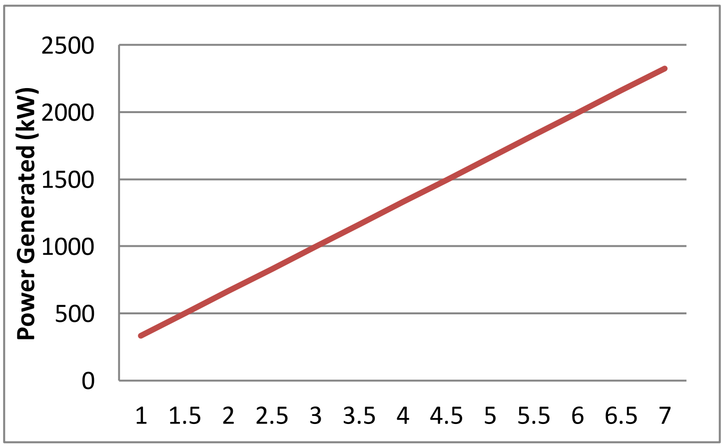

Figure 8: Effect of Mass Flow on Power Generated

The analysis of the steam turbine showed that inlet pressure and temperature as well as inlet steam flow and outlet pressure had effects on the power generated. This was important to illustrate in order to find out the range that may be adopted to satisfy manufacturing process.

III. Heat Recovery Steam Generator

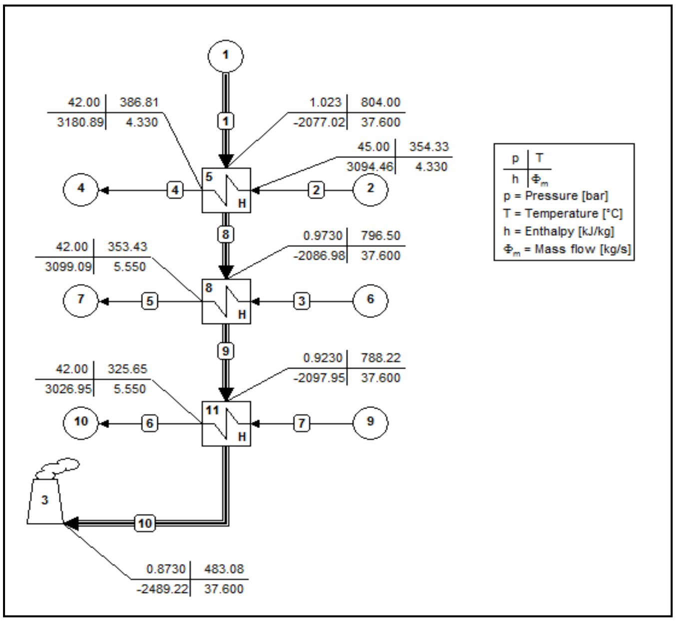

Figure 11: HRSG scheme on Cycle Tempo

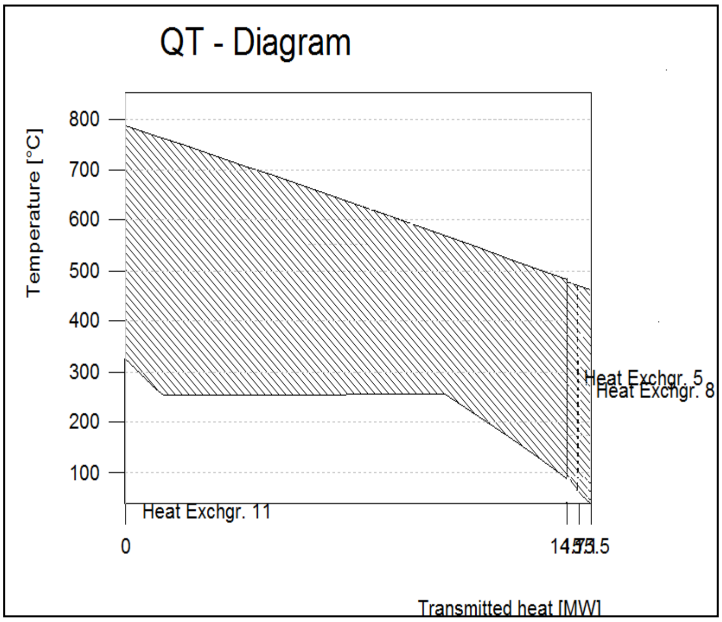

Figure 10: T-Q Diagram for HRSG

Table 3: HRSG Simulations Results

Heat Recovery Steam Generator			
Method of Operation	**Steam Generated**		
Unfired	Mass Flow (kg/s)	Temperature (°C)	Pressure (barg)
Single GT	2.36	402	45
Double GT	4.72	382	45
Fired			
Single GT	6.94	419	45
Double GT	13.88	405	45

The amount of steam generated is important to determine as it directly affects the performance of the steam turbine and the steam exhaust. The effect has to be monitored since it will affect the manufacturing process and will have a huge say in terms of thermal efficiency of a CCGT and heat recovered.

Conclusions

In this research, the analysis of a Cogeneration plant was made where each component was analyzed as standalone and performance criteria were deducted. It was found that an increase of the compression ration of the two gas turbines, while aiming to maintain the inlet air temperature at a low degree would increase the efficiency from the current 27% to 31%.

Also, it was found that setting the exhaust steam from the system to manufacturing at the lowest level required of manufacturing (1 bar and 124°C) would spark an increase in power generated and would thus increase the thermal efficiency, while reducing electricity import from the grid.

The Heat Recovery Steam Generator was analyzed in its four possible operating conditions. It was found that the effectiveness of the three heat exchangers that comprise it were 33% for the Superheater, 25% for the Evaporator and 72% for the Economizer. It was also shown that the maximum steam output was produced when both gas turbines are operating with supplementary firing, thus having an efficiency that is higher.

Further improvements may be by installing a heat exchanger at the entry of the stack to recover the heat from the exhaust and pre heating the feedwater required to produce steam by taking a steam bleed from the steam turbine.

The combination of the above conditions within the already existing system should allow for an increase in the efficiency and generate more savings and create energy efficiency system.

Finally, it is important to note that these CCGT systems, operating in cogeneration mode are the basis of district heating. And thus a study on such a system may allow to produce savings in district systems attaining hundreds of homes, and thus reducing the carbon footprint on a larger scale.

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