Simulating and Optimizing the Separation Process of the Gas-to-Liquid Condensation Products by the Use of Exergy Technology

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Abstract:
GTL process has been analyzed herein based on exergy technology principles. The objective sought in doing so was finding the energy bottlenecks and the possible ways of creating changes aiming at the optimization of energy consumption. The survey of the physical and chemical exergy output and wastage for the equipment indicated that the greatest wastage pertains to the reactor. It was through optimizing the reactor's operational parameters that exergy wastages were decreased by 41%.

Keywords
Simulating, separation process, exergy

1. Introduction

An appropriate method for making use of the country's natural gas reservoirs and creation of suitable added value is the process of transforming gas to petroleum byproducts that is commonly termed gas-to-liquids conversion process. In this process, the natural gas is changed into valuable byproducts like methanol, dimethyl ether and the other intermediate byproducts of distillation like gasoline and kerosene. The process of gas to liquids conversion was invented by two scientists, France Fischer and Hans Tropsch, in 1923 so it is sometimes reminded of as the Fischer-Tropsch synthesis. Although the gas-to-liquids process has drawn the attentions but it is not used as a pervasive commercial solution for the exploitation of the natural gas resources due to its lack of cost-ineffectiveness (high utility consumption). Considerable advances have been made in utility consumption in GTL process during the recent years. The major problem of gas to liquids process (including LNG, NGI and GTL) is the high energy consumption that practically renders the research and investigation on energy consumption optimization a must. In the current research paper, GTL synthesis is analyzed based on exergy principles. The objective of doing so is finding the energy bottlenecks and the possible ways for creating changes aiming at optimization of energy consumption. Exergy is regarded as a scale of energy quality as well as the extent to which it is destroyed in the irreversible processes in a thermal system. One primary use case of the exergy concept is in the analysis of thermal systems by the use of its equilibrium. The exergy loss calculation of a process indicates the extent to which it is irreversible. An accurate analysis of the contributing parameters to such a loss can be of a considerable help in the recognition of the roles played by various factors and in the elaboration of the way it can be changed and finally optimized. In fact, exergy is the maximum attainable theoretical useful work in a state that the system moves toward reaching equilibrium with its surrounding and it only exchanges heat with the environment. Of course, exergy can be defined as the minimum axial or electrical theoretical work required for moving a quantity of some matter from equilibrium with its surrounding to a given state. Therefore, it can be comprehended that exergy is expressive of the degree to which the state of a system is deviated from its surrounding. Environment is in fact a very large equilibrated system and its temperature, pressure and the chemical potential of its constituents remain fixed when exchanging mass or heat with the other system(s). The important in this state is the nonexistence of any chemical reaction between the components constituting the surrounding. The surrounding becomes devoid of any irreversibility and the environment's exergy equals zero. Thus, environment is in fact part of the space surrounding every system. Exergy is comprised of four parts: physical exergy, kinetic exergy, potential exergy and chemical exergy. In the absence of the nuclear, magnetic, electrical and surface tension effects, the total exergy of a system can be similarly divided to four parts: physical exergy, kinetic exergy, potential exergy and chemical exergy [1]. The following sections are a succinct discussion of each of the abovementioned exergies:

2. Physical Exergy

It is the maximum possible work attainable at the time the system reaches equilibrium from an initial state with a certain temperature and pressure to the temperature and pressure of the environment.

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Kinetic and Potential Exergies:

When the system is in a state of inaction in respect to its surrounding, the kinetic and potential energies are completely capable of being converted to work and the environmental parameters are practically considered as the reference parameters in the final state. Therefore, potential and kinetic exergies are corresponding to potential and kinetic energies, respectively. Of course, kinetic and potential exergies are usually ignored.

Chemical Exergy: it is the maximum possible attainable work when the system reaches equilibrium from an initial state with certain temperature and pressure to the surrounding's temperature and pressure. In this state, besides the thermal and mechanical equilibrium, the chemical equilibrium with the surrounding is also taken into account. Thus, besides temperature and pressure, the chemical composition of the system should be made clear, as well. Our natural surrounding is not in equilibrium hence a reference environment should be determined as the exergy surroundings.

Exergy analysis clarifies the place and the amount of the thermodynamic ineffectiveness in a system. These data that are impossible to be acquired through running energy analysis or via the first energy rule are highly useful for improving a system's efficiency and/or for comparing the performance of various systems. Also, the exergy analysis, exergy of every current, determines the real amount of energy loss or, in other words, thermodynamic ineffectiveness as well as the exergetic efficiency of each of the system's constituents. Exergy analysis usually aims at determining the maximum useful performance of a system. Exergy analysis is an engineering tool that is used for the purpose of thermodynamically investigating a process and the determining the maximum amount of useful work attainable by inputting a given amount of energy. In exergy analysis, the irreversibility cases causing an increase in the wasted work of a system are identified and the degree to which they exert an effect on the process efficiency is determined. The results of exergy analysis can formulate a premise for structural optimization of a process. Exergy analysis combines the first and the second thermodynamic rules and this has rendered it one of the strongest tools for the qualitative and quantitative evaluation of the energy consumption in the processes. The maximum possible work produced when a system undergoes certain conditions and goes through certain process to reach to its surroundings' conditions is called the system's exergy. Since the maximum amount of work can be produced when the process is reversible, exergy can additionally be defined as the amount of work that is obtained from changing a certain state of a system to that of the surrounding in the course of a reversible process. Two important indices are proposed in exergy analysis: the pace of exergy destruction and exergy efficiency [1].

3. Exergy Analysis

The present study makes use of exergy analysis for the calculation of the extent to which the exergy is lost as well as for the determination of the exergy throughput in the GTL production process. The first step in analyzing exergy is the simulation of this process that has been conducted assisted by Aspen HYSYS software herein. After simulating the process, the obtained results are applied to calculate the amount of exergy for each of the input and output currents followed by an eventual computation of the exergy destruction as well as exergy output for each equipment as presented below.

1) Compressors:

The exergy of these types of equipment depends on the input and output currents' exergies as well as the amount of work produced therein. The exergy and its loss is illustrated in figures (1) and (2) based on the thermodynamic data obtained from the simulations and according to the exergy relationships of the related results.

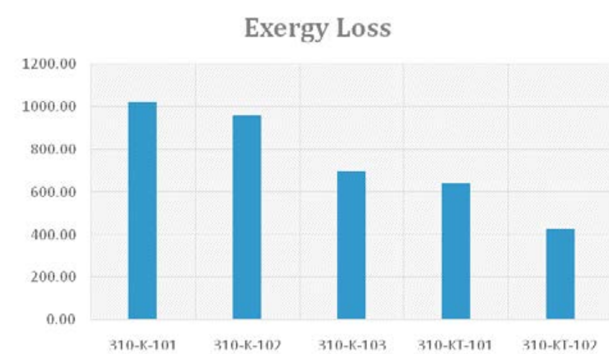

Figure (1): Exergy loss in the single compressors

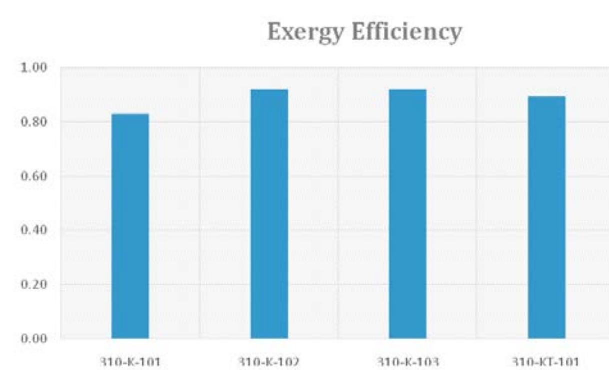

Figure (2): exergy output in the single compressors

2) Thermal Fields:

Thermal Converter: converters are applied in liquefying natural gas. Each converter features several input and output currents. Based on thermodynamic data obtained from the simulations and according to the exergy relationships of the results pertaining to the output, the exergy and its loss are demonstrated in figures (3) and (4), respectively.

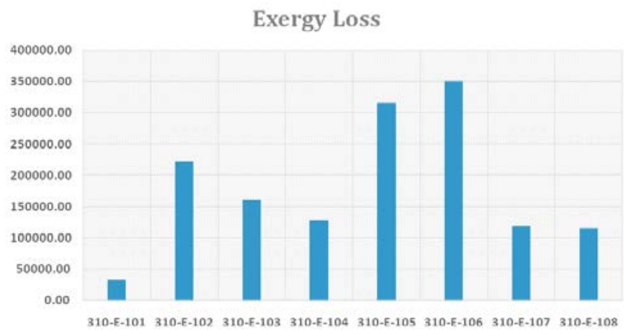

Figure (3): exergy loss in single thermal converters

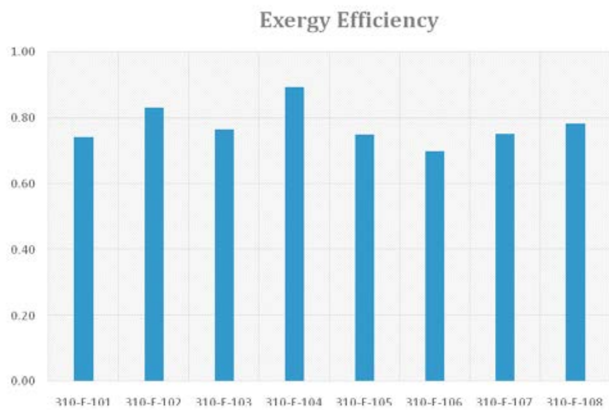

Figure (4): exergy output in single thermal converters

3) Distillation Towers:

These types of equipment are the most important part of every operational unit. Two processes, heat transfer for evaporation and refrigeration and mass transfer for mixture separation. It is worth mentioning that thermal exergy is converted to chemical exergy in distillation columns. Three distillation columns are used in gas-to-liquid conversion process for separating the hydrocarbon splits. For every column, the feeds and products exergetic distillation as well as the thermal exergy is of a great importance. Based on the thermodynamic data obtained from the simulations and the output-related results exergy relationships, the exergy and its loss are shown in figures (5) and (6), respectively.

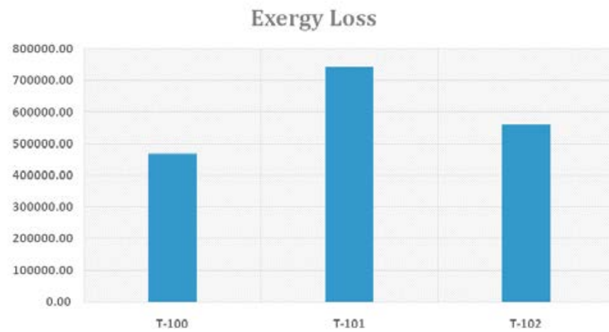

Figure (5): exergy loss in single distillation columns

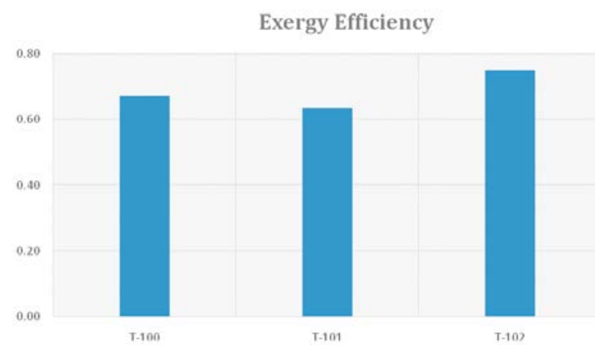

Figure (6): exergy output of single distillation columns

4) Mixers, separators and Pumps:

They are tools that are applied to physically mix the currents. The mixer features more than one input current and the separator is characterized by more than one output current. Based on the thermodynamic data obtained from the simulations and the exergy relationship of the results pertaining to the outputs, the exergy and its loss are illustrated in figures (7) and (8). It is noteworthy that exergy outputs of the mixer and separator are very suitable. That is because no change is practically made in the chemical and physical exergies upon amalgamation. It has to be reminded that the pumps feature high output and low loss.

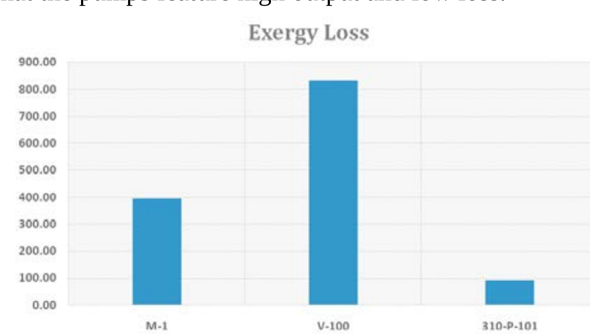

Figure (7): exergy loss in single mixers, separators and pumps

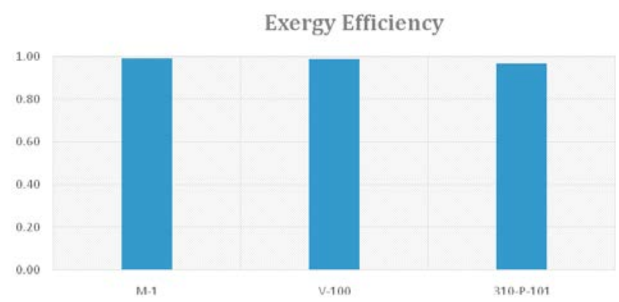

Figure (8): exergy output in single mixers, separators and pumps

4. Results

The investigation of the physical and chemical exergies' output and loss for the equipment indicated that the highest loss belongs to the reactor. Thus, an optimization thereof was taken into account. The parameters effective on the reactor's performance are temperature, pressure, H2: CO ratio as well as the produced vapor temperature. Response Surface Methods (RSM) was applied to optimize the operational parameters. The exergy loss was reduced by 41% through an optimization of the reactor's operational parameters which also caused a reduction in the consumed water and vapor. The consumed energy and exergy losses functions were modeled by the use of RSM method in the format of polynomial functions of the factors effective on the reactor and the extent to which each parameter exerts an influence on the exergy and energy losses were also determined in the end. So, the followings are suggestions made from an evaluation of the new operational conditions optimization results. It is worth mentioning that the exergy output increases to 73% and the exergy loss is reduced to 540670 KW under such circumstances.

- Reducing the operational temperature of the reactor to 760 °C and increasing the operational pressure of the reactor to 42 Bar.
- Recovery of the reactor's generated heat with the objective of producing intermediate-pressure vapor and with a temperature of 165 °C.
- Increasing the molar ratio of hydrogen to carbon monoxide to 2.1.

5. Conclusion:

An investigation of the outputs and losses of the physical and chemical exergies for the equipments indicated that the highest loss belongs to the reactor. Exergy loss was reduced by 41% with an optimization of the reactor's operational parameters which also caused a reduction in the required water and vapor. The loss functions of the consumed energy and exergy were modeled based on RSM method in the form of polynomial functions considering the parameters influencing the reactor and the extent to which each parameter influences the exergy and consumed energy losses was determined in the end. Under such conditions, the computed exergy output was 73% and the loss rate reached to a value of 540670 KW.

References

[1] Rahimpour, M.R., Bahmanpour, A.M.,."Optimization of hydrogen production via coupling of the FischereTropsch synthesis reaction and dehydrogenation of cyclohexane in GTL technology". Appl. Energy 88, 2011, 2027-2036.