Volume 2, No. 11 November 2023 (1396-1405)
p-ISSN 2980-4868 | e-ISSN 2980-4841
https://ajesh.ph/index.php/gp

ENERGY ANALYSIS OF AN EXISTING CO2 PLANT SIMULATED IN ASPEN PLUS V8.8

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ABSTRACT:

Assessing the energy consumption of a CO2 plant helps estimate the plant's greenhouse gas emissions and its environmental impact, which then facilitates the development of an eco-friendly strategy. The main objective of this research is to conduct a fundamental energy analysis in Aspen Plus V8.8 for an already simulated CO2 production system utilizing natural gas as feed. The findings show that the available energy savings of the plant is 4.329×105 watts. There are no CO2 emissions, portraying a carbon-free synthesis process, which is often the desire of environmental protection agencies. This analysis should be used in future studies to determine the appropriate sizing of equipment and utilities, ensuring that the plant operates at its optimal capacity and avoids overdesign.

Keywords: CO_2 plant, Aspen Energy Analyzer, Heat Exchanger Network, Utilities, Carbon emission

INTRODUCTION

Energy analysis helps identify areas of inefficiency in the plant, allowing engineers to optimize the process to minimize energy consumption and reduce operational costs (Gollangi & Nagamalleswara, 2022). By understanding the energy requirements, the plant can use resources more efficiently, leading to reduced energy waste and a smaller environmental impact.

In the literature, the Aspen Energy Analyzer (AEA) process tool is used to carry out energy analysis, including heat integration and pinch analysis for a complete plant or heat exchanger network (Burgos et al., 2023; Pethe et al., 2022. Typically, using ionic liquid to absorb CO2 and CH4, Qureshi et al. (2023) reported the use of AEA, where they presume a cost reduction upon adding a heat exchanger. According to Maes (2018), heat integration is the usage of the hot streams that need to be cooled down to heat the cold streams and vice versa. One of the big reasons why heat integration is important is due to the economic costs associated with heating up and cooling down streams. Another reason is due to environmental reasons caused by using utilities. Another quite overlooked activity that damages the environment is the use of heated-up or cooled-down water. When this water gets returned to the natural environment, it's often at a different temperature. This temperature change can have a negative effect on the organisms living in the water.

In a CO2 plant, energy integration is important as it also helps track the emission of greenhouse gases. Achieving 0 kg/s of carbon emissions is often a desirable outcome as it indicates a high level of environmental sustainability and eco-friendliness. The simulated processes are operating efficiently and cleanly, with minimal or no contribution to greenhouse gas emissions, which can have positive implications for environmental impact and sustainability. The goal of this research is to run an energy analysis on an existing CO2 plant in Aspen Plus. The results of the energy analysis using AEA, including total cooling and heating utilizes energy cost savings, level of CO2 emissions and the heat exchangers fluid temperatures, were vividly discussed. It will be a starting point to further carry out pinch analysis or heat integration in future studies, which will open the door for optimizing the process (Weixin et al., 2020).

RESEARCH METHODS

Aspen Plus V8.8 chemical process simulation environment was used to carry out an energy analysis of an already modelled and simulated CO2 production plant. In the existing Aspen file, it was discovered that the ENRTL-RK base property model was selected, and natural gas component compositions were entered.

It was observed that in the simulation environment, the modelled plant (Figure 1) consists of several heat exchangers on which the energy analysis in this work was based.

To carry out energy analysis, the 'Energy Analysis' icon on the left-hand side of the Aspen Plus environment was clicked.

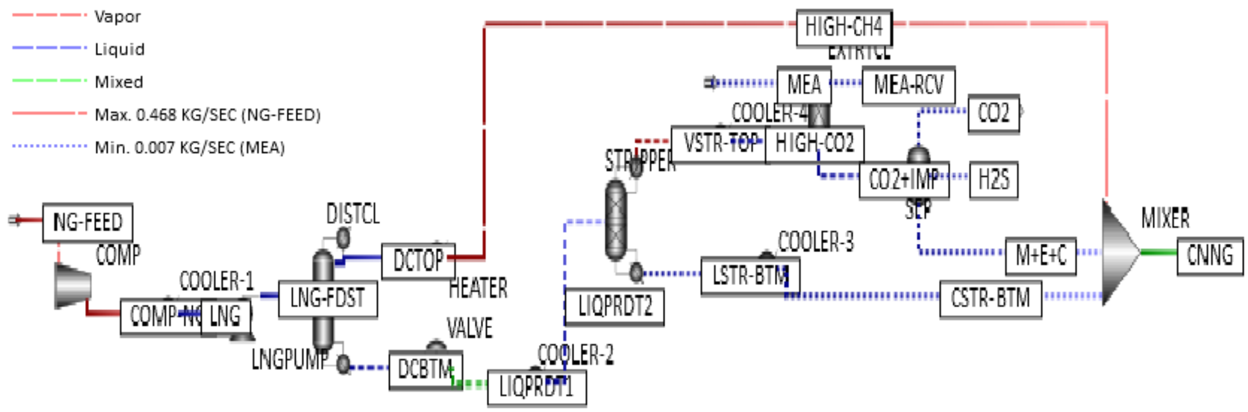

Figure 1. Process Flow Diagram of the CO2 Manufacturing Plant

During the energy analysis of the process diagram in Figure 1, Aspen Plus is expected to perform the analysis on only the exchangers in the plant. Figure 1 is part of Masters' Thesis of the Corresponding Author and was made available here by him.

RESULTS AND DISCUSSION

Upon running the simulation again after energy analysis, Aspen Plus gives the summary of the energy savings, utilities used and the existing exchanger details. The AEA actually enabled the analysis in Aspen Plus.

Summary of Energy Savings

Savings on flow and cost basis can be obtained from Aspen Plus. These can be found in Tables 1 and 2, respectively (or Appendix A).

Table 1

Flow Basis Summary of Energy Savings

	Actual	Target	Available savings	% of Actual
Total Utilities [Watt]	881700	448800	432900	49.09
Heating Utilities [Watt]	216400	0	216400	100
Cooling Utilities [Watt]	665300	448800	216500	32.53
Carbon Emissions [kg/sec]	0	0	0	0

In Table 1, it is observed that the plant is consuming 216400 watts of heating utility, but the desired goal is to minimize this consumption and bring it down to zero. By setting a target of zero, the analysis aims to optimize the plant's energy usage and minimize the need for external heating sources. Also, when the % of actual energy savings on cooling utility is 32.53%, it means that a specific energy-saving measure or modification implemented in a cooling system has resulted in reducing the cooling energy consumption by 32.53% compared to the previous energy usage. For example, if the cooling system used to consume 100 units of energy before the energy-saving measure was implemented, it now consumes only 67.47 units of energy after the measure. The reduction in energy consumption is equivalent to a 32.53% decrease, which is considered a significant improvement in energy and cost savings. Secondly, the cost basis of the energy savings is shown in Table 2.

Table 2
Cost Basis Summary of Energy Savings

	Actual	Target	Available savings	% of Actual
Total Utilities [$ Millions /yr]	0.1199	0.0656	0.0543	45.27
Heating Utilities [$ Millions /yr]	-0.05769	0	-0.05769	-100
Cooling Utilities [$ Millions /yr]	0.1776	0.0656	0.112	63.06
Carbon Emissions [$ Millions /yr]	0	0	0	0

When we talk about available savings on total utilities of 0.0543 $ million/yr, as shown in Table 2, it means that there is a potential cost reduction or savings of 0.0543 million dollars per year in the overall utility expenses for a specific process or operation. This savings amount is usually calculated by comparing the current utility costs with the projected costs after implementing energy-saving measures or process optimizations. If the available savings are indeed achieved, it will result in a considerable financial benefit for the organization or plant by lowering their utility-related expenses by the specified amount annually.

Table 1 gives a carbon emission of 0 kg/s, resulting also in 0 $ million/yr cost equivalent in Table 2. When the Aspen Plus energy analysis shows 0 kg/s of carbon emissions, it means that the simulation or model has been designed in a way that there are no carbon emissions associated with the processes being analyzed. This result implies that the specific configuration of the plant or system, along with the chosen input parameters, ensures that no CO2 or carbon-containing compounds are being released into the atmosphere during the operation.

Utilities

It is important to know the differences between hot and cold utilities. Hot utility refers to the supply of high-temperature fluids or steam used to support various processes within a chemical manufacturing plant, and cold utility refers to a cooling medium or fluid used to remove heat from a process or equipment, lowering its temperature. Table 3 gives the energy cost savings and the minimum temperature difference of the total hot and cold utilities of the plant after energy analysis.

Table 3
Energy Use Details

	Current [Watt]	Target [Watt]	Saving Potential [Watt]	Energy Cost Savings [$/Yr]	Energy Cost Savings [%]	ΔTmin [K]
Refrigerant 4 Generation	216400	0	216400	-57,695	-100.00	2.0
Total Hot Utilities	216400	0	216400	-57,695	-100.00	-
Refrigerant 2	18970	20130	-1156	-123	-6.09	3.0
Very Low Temperature	225900	225900	-2.842×10^{-11}	0	0.00	2.0
Refrigerant 4	416300	0	416300	112,083	100.00	2.0
Air	4027	202800	-198700	-6	-4,935.66	10.0
Total Cold Utilities	665300	448800	216400	111,954	63.05	-

The only hot utility, as shown in Table 3, is Refrigerant 4, while Refrigerant 2, Air, low temperature and Refrigerant 4 make up the cold utilities. Refrigerant 2 and Refrigerant 4 do not represent specific real-world refrigerants like R134a or ammonia. Instead, they are used to simplify the modelling process and are usually associated. With generic refrigerant properties provided by Aspen Plus.

Since the total hot utility energy cost saving is --100 %, it implies that there is no actual cost savings but rather an increase in energy costs compared to the baseline scenario. On the other hand, a -100% savings suggests that no energy was saved, and the energy consumption remained the same or even increased. There are better outcomes than this, as the goal of energy-saving measures is to achieve positive savings by reducing energy consumption.

'Current energy potential' (CEP), as shown in Table 3, refers to the actual energy available at the current operating conditions. In contrast, the 'target energy potential' (TEP) refers to the maximum attainable energy content that can be achieved under specified conditions, assuming an ideal scenario with no losses. They are mathematically related using Equation 1:

ESP = TEP – CEP (1)

Where the energy saving potential (ESP, found in column 4, Table 3) is the amount of energy that can be saved or conserved by improving the system's efficiency, a positive value for ESP (e.g., 216400 & 416300 watts) indicates that energy is being saved. In contrast, a negative value (e.g., -1156, -2.842 & -198700 watt) indicates that the current energy potential exceeds the target, meaning there is room for improvement to achieve higher energy savings.

Existing Exchangers Details

Nine heat exchangers, as shown in column 1, Table 4, are found in the CO_2 production plant. Obtaining 198000 watts and 864.4 watts, which are both positive, as recoverable heat duties of COOLER-1 and COOLER-3 heat exchangers, indicates that there is some excess heat in the outlet stream that can be recovered and utilized elsewhere in the process. This means that the heat exchanger is operating efficiently, and there is a potential for energy savings by capturing the excess heat.

Table 4
Plant Exchanger Details from AEA

Heat Exchanger	Type	Base Duty [Watt]	Rcv Duty [Watt]	Hot Inlet Temp. [K]	Hot Outlet Temp. [K]	Cold Inlet Temp. [K]	Cold Outlet Temp. [K]
COOLER-1	Cooler	386400	198000	459.5	200	170.2	171
COOLER-3	Cooler	4069	864.4	343.5	184.6	170.2	171
Condenser@STRIPPER	Cooler	18970	0	250.5	246.3	233.2	234
Condenser@DISTCL	Cooler	225900	0	111.9	111.4	3.1	4.1
HEATER	Heater	216400	0	171.2	170.2	111.4	112
COOLER-4	Cooler	18700	0	246.3	200	170.2	171
Reboiler@STRIPPER	Cooler	4027	0	351	343.5	303.2	308
COOLER-2	Cooler	7157	0	212.1	190.6	170.2	171
Reboiler@DISTCL	-	0	0	273.2	273.2	273.2	273

On the other hand, obtaining '0 watts' as the recoverable duty, as shown in Table 4 for the rest of the exchangers, means that the heat exchangers are operating at their maximum potential, and there is no additional heat available in the outlet stream that can be recovered.

The inlet and outlet temperatures of the hot and cold fluids of the respective heat exchangers in Table 4 were determined using Equation 2.

$$Q = m_{hot} Cp_{hot}\left(T_{HOT}^{out} - T_{HOT}^{in}\right)$$
$$= m_{cold} Cp_{cold}\left(T_{COLD}^{out} - T_{COLD}^{in}\right) (2)$$

Where, Q = heat duty (watt), m_{hot} & m_{cold} = mass flow rates of hot and cold fluid respectively (kg/s), Cp = specific heat capacity (J/kg/K) and T = temperature of hot or cold fluids (K). The fluids implied by this energy analysis are shown in Table 5.

Table 5
Specific Fluids for the Hot and Cold Side of the Heat Exchangers

Heat Exchanger	Hot Side Fluid	Cold Side Fluid
COOLER-1	COMP-NG_To_LNG	Refrigerant 4
COOLER-3	LSTR-BTM_To_CSTR-BTM	Refrigerant 4
Condenser@STRIPPER	To Condenser@STRIPPER_TO_VSTR-TOPDuplicate	Refrigerant 2
Condenser@DISTCL	To Condenser@DISTCL_TO_DCTOPDuplicate	Very Low Temperature
HEATER	Refrigerant 4 Generation	DCTOP_To_HIGH-CH4
COOLER-4	VSTR-TOP_To_HIGH-CO2	Refrigerant 4
Reboiler@STRIPPER	To Reboiler@STRIPPER_TO_LSTR-BTMDuplicate	Air
COOLER-2	LIQPRDT1_To_LIQPRDT2	Refrigerant 4

Units in Tables 4 and 5 are drawn from Figure 1, showing the overall process flow diagram. From the results, available energy savings for the CO2 plant was 4.329×105 watt and 49.09 % of the actual. According to Pethe et al. (2022), the more the amount of energy consumed in the process plant, the higher the cost for the production will be required and vice versa. It is also reported by Qureshi et al. (2023), that there would be a possible cost saving of about $340182/yr at a low payback period of 0.0586 yrs for a CO2 absorption plant if an additional exchanger is installed. However, a basis for comparing results obtained in this study and literature values cannot be established since varying conditions were used.

A heat exchanger network may be simulated in Aspen Plus to carry out energy integration for the CO2 plant in future work. Process integration, heat-integration energy-integration, and pinch analysis are other terms for the same thing, whose steps are clearly given by Pethe et al. (2022). Pinch analysis concept can be understood in terms of composite curves, grand composite curves, grid diagrams, or grid diagrams for retrofit analysis (Nagamalleswara, 2016; Nagamalleswara et al., 2014, 2015). In pinch analysis, there is a pinch point. This pinch point is the point where the temperature difference between the hot composite curve and the cold composite curve is the lowest (Maes, 2018).

CONCLUSION

Energy analysis in Aspen Plus V8.8 for the CO2 plant in Figure 1 was successfully carried out under the NRTL property model. Almost half (49.09%) of the actual energy requirement of the plant can be saved, according to the findings. The analysis was based on 9 heat exchangers, namely 4 coolers, 1 heater, the stripper column reboilers and condenser, and the distillation column condenser and reboiler. Based on the 0-watt recoverable duty obtained in the 2 separation column's heat exchangers as well as HEATER-1, COOLER-2 and COOLER-4, it can be said that the respective units are operating optimally. There is a need to illustrate the energy analysis carried out using pinch diagrams, composite curves and grand composite curves in future work for the same CO2 production process flow diagram.

BIBLIOGRAPHY

Gollangi, R., & Nagamalleswara, R. K. (2022). Energy, exergy analysis of conceptually designed monochloromethane production process from hydro chlorination of methanol. *Energy*, *239*(121858). https://doi.org/10.1016/j.energy.2021.121858

Maes, B. (2018). *Exploring Aspen Energy Analyzer to improve processes global energy efficiency* (S. Alves, H. A. S. de Matos, & M. C. C. Fernandes (eds.); pp. 1–70).

Nagamalleswara, R. K. (2016). Pinch analysis of acrylic acid process plant. *International Journal of ChemTech Research*, *9*(6), 432–439.

Nagamalleswara, R. K., Koteswara, R. G., Rajendra, P. P., & Sujatha, V. (2014). Design and pinch analysis of mono-isopropyl amine production process using Aspen Plus and Aspen Energy Analyzer. *Emerging Trends in Chemical Engineering*, *1*(3).

Nagamalleswara, R. K., Koteswara, R. G., Rajendra, P. P., & Sujatha, V. (2015). Pinch analysis of cumene process using Aspen Energy Analyzer. *International Journal of Chemical Engineering and Processing (IJCEP)*, *1*(1), 21–30.

Pethe, K. R., Dabhade, P. M., Kolekar, V. J., & Sardare, M. D. (2022). Heat integration and heat exchanger network design with Aspen Energy Analyzer. *International Conference on Advances in Mechanical Engineering-2022 (ICAME-2022): IOP Conference Series-Materials Science and Engineering*, *1259*(012006), 1–10. https://doi.org/10.1088/1757-899X/1259/1/012006

Qureshi, T., Khraisheh, M., & Almomani, F. (2023). Cost and heat integration analysis for CO2 removal using imidazolium-based ionic liquid-ASPEN PLUS modelling study. *Sustainability*, *15*(3370), 1–23. https://doi.org/10.3390/su15043370

Gollangi, R., & Nagamalleswara, R. K. (2022). Energy, exergy analysis of conceptually designed monochloromethane production process from hydro chlorination of methanol. *Energy*, *239*(121858). https://doi.org/10.1016/j.energy.2021.121858

Maes, B. (2018). *Exploring Aspen Energy Analyzer to improve processes global energy efficiency* (S. Alves, H. A. S. de Matos, & M. C. C. Fernandes (eds.); pp. 1–70).

Nagamalleswara, R. K. (2016). Pinch analysis of acrylic acid process plant. *International Journal of ChemTech Research*, *9*(6), 432–439.

Nagamalleswara, R. K., Koteswara, R. G., Rajendra, P. P., & Sujatha, V. (2014). Design and pinch analysis of mono-isopropyl amine production process using Aspen Plus and Aspen Energy Analyzer. *Emerging Trends in Chemical Engineering*, *1*(3).

Nagamalleswara, R. K., Koteswara, R. G., Rajendra, P. P., & Sujatha, V. (2015). Pinch analysis of cumene process using Aspen Energy Analyzer. *International Journal of Chemical Engineering and Processing (IJCEP)*, *1*(1), 21–30.

Pethe, K. R., Dabhade, P. M., Kolekar, V. J., & Sardare, M. D. (2022). Heat integration and heat exchanger network design with Aspen Energy Analyzer. *International Conference on Advances in Mechanical Engineering-2022 (ICAME-2022): IOP Conference Series-Materials Science and Engineering*, *1259*(012006), 1–10. https://doi.org/10.1088/1757-899X/1259/1/012006

Qureshi, T., Khraisheh, M., & Almomani, F. (2023). Cost and heat integration analysis for CO2 removal using imidazolium-based ionic liquid-ASPEN PLUS modelling study. *Sustainability*, *15*(3370), 1–23. https://doi.org/10.3390/su15043370