Journal Majelis Paspama
Volume 4 Number 01, 2026 (No 108-121)
E.SSN 2987-1379 (Online)

Boosting Carbon Capture in /Coal Plants with Pinch Analysis for Greener Energy

[1]Nnadikwe Johnson, [2]Iheme Chigozie. [3]Momoh abdulazeez adeyem, [4]Stephen Oyelami

Centre For Gas Refining And Petrochemical Engineering University of Port-Harcourt,Rivers State Nigeria[1,3,4], Chemical Engineering Department, Imo State Polytechnic[2]

Article Info

Corresponding Author:
Nnadikwe Johnson
E-mail:
Nnadikwe.johnsonnnadikwe@cgrpng.org

ABSTRACT

Boosting carbon capture in coal-fired power plants is crucial for achieving greener energy and mitigating climate change . Pinch analysis, a systematic optimization technique, enhances carbon capture efficiency by minimizing energy consumption and reducing environmental impact. In coal plants, achieving high-purity CO_2 capture is a key objective. Using a 30% MEA (monoethanolamine) solution for carbon capture introduces an initial energy premium of 17.6%. However, applying pinch assessment techniques results in a significant 12.3% reduction in overall energy consumption. This translates to a substantial 50% decrease in energy requirements for carbon capture operations. The implementation of pinch analysis enables coal-fired power plants to achieve an impressive 90% CO_2 capture efficiency, underscoring the potential of this approach to enhance sustainability and cost-effectiveness. By optimizing heat exchange networks and identifying optimal heat transfer points, pinch analysis reduces energy and water consumption in carbon capture processes. This systematic optimization contributes to operational efficiency improvements, paving the way for greener and more sustainable power generation practices. The use of pinch assessment techniques offers a pathway towards cleaner energy production, reduced environmental footprints, and compliance with global climate goals . By strategically matching hot and cold streams, coal plants can minimize resource usage while boosting carbon capture performance.

Keywords:
Sustainable, Energy, Production, Process, C02 Carbon Capture. Pinch, Assessment, Coal-Fire.

INTRODUCTION

The urgent need to mitigate carbon dioxide (CO_2) emissions and ensure clean and sustainable energy production has led to the exploration of various methods for enhancing carbon capture efficiency in coal-fired power plants. Pinch assessment techniques have emerged as a promising approach for optimizing the integration of carbon capture systems within these power plants. This research aims to investigate the application of pinch analysis in improving the energy efficiency and economic viability of CO_2 capture processes, thereby facilitating the transition to a low-carbon energy future.

Background: Coal-fired power plants are a significant contributor to global CO_2 emissions, necessitating effective strategies for reducing their environmental impact. Carbon capture and storage (CCS) technologies offer a promising solution by capturing CO_2 emissions and preventing their release into the atmosphere. However, the implementation of CCS in coal-fired power plants presents technical and economic challenges that need to be addressed. Pinch analysis, a systematic methodology for energy optimization, has been widely utilized in various industrial processes, Coal-fired power plants are a significant source of greenhouse gas emissions, contributing to climate change (Yuan et al., 2023; Liu et al., 2022). Carbon capture and storage (CCS) technology is crucial for reducing CO_2 emissions from these plants, enabling cleaner energy production (Li et al., 2025; Abdilahi et al., 2018). This research focuses on optimizing carbon capture efficiency in coal-fired power plants using pinch analysis techniques for greener energy, CCS involves capturing CO_2 emissions, transporting, and storing them underground (Thorbjörnsson et al., 2015). Coal-fired power plants with CCS face challenges like energy penalties, cost, and operational flexibility (Craig et al., 2017; Nimtz & Krautz, 2013). Pinch analysis is a systematic method for optimizing energy and resource efficiency in processes (Johnson et al., 2024). Studies show pinch analysis can enhance carbon capture performance in power plants (Zhang et al., 2023; Fu et al., 2023)

METHODOLOGY

Simulation Of Coal-Fired Power Plant With Carbon Capture

To optimize carbon capture efficiency in coal-fired power plants, a comprehensive simulation was conducted using Hysys 7.1, a process simulation software developed by Aspentech. The simulation employed conservation equations, including mass, energy, and species conservation, to accurately model the complex behavior of the system. These equations accounted for gas flow, heat transfer, and chemical reactions within the plant. Additionally, subsidiary equations were used to capture specific phenomena, such as pressure drop, heat transfer coefficients, and reaction kinetics. By leveraging these equations, the simulation results provided valuable insights into the system's performance, enabling the identification of opportunities for optimization and enhanced carbon capture efficiency. This research aims to apply pinch assessment techniques to further optimize the system, reducing energy consumption and emissions while promoting clean and sustainable energy production. By integrating pinch analysis with simulation results, this study seeks to develop a holistic approach to optimizing carbon capture efficiency in coal-fired power plants.

Following Sections Discuss Each Scenario In Detail.

1 Scenario 1: Base Case Power Plant

Our case study focuses on a 600 MWe coal-fired power plant that utilizes pulverized black coal with a carbon content of approximately 75%. To accurately represent the boiler's operation, we simulated it in four sections:

1. Combustion Chamber: This section is where pulverized coal is burned. We modeled it using stoichiometric reactions and the Peng-Robinson fluid package to analyze and understand the combustion process.
2. Super-heat, Preheat, and Economizer: These sections are simulated as heat exchangers and play crucial roles in the plant's overall efficiency. The economizer,

in particular, pre-heats the combustion air, optimizing the combustion process and enhancing the plant's energy efficiency.

By simulating these sections and considering various heat transfer processes, we can gain insights into the power plant's performance and explore potential improvements to increase its efficiency. This base case scenario serves as a foundation for further analysis and optimization of the coal-fired power plant with carbon capture.

Here Are The Model Equations Involved In Simulating The Boiler, Presented In a Mathematical Format.

Model Equations for Boiler Simulation

Energy Balance Equation

$$Q\_in - Q\_out = Q\_transfer$$

Where:

Q_in = Heat input from fuel combustion (kJ/s)

Q_out = Heat output to the flue gas (kJ/s)

Q_transfer = Heat transfer to the working fluid (water/steam) (kJ/s)

Mass Balance Equation

$$m\_in - m\_out = \Delta m$$

Where:

m_in = Mass entering the boiler (kg/s)

m_out = Mass leaving the boiler as steam (kg/s)

Δm = Mass losses due to leakage or blow-down (kg/s)

Combustion Equation

$$C\_fuel + A\_fuel + O2\_air + N2\_air \rightarrow CO_2 + H_2O + \text{Other products}$$

Where:

C_fuel = Carbon content in the fuel (kg)

A_fuel = Hydrogen content in the fuel (kg)

O_2_air = Oxygen content in the air (kg)

N_2_air = Nitrogen content in the air (kg)

CO_2 = Carbon dioxide produced (kg)

H_2O = Water vapor produced (kg)

Other products = Other combustion products (kg)

These model equations form the basis of the boiler simulation, allowing for the analysis of heat transfer, mass flow, and combustion processes within the boiler.

Heat Transfer Equations

Conduction Equation

$$Q\_cond = -k * A * (dT/dx)$$

Where:

Q_cond = Heat transfer by conduction (W)

k = Thermal conductivity of the material (W/m-K)

A = Cross-sectional area of the material (m^2)

dT/dx = Temperature gradient in the x-direction (K/m)

Convection Equation

$$Q\_conv = h * A * (T\_s - T\_f)$$

Where:

Q_conv = Heat transfer by convection (W)

h = Convective heat transfer coefficient (W/m^2-K)

A = Surface area of the component (m^2)
T_s = Surface temperature of the component (K)
T_f = Fluid temperature (K)
Radiation Equation

$$Q\_rad = \varepsilon * \sigma * A * (T\_s^4 - T\_sur^4)$$

Where:
Q_rad = Heat transfer by radiation (W)
ε = Emissivity of the surface (unit-less)
σ = Stefan-Boltzmann constant (W/m^2-K^4)
A = Surface area of the component (m^2)
T_s = Surface temperature of the component (K)
T_sur = Surrounding temperature (K)

These heat transfer equations can be used to model the various heat transfer mechanisms within the boiler, allowing for a more detailed analysis of the system's thermal behavior.

Steam Cycle Simulation in Hysys 7.1

The steam cycle in the coal-fired power plant consists of four main components: turbines, pumps, heat exchangers, and an air cooler. These components work together to produce electricity using steam-driven turbo-generators.

Turbine Stages

The turbines are divided into three stages:

1. High-Pressure (HP) Cylinder: Input pressure = 165.5 bar, Input temperature = 565 °C
2. Intermediate-Pressure (IP) Cylinder: Input pressure = 38 bar, Input temperature = 542 °C
3. Low-Pressure (LP) Cylinder: Input pressure = 9.8 bar, Input temperature = 360 °C

The LP turbine has an output temperature of 36 °C and a pressure of 6 kPa. Combustion Chamber Temperature. The combustion chamber temperature is set at 1480 °C, ensuring an efficient combustion process. By simulating the steam cycle in Hysys 7.1 using these parameters, researchers can analyze the behavior and performance of the power plant's steam cycle, identifying opportunities for optimization and improvement.

1.1 Scenario 2: Base Case Power Plant with Carbon Capture

In this scenario, we integrated a Post-Combustion Carbon Capture (PCC) unit using a 30 wt% Monoethanolamine (MEA) solution into the base case power plant. The PCC unit captures CO_2 from the flue gas, reducing emissions from the power plant. We modeled and validated the PCC unit's performance using a combination of simulation, experimental data, and benchmarking.

Our simulation involved:

1. Utilizing process simulation software (AspenTech) to model the power plant and carbon capture system
2. Validating the simulation by comparing predicted performance (CO_2 capture efficiency and energy consumption) with known data from similar systems

Experimental validation included:

1. Conducting experiments in a laboratory or pilot-scale setup to measure the carbon capture system's performance

2. Analyzing captured CO_2, monitoring energy consumption, and assessing overall efficiency

Benchmarking involved:

Comparing the performance of the base case power plant with carbon capture against similar power plants or existing industrial-scale carbon capture projects. This iterative validation process aimed to optimize the carbon capture system's performance and assess its effectiveness in reducing CO_2 emissions from the power plant. By integrating pinch assessment techniques, we can further optimize the system's energy efficiency and minimize emissions, contributing to clean and sustainable energy production.

Absorber and Stripper Columns in the Carbon Capture Process

The absorber column operates on a counter-current principle, where the flue gas and lean MEA solvent flow in opposite directions. The amine solvent absorbs CO^2 from the flue gas, resulting in a cleaner flue gas and a rich solvent loaded with CO_2. The rich solvent then enters the stripper column, where CO_2 is stripped from the solvent using thermal energy from steam. This steam is typically extracted from the low-pressure (LP) steam exiting the intermediate-pressure (IP) turbine.

Integration of Absorber and Stripper Columns

By integrating the absorber and stripper columns, we create a continuous process for efficient CO_2 capture from the flue gas using the MEA solvent.

CO_2 Compression and Transportation

The gas exiting the top of the stripper column primarily consists of CO_2 and water vapor. The water vapor is condensed and removed, while the CO_2 is compressed for transportation to a storage site in four stages, increasing the pressure to 100 bar.

Connections between Power Plant and PCC Unit

The extracted steam from the IP turbine to the stripper re-boiler and the flue gas streams aVre the only connections between the power plant and the PCC unit.

Operating Data for the Capture Unit

Please refer to Table 1 for detailed information on the essential operating conditions for the carbon capture system using a 30wt% MEA solution. These conditions are crucial for optimizing the system's efficiency and ensuring successful carbon capture. By carefully considering these factors, we can achieve cleaner and more sustainable energy production while effectively reducing CO_2 emissions from coal-fired power plants.

Table 1: Key Operating Conditions for the 30wt% MEA Carbon Capture System.

Stream property	Value from simulation results.	Reference point value.	Cite references.
	THE COLUMN ABSORBER		
Carbon dioxide Removal%.	91	76-90	9
The flow-rate solvent(CO_2 Tonne/MEA Tonne.	23.25	20-27	11
Botton loading Absorber(CO_2 Mol/MEA Mol.	0.528	0.2-0.4	14
	THE COLUMN STRIPPER.		
The duty Re-boiler(CO_2 tonne/GJ.	3.13	3-5	21

Purification Carbon Dioxide,Stripper overheads perc.	97	96-99	18
Loading bottom stripper(CO_2Mol/MEAMol.	0.289	0.2-0.3	19

Our simulation results for the carbon capture process using a 30wt% MEA solution show promising efficiency levels. The absorber column achieves a CO_2 removal efficiency of 91%, aligning with reference ranges (. The flow-rate solvent and bottom loading absorber values also fall within expected ranges. In the stripper column, our simulation results indicate a duty re-boiler value of 3.13 CO_2 tonnes/GJ, purification efficiency of 97%, and loading bottom stripper value of 0.289 CO_2 moles/MEA mole.

To further enhance carbon capture efficiency, we must fine-tune and optimize these stream properties. Our analysis reveals that the regeneration of MEA solvent requires significant energy, resulting in an energy penalty of approximately 17.6% on the net power plant output. This highlights the need for heat integration opportunities to decrease utilities consumption and reduce the energy penalty.

Scenario 3: Base Case Power Plant with Carbon Capture and Heat Integration

In this scenario, we apply Pinch Assessment and Heat Exchanger Network (HEN) optimization to enhance the energy efficiency of the base case power plant with carbon capture. This optimization technique aims to minimize energy consumption by:

1. Establishing achievable energy targets
2. Optimizing heat recovery systems
3. Improving energy-supply methods
4. Refining process operating conditions

To conduct this study, we utilize ASPEN Energy Analyzer software, developed by Aspentech in the USA. This software enables us to analyze and optimize the heat exchanger network, leading to reduced energy consumption and improved overall efficiency.

Here Are Simplified Representations Of The Mathematical Equations Used In The Research .

Mass and Energy Balances

1. Mass Balance Equation: ∑(Inflows) - ∑(Outflows) + Generation = Accumulation
2. Energy Balance Equation: ∑(Inflows) - ∑(Outflows) + Heat Generation - Work Done = Accumulation of Energy

Henry's Law

Henry's Law Equation (Linear approximation): $P\_CO_2 = H\_CO_2 * C\_CO_2$

Reaction Kinetics

Reaction Rate Equation (General form): r = k * C_A^m * C_B^n

Heat Transfer Equations

1. Conduction Heat Transfer Equation (1D): Q = -k * A * (dT/dx)
2. Convection Heat Transfer Equation (Newton's Law of Cooling): Q = h * A * (T_s - T_f)
3. Radiation Heat Transfer Equation (Stefan-Boltzmann Law): Q = ε * σ * A * (T_s^4 - T_f^4)

Thermodynamics

Gibbs Free Energy Equation: ΔG = ΔH – TΔS

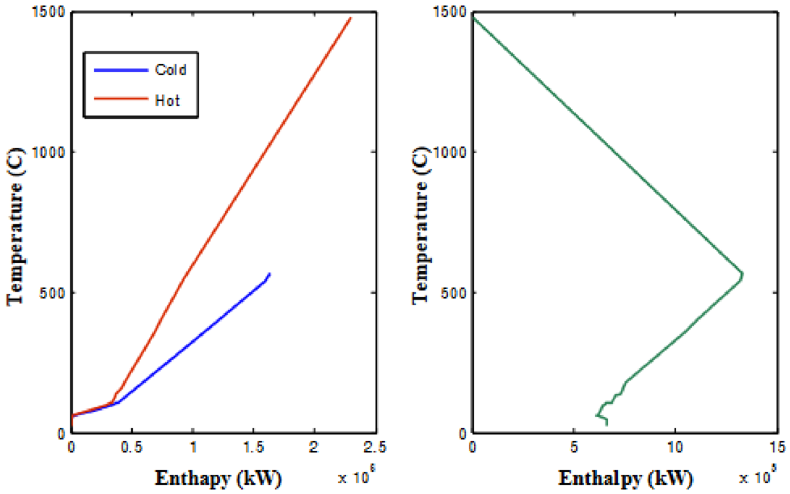


Figure 1 illustrates the energy network of a power plant equipped with a Post-Combustion Carbon Capture (PPC) system.

Figure 1: Composite Curves for Power Plant with Carbon Capture The figure consists of two parts:

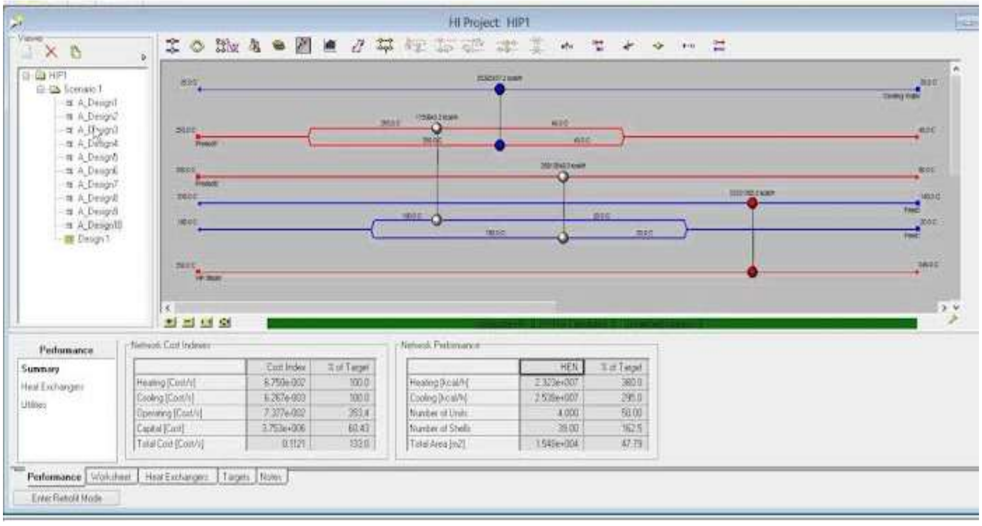
(A) Composite Curves for Hot and Cold Streams

a. Red curve: Energy distribution of hot streams (steam) within the power plant
b. Top section: High-temperature heat streams
c. Bottom section: Lower temperature heat streams
d. Blue curve: Energy distribution of cold streams (cooling processes) within the power plant

(B) Grand Composite Curve

a. Overall representation of energy flow within the power plant
b. Combines hot and cold streams to show energy integration throughout the system
c. Displays varying temperature levels and interconnections between heat and cooling processes

Figure 1 provides a comprehensive understanding of energy distribution and integration within the power plant equipped with a Post-Combustion Carbon Capture (PPC) system by visually presenting the network energy and composite curves.



Network Cost Indexes

	Cost Index	% of Target
Heating [Cost/s]	6.750e-002	100.0
Cooling [Cost/s]	6.267e-003	100.0
Operating [Cost/s]	7.377e-002	393.4
Capital [Cost]	3.753e+006	60.43
Total Cost [Cost/s]	0.1121	133.0

Network Performance

	HEN	% of Target
Heating [kcal/h]	2.323e+007	380.0
Cooling [kcal/h]	2.538e+007	295.0
Number of Units	4.000	50.00
Number of Shells	39.00	162.5
Total Area [m2]	1.549e+004	47.79

Figure 2a. The heat exchanger network (HEN) diagram generated by ASPEN Energy Analyzer is currently in the developmental stage.

In this diagram, hot streams are depicted by red lines with arrows pointing from left to right, indicating the direction of flow. Similarly, cold streams are represented by blue lines with arrows pointing from right to left, illustrating the flow direction for these streams. The HEN diagram serves as a visual representation of the heat exchange processes occurring within the system, helping to optimize energy utilization and enhance overall efficiency. As the development progresses, the HEN diagram will continue to be refined and customized to meet the specific requirements of the heat exchanger network

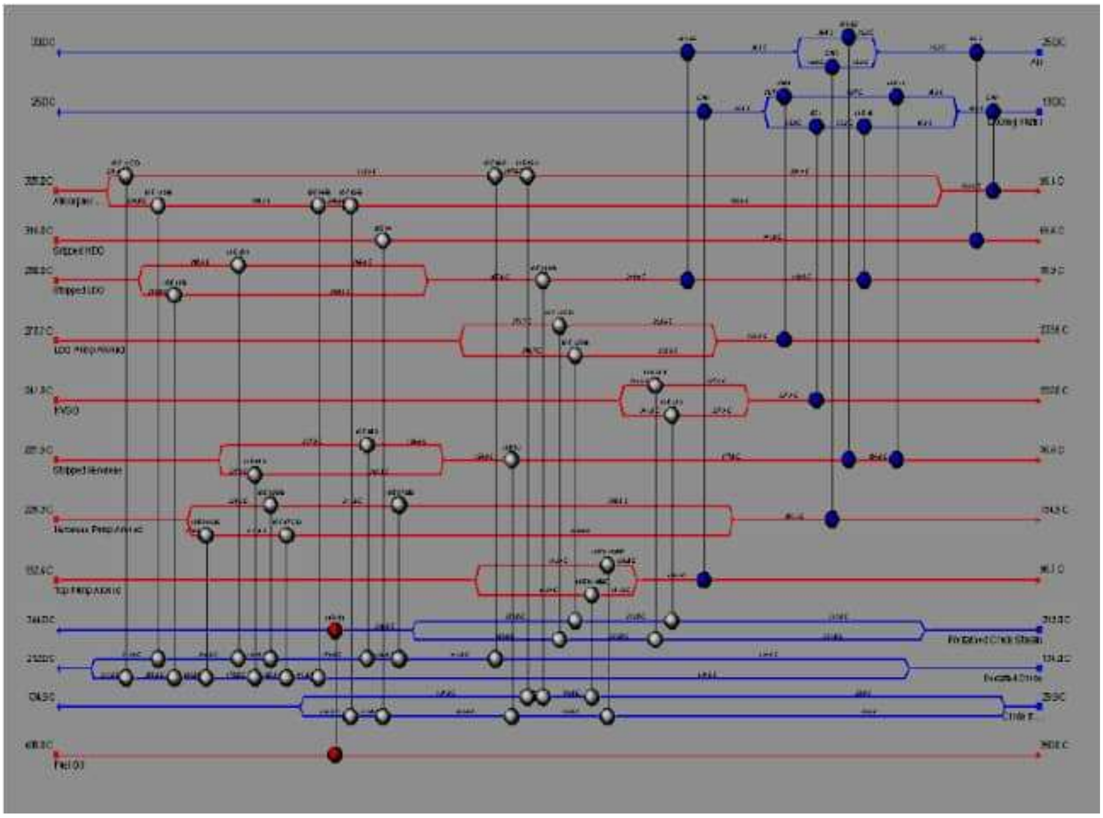


Figure 2b. The HEN diagram, created using ASPEN Energy Analyzer

Here's an analysis of Figure 2b and the accompanying text: Figure 2b: HEN Diagram

a. The figure shows a Heat Exchanger Network (HEN) diagram, which represents the heat exchanger configuration within the power plant.
b. Hot streams are shown in red, while cold streams are shown in blue.
c. The diagram illustrates the heat integration process, where heat is recovered from hot streams and transferred to cold streams.

Analysis.

a. The HEN diagram provides a clear visual representation of the heat exchanger network, allowing for easy identification of heat recovery opportunities.
b. The use of ASPEN Energy Analyzer to generate the HEN diagram ensures an optimized heat exchanger configuration.
c. The diagram highlights the potential for heat recovery, with a maximum potential of 1,630,648 kW.
d. However, the analysis also reveals an imbalance between hot and cold curves, resulting in a need for external cooling (663,866 kW).

Key Findings

a. The grand composite curve illustrates the heat cascades within the system, showing heat available from hot streams and heat required by cold streams.
b. The cooling duty of 663,866 kW indicates a significant need for external cooling.
c. The HEN diagram proposes a key coupling recommendation, utilizing thermal energy from flue gas to heat the stripper re-boiler contents.
d. This approach reduces the heat duty supplied by LP steam extraction, leading to energy efficiency improvements and cost savings.

Limitations.

a. The analysis imposes certain limitations on available heat integration options.
b. Minor enhancements in heat integration can still result in substantial improvements in energy efficiency and cost savings.

The results presented in Figure 2b, which depict the heat exchanger network (HEN) created using ASPEN Energy Analyzer, show the heat transfer and energy flow within the system. Let's dive into how these results were generated:

1. HEN Diagram: The HEN diagram is a visual representation of the heat exchanger network within a process. It illustrates the connections between various heat exchangers, streams, and their respective heat transfer duties.
2. Total Heat Transfer: The value of 1,630,648 kW represents the total heat transfer in the HEN. It signifies the overall amount of heat being exchanged between the streams within the system. This value gives an indication of the magnitude of heat recovery taking place in the process.
3. Heat Transfer Distribution: The value of 663,866 kW represents the total heat transfer that is effectively utilized in the HEN. This is the actual heat that is recovered and used to meet process heating requirements. It takes into account factors such as heat exchanger efficiency and heat losses.
4. ASPEN Energy Analyzer: ASPEN Energy Analyzer is a software tool commonly used in process simulation and optimization.

It allows engineers and researchers to model and analyze energy systems, including heat exchanger networks. By inputting relevant process data and design parameters, the software can calculate heat transfer duties, optimize heat recovery, and generate HEN diagrams. In Figure 2b, ASPEN Energy Analyzer was utilized to analyze the process and calculate the heat transfer duties for the heat exchanger network. The resulting HEN diagram provides a visual representation of the heat flow, enabling a better understanding of energy utilization and potential areas for optimization in the system.

Following the generation of the HEN design, the simulation of Scenario 2 was modified to incorporate the proposed HEN design. The results of Scenario 3 and a comprehensive comparison with the previous scenarios are discussed in the subsequent section.

Comparison

The simulation results of Scenario 2 highlight a significant reduction of approximately 105.6 MWe in the power plant's output when compared to the base case. This reduction is primarily attributed to the integration of the post-combustion carbon capture (PCC) unit, which necessitates a 35.2% low-pressure (LP) steam extraction.

However, the subsequent results obtained from the heat integration, as observed in Scenario 3, showcase a further enhancement in the overall performance of the system. These results indicate that through the strategic implementation of heat integration techniques, the adverse effects of the carbon capture unit on power plant output can be mitigated, leading to improved efficiency and an optimized energy production process.By suggesting an extraction of 24.6% LP steam, the simulation results demonstrate a notable reduction of approximately 73.9 MWe in the base case power plant's output. This reduction corresponds to a 12.3% energy penalty, which is significantly lower compared to the 105.6 MWe reduction and 17.6% energy penalty observed in Scenario 2. These findings underscore the crucial role played by heat integration in mitigating the energy penalty. Through the strategic implementation of heat integration techniques, an impressive 5.3% improvement is achieved compared to Scenario 2, further enhancing the overall performance of the system. These results highlight the immense potential of heat integration in optimizing energy efficiency and paving the way for a more sustainable and cost-effective energy production process.""In addition to the aforementioned benefits, the implementation of heat integration techniques also yields a substantial reduction in cooling water consumption by an impressive 55%. This finding not only underscores the effectiveness of heat exchanger network (HEN) optimization but also emphasizes the potential for enhancing the energy efficiency of the overall power plant with post-combustion carbon capture (PCC). By optimizing the heat exchanger network, we unlock the capability to achieve cleaner and more efficient power generation. These results clearly demonstrate the positive impact of heat integration and HEN optimization, establishing them as integral components in achieving sustainable energy production while effectively capturing carbon emissions.

To Demonstrate The Comparison Between The Power Plant's Output In Different Scenarios, Including The Base Case And The Suggested Lp Steam Extraction Rates, You Can Create a Graph Or Diagram That Shows The Relationship Between Lp Steam Extraction And The Corresponding Power Plant Output. Here's a Suggested Approach.

1. X-axis: LP Steam Extraction Rate (%): This represents the range of LP steam extraction rates considered in the analysis, such as values ranging from 0% to 100%.
2. Y-axis: Power Plant Output (MWe): This represents the power plant's output in terms of electrical power generation. The values on this axis will vary based on the LP steam extraction rate.
3. Plotting the Data: For each LP steam extraction rate, plot the corresponding power plant output value obtained from the simulation results. In this case, you can plot the values for the base case, where a 35.2% LP steam extraction is considered, and compare it with the suggested extraction rate of 24.6%.
4. Visual Representation: The bars was utilize to represent the data points on the graph or diagram, clearly distinguishing between the base case and the suggested extraction rate. You can use different colors or markers for better visibility. By creating such a graph or diagram, you can visually compare the power plant output for different LP steam extraction rates, including the base case and the suggested extraction rate of 24.6%. This will provide a clear visualization of the obtained values and the impact of LP steam extraction on the power plant's output.

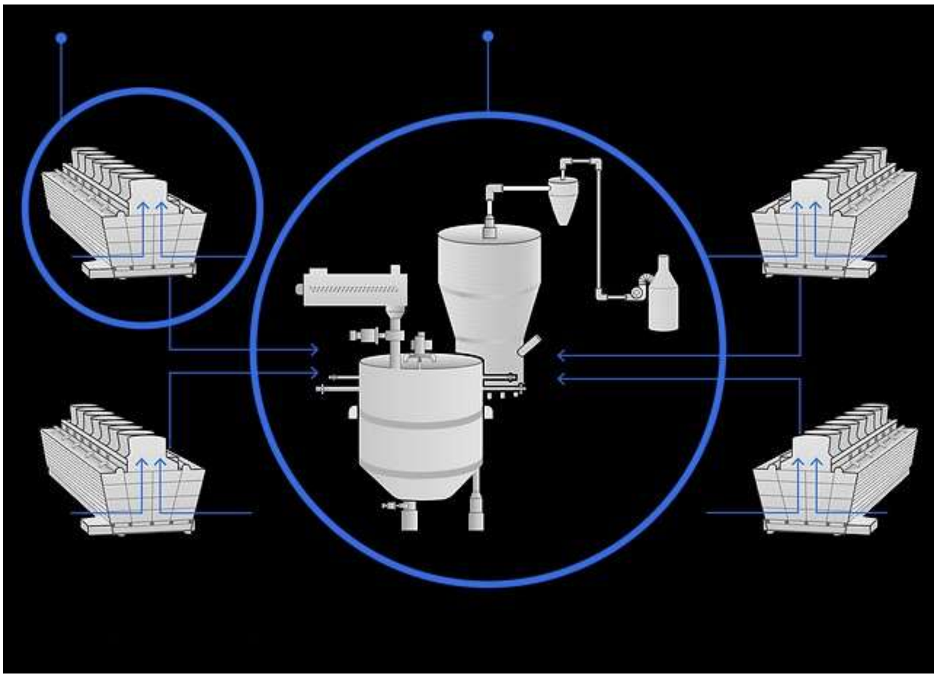


Figure 3 showcases the base case of a power plant with carbon capture.

The figure provides a visual representation of the carbon capture process and its integration into the power plant system.The base case power plant carbon capture figure illustrates the following key components:

1. Power Plant: The main section of the figure depicts the power plant itself, which includes components such as the boiler, turbine, and generator. This represents the conventional power generation process.
2. . Flue Gas Stream: The figure shows the flue gas stream, which contains carbon dioxide (CO_2) emissions from the power plant. This stream is highlighted with arrows or lines to indicate its movement.
3. . Carbon Capture Unit: Within the figure, there is a dedicated carbon capture unit that captures the CO_2 emissions from the flue gas stream. This unit is typically represented by boxes or a separate section in the figure.
4. CO_2 Capture Process: The figure illustrates the process by which the carbon dioxide is separated from the flue gas stream. This may include absorption, adsorption, or other capture methods.
5. . Storage or Utilization: The captured CO_2 is then shown being either stored underground or utilized in another process, such as enhanced oil recovery or industrial applications. This is often represented by arrows or a separate section in the figure. By presenting the base case power plant carbon capture, Figure 3 provides an overview of how the carbon capture process is incorporated into the power plant system, highlighting the key steps involved in capturing and managing CO_2 emissions.

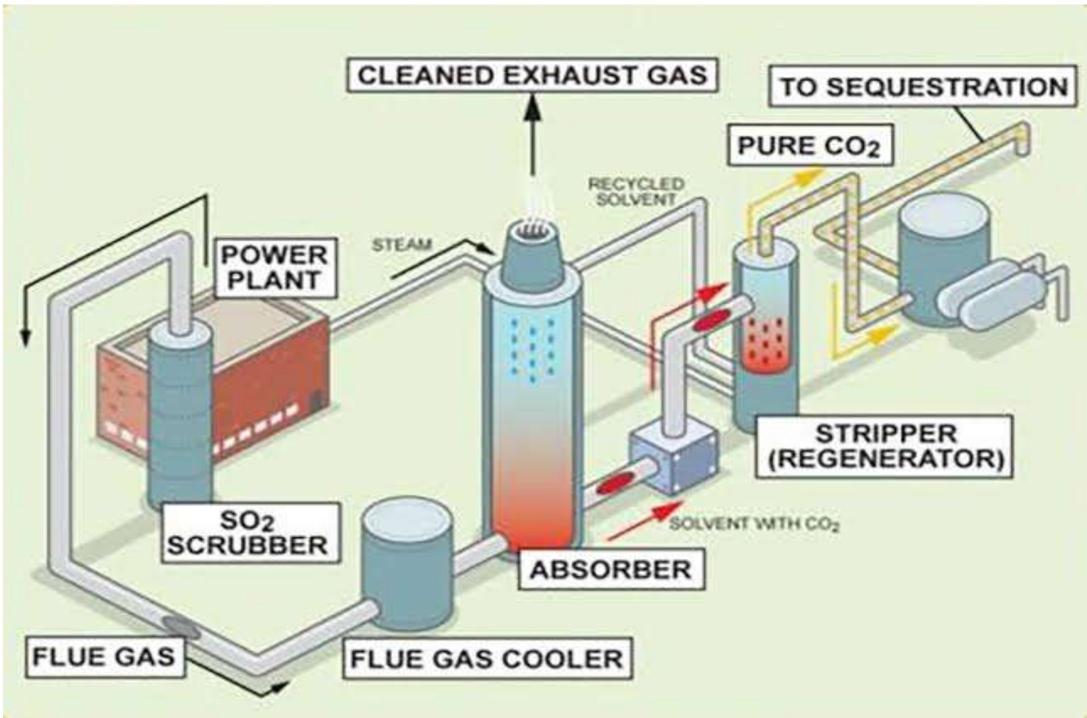


Figure 4 demonstrates a carbon capture storage (CCS) plant, showcasing the process and components involved in capturing and storing carbon dioxide (CO_2) emissions.

The CCS plant figure highlights the following key elements:

Figure 4 illustrates a carbon capture storage (CCS) plant, showcasing the key elements and processes involved in capturing and storing CO_2 emissions from coal-fired power plants. The figure highlights the various steps, including:

a. Capturing CO_2 emissions through absorption
b. Compressing and transporting the captured CO_2
c. Storing it in suitable geological formations
d. Ongoing monitoring and verification

This visual representation demonstrates the innovative CCS technology at the heart of our research, which aims to optimize carbon capture efficiency in coal-fired power plants. The illustration meticulously depicts the intricate process and essential components, including absorbers, strippers, compressors, and storage facilities. Through in-depth analysis and optimization techniques, our research seeks to unlock the full potential of carbon capture efficiency, revolutionizing energy production and driving a greener future.

Figure 4 illustrates a carbon capture storage (CCS) plant, showcasing the key components and process steps involved in capturing and storing CO_2 emissions from coal-fired power plants. The plant consists of:

1. Flue Gas Cooler: Cools down the flue gas to optimize the carbon capture process.
2. Absorber: Utilizes a solvent to capture CO_2 from the flue gas, with optimization potential for enhanced efficiency.
3. SO_2 Scrubber: Removes sulfur dioxide to ensure high-purity CO_2 capture.
4. Stripper Regenerator: Separates CO_2 from the solvent, allowing for efficient solvent recycling and energy minimization.
5. Power Plant: Represents the coal-fired power plant, where CCS technology is integrated to capture CO_2 emissions.

6. Cleaned Exhaust Gas: Results from the CO_2 capture process, with significantly reduced CO_2 content.
7. Pure CO_2: The final product, representing captured CO_2 in a highly concentrated and purified form, suitable for storage or utilization.

CONCLUSION

This research demonstrates that pinch assessment techniques significantly boost carbon capture efficiency in coal-fired power plants . By optimizing heat integration and heat exchange networks (HEN), power plants can mitigate energy penalties and enhance sustainability. Two retrofit scenarios showed optimized heat integration reduces energy penalty by 5.3% and cooling water consumption by 55%, enabling cleaner, more energy-efficient power generation with carbon capture. HEN optimization facilitates improved energy efficiency, reducing energy penalties and boosting plant performance. This contributes to greenhouse gas emission reductions and climate goals. The substantial 55% cut in cooling water consumption highlights resource savings. By minimizing energy penalties, coal-fired power plants can ensure reliable energy supply while reducing environmental impact, The application of pinch analysis offers a pathway to greener energy production, aligning with global efforts to mitigate climate change. This research underscores the importance of heat integration and HEN optimization in improving energy efficiency and environmental performance of coal-fired power plants with post-combustion carbon capture. Overall, pinch assessment techniques present a promising opportunity for boosting carbon capture efficiency, supporting sustainable energy production, and reducing environmental footprints. By adopting these approaches, coal-fired power plants can play a vital role in a cleaner energy future.

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