इंजीनियर्स इंडिया लिमिटेड
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Delivering Excellence through People

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I would like to extend my heartfelt gratitude to Engineers India Limited (EIL) for providing me with the opportunity to intern in the field of process design. This internship has been an incredible learning experience, allowing me to work extensively with advanced simulation tools such as Aspen Plus, Aspen Plus Dynamics, and Aspen HYSYS.

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I am especially thankful to Mr. Nitin Chautre and Mr. Balaji Lakavath for their invaluable guidance and support throughout this internship. Their expertise and mentorship have significantly contributed to my professional growth and understanding of process design.

Sudhakar Verma

Steady State and Dynamic Control of Post Combustion CO_2 Capture Process Using Monoethanolamine

Contents

Keywords

- Chemical Absorption
- Desorber
- Post-Combustion
- Modeling
- MEA

Abstract

In this work, dynamic modeling was used to examine plant wide control of an absorption/stripping CO_2 capture process employing mono-ethanol-amine. In this system, the re-boiler duty in the stripper determines the CO_2 removal ratio, which is impacted by operating variables such lean solvent loading and rate. Furthermore, we discovered that maintaining the water balance is essential to achieving the system's long-term stability. As a result, the following control scheme was suggested. With this system, the lean solvent flow rate to the top of the absorber column ensures the CO_2 removal aim. By employing makeup water to regulate the liquid level in the stripping column's re-boiler, the overall water inventory was kept under check. The re-boiler duty regulates the temperature at the bottom of the stripper to ensure that the process is operating with the proper lean solvent loading. Disturbances in CO_2 concentrations and incoming flue gas flow tested this control structure. Dynamic simulations demonstrated the system's ability to meet removal goals, stabilize fast, and maintain consistent optimal lean loading. The re-boiler temperature set point can be adjusted to optimize control and guarantee minimum energy consumption.

The process of chemical absorption has been thoroughly investigated as a primary method for capturing and separating carbon dioxide. The two steps of this process are the absorption of CO_2 into the solvent and the desorption, which produces the highly concentrated CO_2 gas and regenerates the solvent.

The chemical absorption process must be scaled up with the help of proven simulation models, which are usually validated using data from a single pilot plant. In this study, four experimental pilot campaigns employing 30 weight percent MEA were used to validate a simulation model of the desorption column created in ASPEN PLUS v8.6. The diameters, structured packing heights, and packing kinds of the desorbers differed among the campaigns.

References

[1] "Systematic study of aqueous monoethanolamine-based CO_2 capture process: model development and process improvement" Kangkang Li1[2], Ashleigh Cousins[3], Hai Yu[1], Paul Feron[1], Moses Tade[2], Weiliang Luo[4] & Jian Chen[4]

[2] "ASPEN PLUS simulation model for CO_2 removal with MEA: Validation of desorption model with experimental data" Monica Garcia[a] , Hanna K. Knuutila[b], Sai Gua[a]

Introduction

One well-known method that has been suggested as the most important technology for CO_2 capture in power plants before 2030 is chemical absorption. Similar to the desulfurization process, the CO_2 collection via chemical absorption requires modifications to both the method and the solvent in order to be economically viable.

Absorption and desorption are the two stages of the chemical absorption process. Power plant flue gas is piped to a desorber column for regeneration after entering a packed column and coming into contact with a solvent that absorbs CO_2. Heat is used to reverse the solvent - CO_2 reaction, releasing gaseous CO_2 and water vapor. The gases are directed toward a condenser, which produces gas that is rich in CO_2. The solvent is regenerated and sent back into the absorber with a reduced CO_2 concentration. An important component of regeneration optimization is energy investment.

Anthropogenic carbon emissions have been identified as a major contributor to global warming and climate change during the last several decades. Thus, the collection, sequestration, and use of carbon dioxide has emerged as a new area of study for chemical process technology. The primary source of CO_2 emissions is the flue gas from coal-fired power plants. The absorption/stripping CO_2 capture system is regarded as the most practical way to handle flue gas from power plants among a variety of separation technologies. The absorption/stripping method offers reduced energy usage and higher capture efficiency as compared to other capture techniques. The typical absorption/stripping procedure primarily consists of two columns and a heat exchanger.

Flue gas from power plants that contains CO_2 is transported to the bottom of a packed absorber where it comes into contact with a lean solvent. 30% MEA is a common absorbent used in the absorption/stripping process.
The treated gas is released into the atmosphere via the absorber's top.
Rich solvent is transferred to a stripper with a re-boiler after absorbing to replicate MEA solvent.
The stripper's hot lean solvent is recovered and repurposed after cooling via a heat exchanger and cooler.

References

[2] "ASPEN PLUS simulation model for CO_2 removal with MEA: Validation of desorption model with experimental data" Monica Garcia[a] , Hanna K. Knuutila[b], Sai Gua[a]

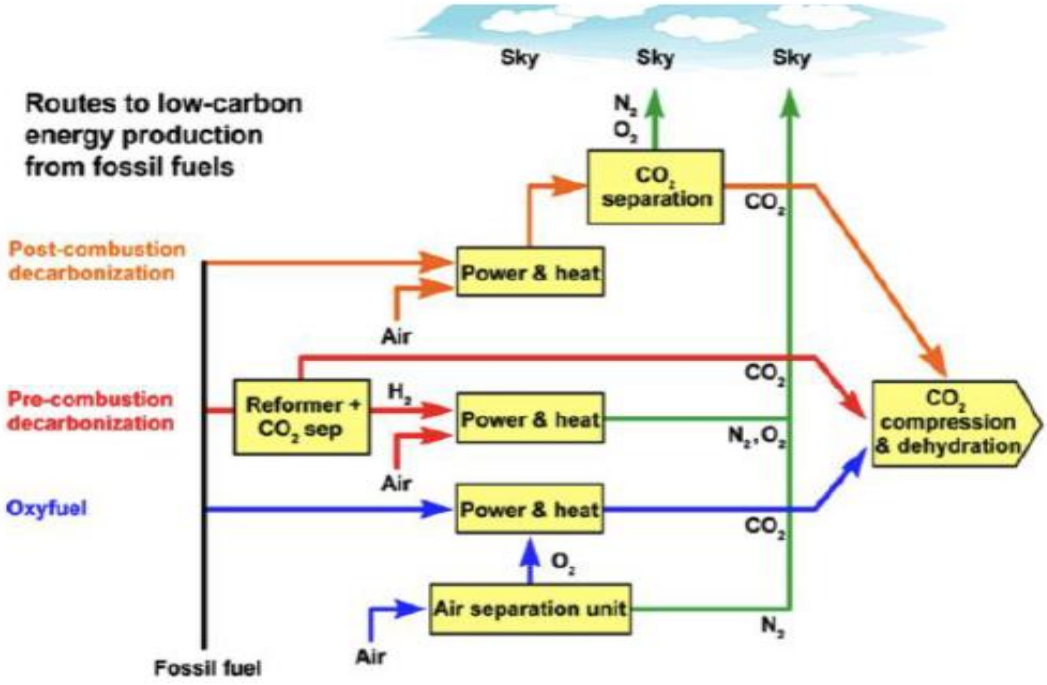
CCS Technologies -

CCS technologies can be broadly classified into three types:

- Pre-combustion capture involves reforming and gasification of fossil fuels to produce syngas, a mixture of hydrogen and carbon monoxide. The CO_2 is then captured from the syngas, leaving a high-hydrogen gas stream that can be used in integrated gasification combined cycle (IGCC) power plants. This technology is not yet widely deployed due to its high cost.

- Oxy-combustion involves combusting fossil fuels in pure oxygen instead of air. This produces a highly concentrated CO_2 exhaust stream that can be easily captured and stored. However, this technology is also expensive due to the need for a continuous oxygen supply.

- Post-combustion capture involves removing CO_2 from the exhaust gas of conventional fossil fuel combustion processes. The CO_2 is typically diluted in the exhaust gas, so specialized separation processes are required. Various post-combustion capture technologies are available, including adsorption, physical absorption, cryogenic separation, membrane absorption, and algal systems. Chemical absorption is the most widely used post-combustion capture technology due to its Srelative simplicity and ease of integration with existing power plants.



CO_2 Capture And Sequestration

Given its established maturity and promising potential for industrial application, this thesis explores the fundamentals of CO_2 post-combustion capture through chemical absorption, a technology poised to play a pivotal role in mitigating greenhouse gas emissions.

This thesis presents the implementation of a CO_2 post-combustion capture process model using reactive absorption-stripping in Aspen Plus. Also, a Comprehensive CO_2 capture system model was developed in Aspen Plus Dynamics to investigate the dynamic behaviour of the absorption process using MEA solution. Three key factors influencing CO_2 removal efficiency, energy consumption, and long-term stability were identified: lean solvent flow rate, lean solvent loading, and water replenishment in the balance system. These factors served as guiding principles for the dynamic modelling of the CO_2 capture system.

Even though CCS is not a new technology, it has several issues to implement before introduction into the industrial flue gas treating processes. The main problem arises from the cost involving CO_2 capture. According to the carbon trading and cost involving with the capturing process, it is costlier to capture and transport the CO_2 compared to releasing it in the atmosphere. Chemical absorption is the most preferred and widely applicable method for the separation of CO_2. The post-combustion chemical absorption process is briefly described in the following section. In chemical absorption process, CO_2 is separated from the flue gas by a continuous scrubbing system. The flue gas stream which has reduced the temperature is sent to the absorption column. Flue gas is entering in the bottom of the absorption column while the solvent is enteringat the top to counter currently react each other. The chemically bound CO_2, then separated by high-temperature steam and pure CO_2 stream is collected for compression section. The main objectives behind the project are to reduce the re-boiler energy demand in the stripping section which is caused by the high operating cost of the CCS project

References

[3] "Modelling Of CO_2 Capture Using Aspen Plus For Coal Fired Power Plant" Udara. S. P. R. Arachchige, Kohilan Rasenthiran, M.P.P. Liyanage

[4] C. Madeddu, M. Errico, and R. Baratti, ―SPRINGER BRIEFS IN ENERGY CO2 Capture by Reactive Absorption-Stripping Modeling, Analysis and Design

Process Description –

CO_2 post-combustion capture utilizing amine-based aqueous solutions employs a reactive absorption-solvent regeneration process. The plant consists of two primary units: the absorber, where carbon dioxide is transferred from the vapor/gas phase to the liquid phase, and the stripper, where the solvent is regenerated. The absorption process is enhanced by the reaction between the CO_2 transferred to the liquid phase and the solvent. Conversely, the reverse reaction occurs in the stripper, detaching the amine from the CO_2, which is then transferred back to the gaseous phase. The two units are interconnected by a cross-flow heat exchanger. For a simplified visualization of the system, refer to Figure.1

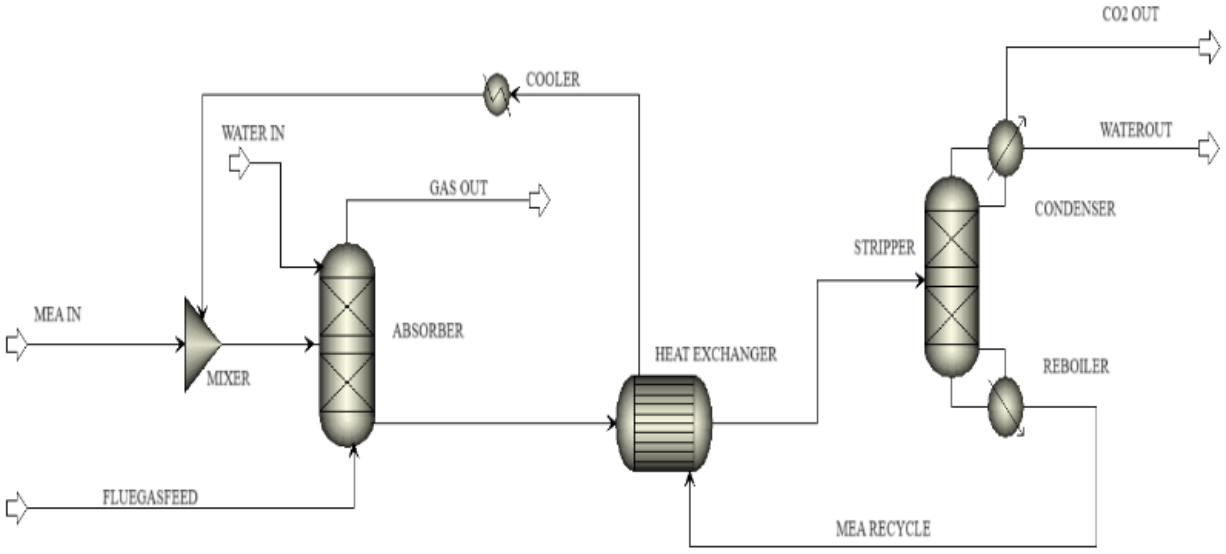


Figure 1. Process flowsheet of the absorption/stripping CO_2 capture process

The dry flue gas stream, composed of CO_2, O_2, N_2, water, and argon, is introduced into the absorber column for CO_2 removal. The absorber column, packed with structured packing to enhance gas-liquid contact, is modelled with 30 stages to effectively capture CO_2 from the flue gas. The flue gas enters the column at the bottom stage, allowing it to counter-currently flow against the lean MEA solvent, which is introduced at the sixth stage. This counter-current flow facilitates efficient CO_2 absorption. Water is injected at the top stage to scrub MEA from the gas stream, minimizing solvent loss and ensuring clean gas exits the absorber's top. The rich solvent, now loaded with CO_2, exits the bottom of the absorber and is directed to the stripper for regeneration.

Reference

[4] C. Madeddu, M. Errico, and R. Baratti, ―SPRINGER BRIEFS IN ENERGY CO2 Capture by Reactive Absorption-Stripping Modeling, Analysis and Design.

Literature Review

Carbon capture and storage (CCS) technologies are critical for mitigating the impact of CO_2 emissions from industrial processes and power plants. Among various CCS methods, post-combustion carbon capture using chemical solvents like mono-ethanolamine (MEA) is widely studied and implemented due to its effectiveness and compatibility with existing infrastructure. This literature review focuses on the dynamic study and advanced process control of post-combustion carbon capture systems using MEA, highlighting the use of dynamic simulations, system identification, and various control strategies.

Stable and dynamic simulations have been conducted using various process simulation tools, such as ASPEN HYSYS, ASPEN PLUS, gPROMS, ASPEN, Custom Modeler, liean with Tsweet, and Protreat. These simulation models are often modified to match experimental data, and model predictions are highly impacted by decisions made about the equilibrium model, mass transfer coefficients, and kinetic parameters. It is crucial to use data from multiple pilot plants to validate the simulation model.

ASPEN PLUS is a widely used program that has been assessed in numerous studies. Zhang and Chen validated their model in a single pilot plant operating under various conditions, while Li et al. obtained smaller errors in temperature and loading prediction than the basic model. Oi & Pedersen employed ASPEN HYSYS to confirm a reduction in heat consumption by modifications to the absorption process configuration.

Numerous references have used ASPEN PLUS to mimic the dynamic response in pilot plants for carbon capture, using ASPEN Custom Modeller and the ENRTL framework for validation. However, some research has noted overestimations regarding loading and steady state outcomes.

Several referneces have represented the absorption/desorption process using gProms, but there is some under-prediction and over-prediction of temperature and loading at the top and bottom of the desorber. Mac Dowell et al. and Mac Dowell & Shah employed a more sophisticated combination of software to predict parameters using a single pilot plant.

Reference

[2] "ASPEN PLUS simulation model for CO_2 removal with MEA: Validation of desorption model with experimental data" Monica Garcia[a] , Hanna K. Knuutila[b], Sai Gua[a]

Steady-State and Dynamic Simulation in Carbon Capture –

Steady-state simulation of carbon capture processes provides a baseline for understanding the system's behavior under constant conditions. Aspen Plus to perform steady-state simulations, establishing a foundation for subsequent dynamic analyses. Transitioning from steady state to dynamic simulations is essential to capture the transient behaviors and control dynamics of the system. Aspen Dynamics is commonly used for this purpose, allowing for the exploration of the system's response to changes in operating conditions over time .

In addition, provide an in-depth analysis of reactive absorption-stripping modelling, which is crucial for understanding the detailed mechanisms involved in CO_2 capture using MEA. Their work emphasizes the importance of integrating dynamic modelling techniques to accurately predict system performance under various operating conditions.

System Identification in Carbon Capture Processes –

System identification involves developing mathematical models based on empirical data, which is crucial for designing effective control systems. (10) highlighted the importance of MATLAB's System Identification Toolbox in deriving accurate models for complex processes like carbon capture. This approach is reinforced by(6), who applied data-driven models to predict the behavior of MEA absorption systems. The identification of dynamic models helps in understanding the process's inherent delays and interactions, which are vital for controller design. (11) in his textbook "Process Systems Analysis and Control" provides foundational knowledge on system dynamics and control strategies, which are essential for effective system identification. His work offers valuable insights into the theoretical underpinnings that support the practical applications in carbon capture processes.

Reference

[4] C. Madeddu, M. Errico, and R. Baratti, ―SPRINGER BRIEFS IN ENERGY CO2 Capture by Reactive Absorption-Stripping Modeling, Analysis and Design.

Building the Model in Aspen Plus

Aspen Plus is a leading steady-state process modelling and simulation software package widely utilized in the field of process engineering. Its versatility and comprehensive capabilities make it a preferred choice for both academic and industrial applications. Aspen Plus enables the modelling of a diverse spectrum of processes, encompassing classic distillation columns, various types of reactors, and the auxiliary equipment typically found in chemical plants, such as valves, pumps, compressors, mixers, and pipelines. Additionally, Aspen Plus can be seamlessly integrated with Aspen Properties, providing access to an extensive database of physical properties. This integration empowers users to conduct highly accurate simulations, making Aspen Plus an invaluable tool for process design, optimization, and troubleshooting.

As elaborated upon in the preceding section, CO_2 post-combustion capture employing amine-based aqueous solutions entails a reactive absorption-stripping process. Within Aspen Plus, this type of process is typically modelled utilizing the RadFrac unit operation, which enables the modelling of absorbers and strippers incorporating chemical reactions. The subsequent sections provide a comprehensive examination of the model's.

- Components and thermodynamics
- Chemical reactions
- Material and energy balances
- Interphase transfer
- Fluid dynamics

Properties Environment –

The first step in building an Aspen Plus model is to define the system's components and their thermodynamic properties. This is done in the Aspen Properties environment.

Components –

The process involves two distinct phases: a gas phase and a liquid phase. The gas
phase consists of nitrogen, oxygen, water vapor, and CO_2, some other components such as Argon can be present as impurities in the flue gas. The liquid phase is characterized by a complex reaction between CO_2, H_2O, and amine molecules, resulting in the formation of ions through ionic dissociation. MEA was selected as the target solvent for this investigation owing to its extensive study and established maturity for this process.

Within the Components-Specifications panel, Aspen Properties identifies the potential presence of ionic species and prompts the user to select the appropriate approach for their treatment:

- **Apparent components:** This approach assumes that all components in the liquid phase remain un-dissociated.
- **True components:** This approach accounts for the dissociation of components into free and dissociated forms in the liquid phase.

To describe the system more accurately, the true components approach was used to build the model. When this option is turned on, Aspen Properties automatically generates all the necessary components, including the ions, as shown in Figure.2

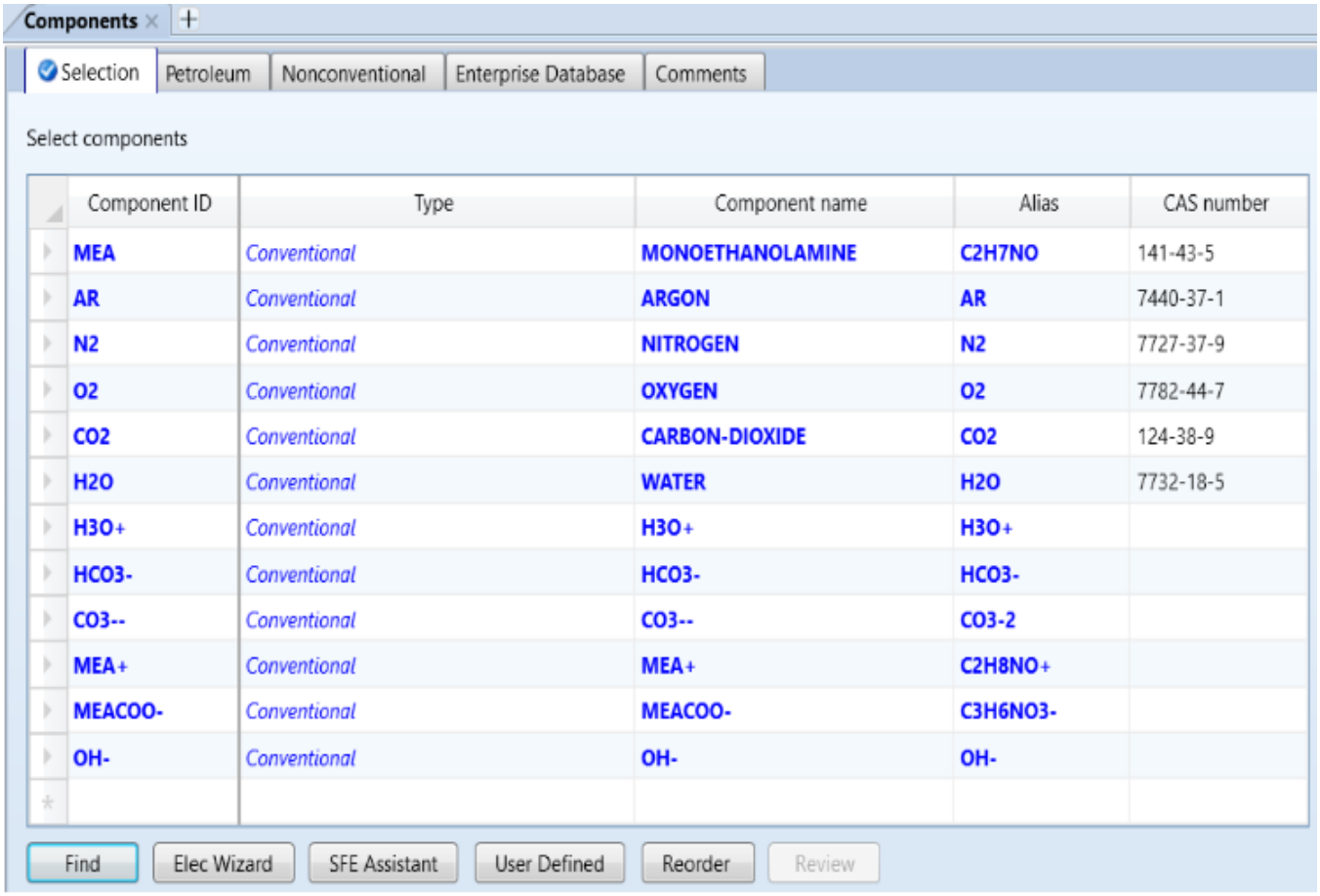


Figure 2 List of components in the Aspen Properties® —Components—Specifications panel

The software employs a set of ionic equilibrium reactions and salts dissociation reactions to determine the compositions of the various streams involved in the process. The user has the option to select the reactions to be used. The salts dissociation reactions are assumed to be insignificant, leaving a set of five chemical equilibrium reactions to be considered. These ionic equilibrium reactions are summarized in Figure.3

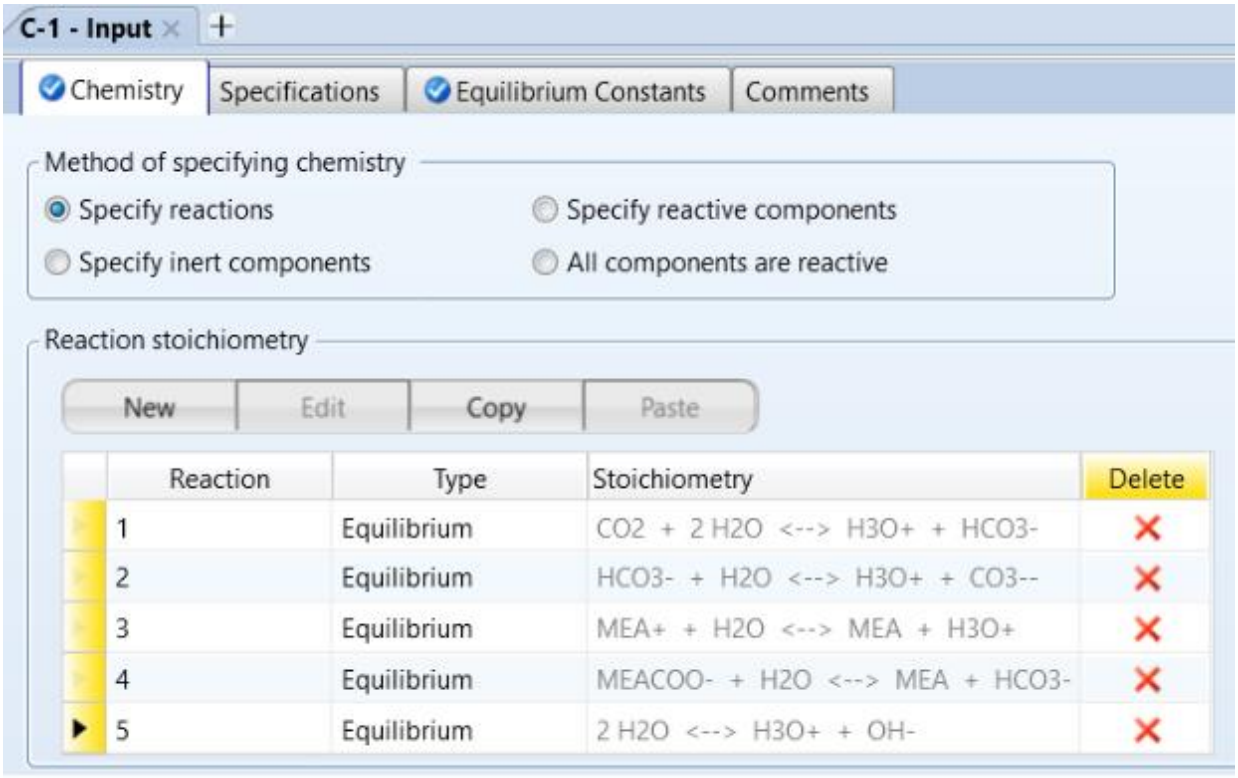


Figure 3 Equilibrium reactions for the CO2-MEA-H2O system

Thermodynamics –

Following the definition of the components, the model for evaluating the thermodynamic properties can be specified. This model must be capable of accounting for the strong non-ideality of the liquid phase due to the presence of ions. Numerous studies in the literature indicate that the Electrolyte Non-Random Two Liquid model is the most suitable for describing the electrolytic interactions in the CO_2-MEA-H_2O system. Therefore, the Elec-NRTL model was employed to evaluate the thermodynamic properties in the liquid phase. Aspen Properties automatically retrieves all the parameters from the database once the thermodynamic model is specified. However, there is also the option to modify the parameter values, which may be necessary in certain situations.

Reference

[4] C. Madeddu, M. Errico, and R. Baratti, ―SPRINGER BRIEFS IN ENERGY CO2 Capture by Reactive Absorption-Stripping Modeling, Analysis and Design.

Simulation Environment –

In the Simulation environment, users can define the equipment and streams involved in the process. Additionally, all parameters required for model development are specified in this section. Aspen Plus utilizes a specific symbolic notation to represent streams and equipment in the Main Flowsheet panel, providing a clear visual representation of the process. Figure 4 illustrates a typical CO_2 post-combustion capture by reactive absorption-stripping plant in the Aspen Plus flows.

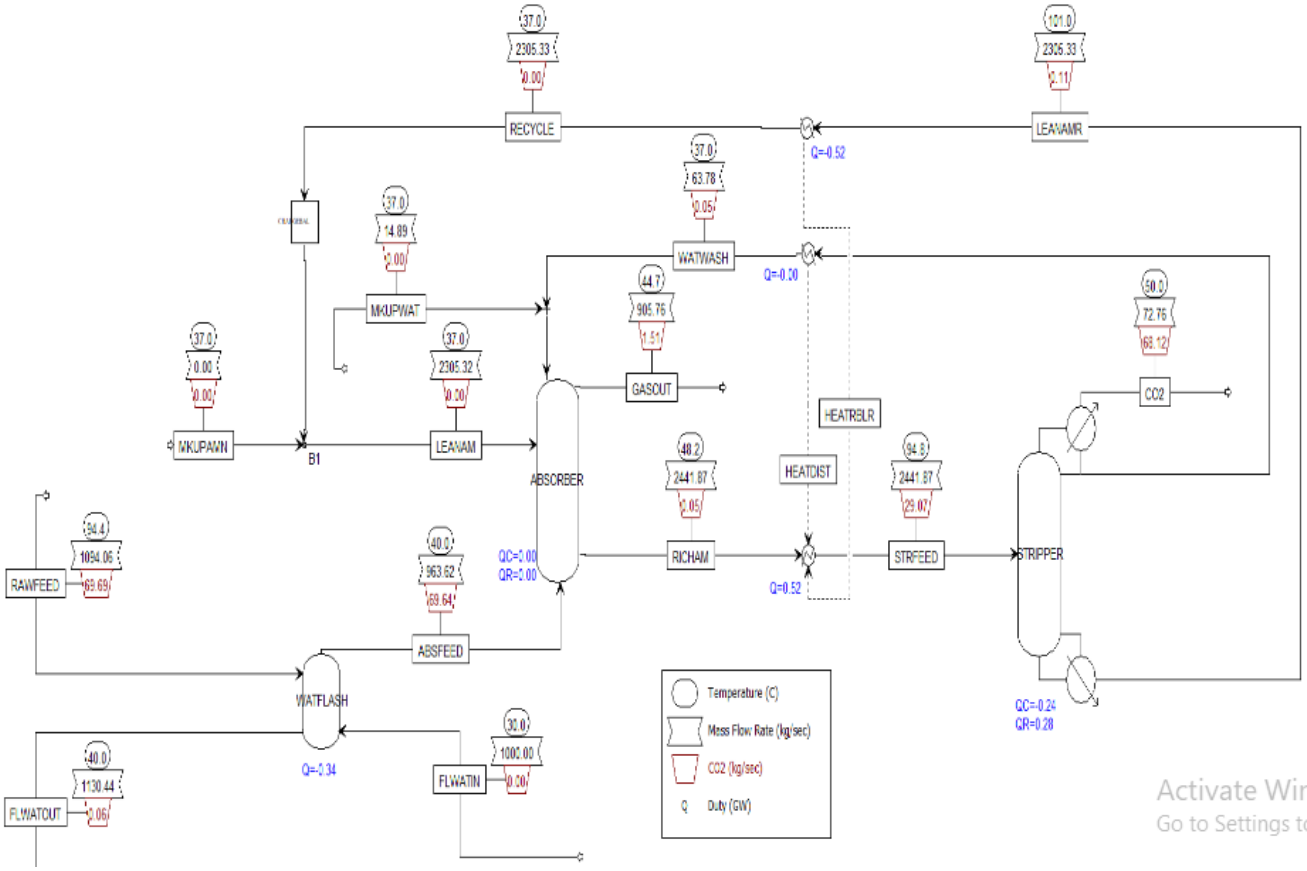


Figure 4 Aspen Plus process flowsheet for the CO_2 reactive absorption-stripping

As evident in Figure 4, each piece of equipment is represented by blocks connected by arrows representing the streams. Upon completing the flowsheet, users must provide specific stream characterization and equipment feature details to eliminate all degrees of freedom and simulate the plant. Additionally, all chemical reactions within the system must be defined in the Reactions panel. As mentioned in Section 2, the RadFrac model in Aspen Plus is specifically designed for modelling reactive absorption stripping processes. The following subsections outline the model setup process

Streams Characterization –

Streams are characterized by various parameters. The user must provide two values among temperature, pressure, and vapor fraction. Additionally, the flow rate must be specified in terms of volume, mass, or moles. Component compositions can be expressed in different forms, such as flow rate, molar fraction, mass fraction, or concentration. For CO_2 post-combustion capture with amine aqueous solutions, the gaseous phase is straightforward. However, the presence of ions in the liquid phase presents two options for the user:

- Specify only the apparent composition of the main components (CO_2, MEA, and H_2O). In this case, Aspen Plus determines the ion compositions by solving a system of equations that incorporates the equilibrium reactions defined in the Properties environment, the relationships between apparent and actual compositions, and the electro-neutrality equation.
- Specify the actual composition of each component, including both free and ionic forms. This approach immediately defines the stream composition.

Chemical Reactions :- The reactive nature of the CO_2 post-combustion capture process necessitates defining a proper set of reactions in the reactions panel. As documented in numerous studies, both kinetic and equilibrium reactions are involved. Specifically, a set of three ionic equilibrium reactions and two kinetic reversible reactions involving CO_2 was considered.

$$2H_2O \Leftrightarrow H_3O^+ + OH^-$$

$$MEA^+ + H_2O \Leftrightarrow H_3O^+ + MEA$$

$$HCO_3^- + H2O \Leftrightarrow H_3O^+ + CO_3^{2-}$$

$$CO_2 + MEA + H_2O \Leftrightarrow MEACOO^- + H_3O^+$$

$$CO_2 + OH^- \Leftrightarrow HCO_3^-$$

For what concerns the equilibrium reactions, for the determination of the equilibrium constants as a function of temperature, Aspen Plus offers two methods:

- Standard Gibbs free-energy change
- Parameter-based correlation

The Aspen Plus RadFrac mode :- Subsequent to defining the stream of the characteristics and reactions, the next step involves outlining the processes within the columns. The initial decision pertains to the degree of model approximation. As emphasized in previous sections, the process is intricate and encompasses multiple phenomena. To accurately represent the system's behaviour, a model capable of concurrently describing non-ideal thermodynamics, chemical reactions, interphase transfer, component transport in both phases, and fluid dynamics is necessary. Thermodynamics and reactions were discussed in above section. This section focuses on modelling interphase transfer and component transport in both phases in the presence of chemical reactions. The RadFrac model offers two approaches: the equilibrium stages mode and the rate-based mode. In both cases, the column height is discretized into distinct sections, termed stages in Aspen Plus, although they should be referred to as segments for the rate-based mode.

Equilibrium Stages Mode :- The equilibrium stages approach imagines the liquid and gas phase hanging out together long enough for their properties to become identical, like best friends sharing a secret. But in the real world of CO_2 absorption-stripping, things are more complicated. Material transfer and chemical reactions are happening at the same time, making it hard for the liquid and gas phases to reach perfect harmony. Despite this challenge, the equilibrium stages approach can still be used if we introduce the murphree efficiency, which is like a measure of how close the liquid and gas phases get to being best friends. Studies have shown that the murphree efficiency for CO_2 reactive absorption is usually around 0.2, which means the liquid and gas phases are pretty good at sharing secrets, but not perfect**.**

Rate-Based Mode :- The low murphree efficiency values indicate a substantial departure from the phase equilibrium condition. Therefore, the rate-based approach is the favoured method for modelling CO_2 reactive absorption-stripping with MEA. This approach effectively accounts for the limitations imposed on mass transfer by the presence of chemical reactions. While rate-based mode offers greater efficiency, equilibrium stages mode is employed in this study due to Aspen Dynamics current limitations to equilibrium based mode.

Reference

[4] C. Madeddu, M. Errico, and R. Baratti, ―SPRINGER BRIEFS IN ENERGY CO2 Capture by Reactive Absorption-Stripping Modeling, Analysis and Design.

Steady State Simulation Conditions –

Flue gas condition

Property		Value
Mole fraction	Ar	0.0089
	N2	0.7582
	O2	0.1124
	CO2	0.0469
	H2O	0.0736

Inlet gas flow rate kg/s	963.62
Temperature °C	40
Pressure atm	1

Absorber/stripper parameters

Property	Absorber	Stripper
Pressure atm	1	1
No. of stages	30	5
Packing type	Mellapak	
Packing height	40	35
Column diameter	24.5	12.5

Steady state simulation to dynamic state simulation –

Converting the steady-state simulation to a dynamic one necessitates specifying the physical dimensions of the various equipment pieces. The absorption column sump shares the same diameter (24.5m) as the column and has an entering liquid flow rate of 153.7m^3/min. To provide a 5 minute holdup at a 50% level, a base height of 3.261m and a diameter of 24.5m are required. The stripping column sump measures 12.477m in height and 12.5m in diameter to accommodate an inlet liquid flow rate of 144.3m^3/min. The dimensions of the knockout drum, condenser, and heat exchanger, all designed to provide a 5 minute holdup at a 50% level.

Validation in Aspen Plus Dynamics

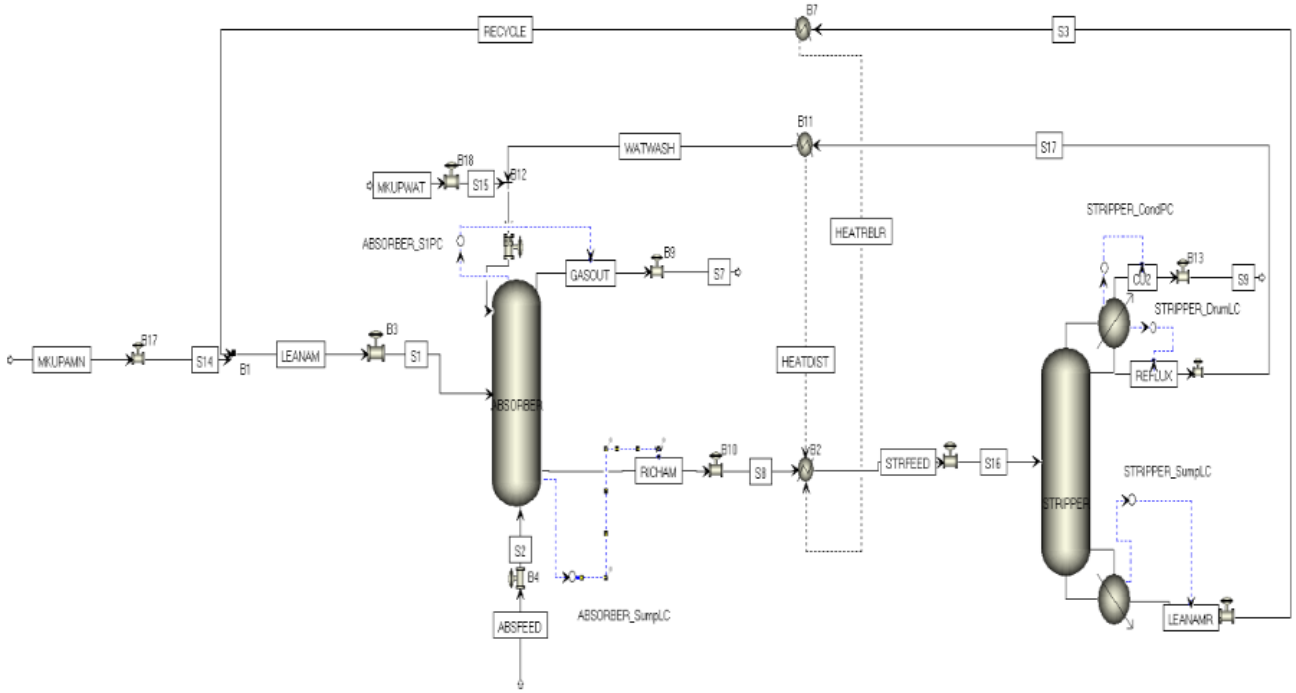


Figure 5 Aspen Dynamics process flowsheet for the flow driven control

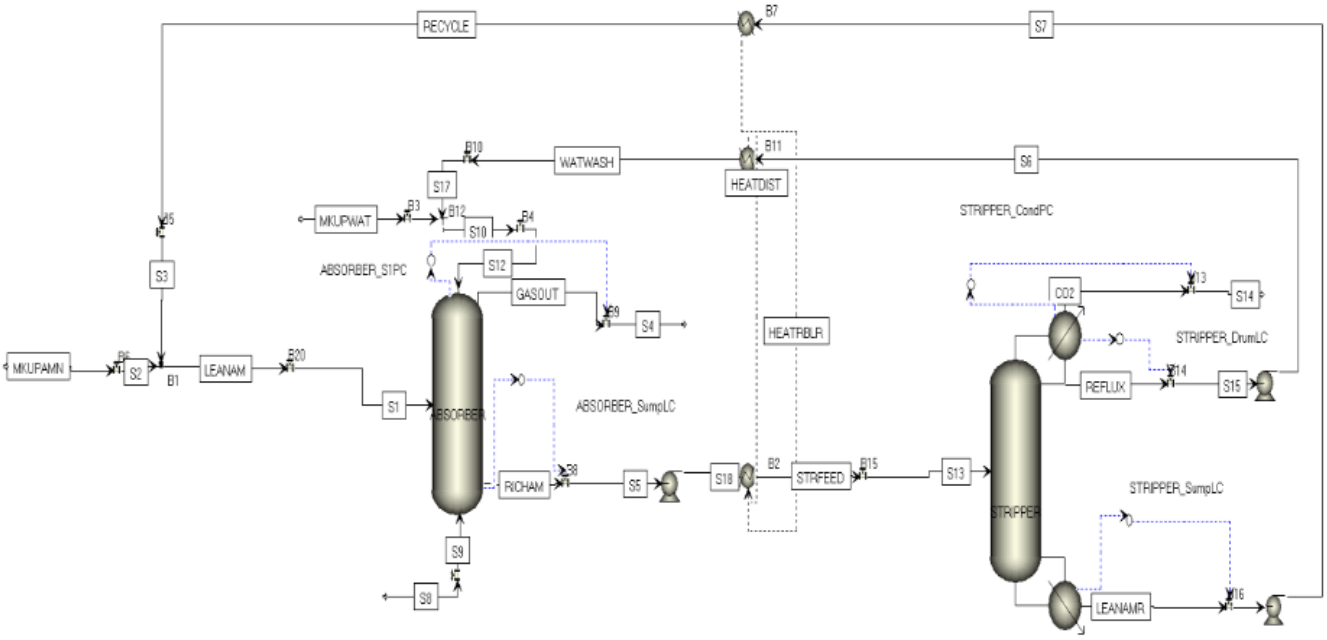


Figure 6 Aspen Dynamics process flowsheet for the Pressure driven control

Stability Controllers –

Upon exporting the file to Aspen Dynamics, five stabilizing controllers are introduced:

- Absorber sump level controller
- Absorber pressure controller
- Stripper condenser pressure controller
- Stripper sump level controller
- Stripper drum level controller

Absorber sump level controller :- The absorber sump level controller maintains the liquid level in the absorber sump at a set point. This is important because the liquid level in the sump affects the efficiency of absorption. If the liquid level is too low, the gas will not be able to properly contact the liquid, and the absorption efficiency will be low. If the liquid level is too high, the gas will not be able to flow through the liquid properly, and the absorption efficiency will also be low.

Absorber pressure controller :- The absorber pressure controller maintains the pressure in the absorber at a set point. This is important because the pressure in the absorber affects the solubility of the gas in the liquid. If the pressure is too low, the gas will be less soluble in the liquid, and the absorption efficiency will be low. If the pressure is too high, the gas will be more soluble in the liquid, and the absorption efficiency will be high. However, if the pressure is too high, the gas will also be more likely to condense, which can lead to flooding of the absorber and further reduce the absorption efficiency.

Stripper condenser pressure controller :- The stripper condenser pressure controller maintains the pressure in the stripper condenser at a set point. This is important because the pressure in the stripper condenser affects the condensation of the vapor from the stripper. If the pressure is too high, the vapor will not condense properly, and the stripping efficiency will be low. If the pressure is too low, the vapor will condense too easily, and the stripping efficiency will also be low.

Stripper sump level controller :- The stripper sump level controller maintains the liquid level in the stripper sump at a set point. This is important because the liquid level in the sump affects the efficiency of stripping. If the liquid level is too low, the liquid will not be able to properly contact the vapor, and the stripping efficiency will be low. If the liquid level is too high, the vapor will 24 not be able to flow through the liquid properly, and the stripping efficiency will also be low.

Stripper drum level controller :- The stripper drum level controller maintains the liquid level in the stripper drum at a set point. This is important because the liquid level in the drum affects the residence time of the liquid in the stripper. If the liquid level is too low, the liquid will flow through the stripper too quickly, and the stripping efficiency will be low. If the liquid level is too high, the liquid will flow through the stripper too slowly, and the stripping efficiency will also be low.

Parameters for Controllers –

S. No	Controller	Action (Direct/Reverse)	Parameter
1.	Absorber sump level controller	Direct	$K_p = 10$ $T_I = 60$ $T_D = 0$
2.	Absorber pressure controller	Direct	$K_p = 20$ $T_I = 12$ $T_D = 0$
3.	Stripper condenser pressure controller	Direct	$K_p = 20$ $T_I = 12$ $T_D = 0$
4.	Stripper sump level controller	Direct	$K_p = 10$ $T_I = 60$ $T_D = 0$
5.	Stripper drum level controller	Direct	$K_p = 10$ $T_I = 60$ $T_D = 0$

Reference

[4] C. Madeddu, M. Errico, and R. Baratti, ―SPRINGER BRIEFS IN ENERGY CO2 Capture by Reactive Absorption-Stripping Modeling, Analysis and Design.

Results

Steady State Simulation Stream Results –

The stream results obtained from the steady-state simulation are given in Figure 7. Since CO_2 removal is the primary objective of this process, we can clearly see from Figure 7 that over 90% of CO_2 is separated from the flue gas.

	Units	ABSFEED	CO2	FLWATIN	FLWATOUT	GASOUT	LEANAM	LEANAMR	MKUPAMN	MKUPWAT	RAWFEED
Mass Density	kg/cum	1.11336	1.54092	995.761	991.1	1.06111	996.517	958.796	1511.25	993.422	0.887336
Enthalpy Flow	GW	-1.20772	-0.660811	-15.8449	-17.8479	-0.741192	-29.3777	-28.8618	-1.25634e-09	-0.235552	-2.87288
Average MW		28.5831	40.6741	18.0153	18.0232	27.6559	23.3723	23.3717	61.0837	18.0153	26.7326
+ Mole Flows	**kmol/sec**	**33.713**	**1.78882**	**55.5084**	**62.7218**	**32.7509**	**98.6349**	**98.6376**	**4.63656e-09**	**0.826716**	**40.9263**
+ Mole Fractions											
− Mass Flows	**kg/sec**	**963.621**	**72.7585**	**1000**	**1130.44**	**905.756**	**2305.32**	**2305.33**	**2.83218e-07**	**14.8935**	**1094.06**
MEA	kg/sec	0	7.28304e-11	0	0	2.83146e-07	218.306	223.418	2.83218e-07	0	0
AR	kg/sec	12.0584	0.0542842	0	0.0842103	12.0041	4.80169e-09	4.80167e-09	0	0	12.1426
N2	kg/sec	716.073	0.00942203	0	0.013182	716.063	0	1.32958e-18	0	0	716.086
O2	kg/sec	121.168	0.601471	0	0.935454	120.566	7.4843e-08	7.48428e-08	0	0	122.103
CO2	kg/sec	69.6352	68.122	0	0.0560384	1.51337	0.000468521	0.110144	0	0	69.6925
H2O	kg/sec	44.6869	3.97137	1000	1129.35	55.6091	1607.21	1606.68	0	14.8935	174.041
H3O+	kg/sec	0	0	0	0.000513737	0	1.56115e-08	4.64044e-07	0	0	0
HCO3-	kg/sec	0	0	0	0.00164787	0	2.96059	7.76294	0	0	0
CO3--	kg/sec	0	0	0	4.11874e-09	0	3.63346	0.697364	0	0	0
MEA+	kg/sec	0	0	0	0	0	183.409	180.216	0	0	0
MEACOO-	kg/sec	0	0	0	0	0	289.802	286.443	0	0	0

Figure 7 Stream results from Aspen Plus

Dynamic State Simulation Results –

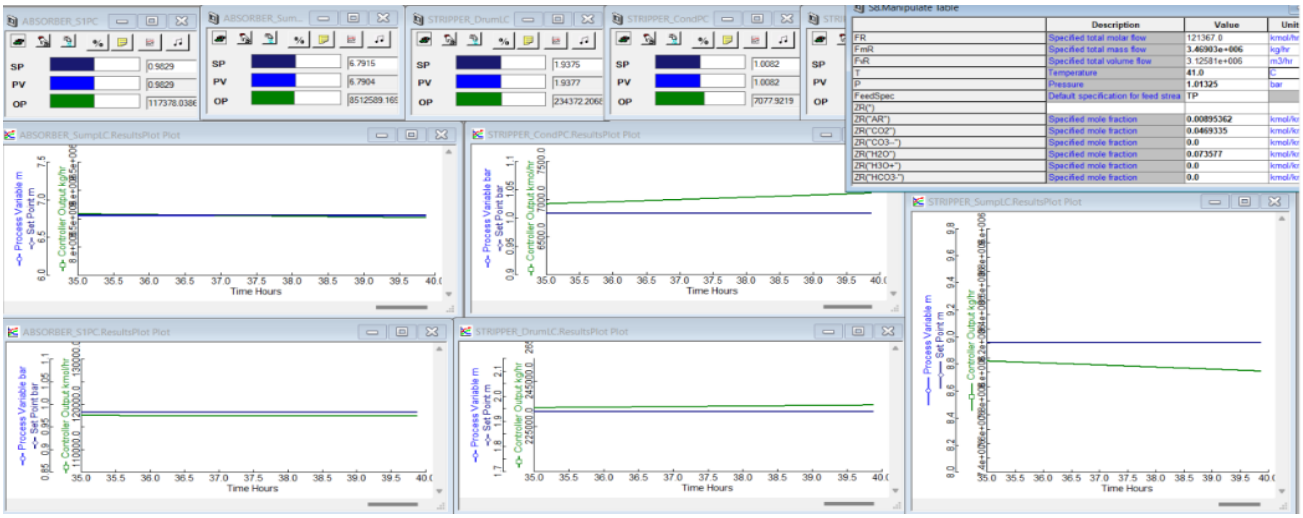


Figure 8 Stabilizing Controllers and their Response to step change

Conclusion

- **Dynamic Simulation Insights:** The study demonstrated the effectiveness of using Aspen Plus for dynamic simulation, providing valuable insights into the transient behavior of CO_2 capture processes with MEA.
- **Process Efficiency:** Results highlighted the capability of MEA to efficiently absorb CO_2 under varying operational conditions, emphasizing its suitability for large-scale applications.
- **Optimization Potential:** The dynamic analysis revealed critical parameters influencing system performance, suggesting avenues for optimizing MEA usage and minimizing energy consumption.
- **Control Strategies:** The study underscored the importance of robust control strategies to handle disturbances and maintain system stability, ensuring continuous and efficient CO_2 capture.
- **Future Applications:** The findings support further research into integrating advanced process control techniques and exploring alternative solvents for enhanced CO_2 capture efficiency.