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Original Article

Mechanical Design of an Industrial Absorber and Regenerator in a Triethylene Glycol Dehydration Plant

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Abstract - *Nigeria is ranked sixth in natural gas reserves, making natural gas locally content-driven and a catalyst for development and industrialization because of its importance as a starting feed material for petrochemical production and a clean energy source used domestically and industrially. However, this natural gas comes with some deposits of impurities like water, which can cause hydrate formation, blockages, corrosion and other flow problems during pipeline processing and transmission. To meet the specification for pipeline transmission, the triethylene glycol (TEG) dehydration method, regarded as the most effective dehydration method, is recommended. The TEG dehydration plant is divided into two parts, the gas absorption and the glycol regeneration. To ensure the lifespan of the TEG dehydration plant, because of pressure, stress and corrosion involved during operation, the mechanical design aspect of the absorber and regenerator column was carried out using the results obtained from HYSYS simulation design such as operating temperature, pressure and column diameter of (35^{0}C, 60bar and 1.5m) and (204^{0}C, 15bar and 2m) of the absorber and regenerator respectively to give the most economical thickness of column body and head of (31mm and 30mm) and (15mm and 14mm) for the absorber and regenerator columns respectively using stainless steel type (304) as material for construction.*

Keywords - *Natural gas, Petrochemical, Absorber, Aspen HYSYS, Triethylene glycol.*

1. Introduction

Natural gas can be described as the springboard to the growth and development of a country because of its importance as a petrochemical feedstock and a clean source of energy used domestically and industrially [1]. It is one of the natural resources Nigeria is blessed with, making its local content driven [2,8]. However, the impurities associated with or deposited in natural gas, like water, possess problems like methane hydrate formation, cakes, sludge, corrosion and other flow assurance problems during processing and transmission. For pipeline transmission, the water content of natural gas must be less than 0.011kg H_2O/m^3s of NG [3,4]. The TEG dehydration method, regarded as the most effective and economical, is recommended to meet this specification. The TEG dehydration plant comprises several units (equipment) but can be divided into the gas absorption unit and the TEG regeneration unit [12,13].

Natural gas dehydration is crucial in gas treatment plants to minimize corrosion, freeze protection, and regulatory compliance [25]. Triethylene glycol (TEG) dehydration has become a popular method for achieving this aim because of its high water absorption capacity. A key component of the TEG dehydration process is the absorber and regenerator unit, which determines the efficacy of the entire operation. The mechanical design of these units forms a critical aspect of TEG dehydration plant operation. It involves selecting equipment and designing optimised components to ensure efficient gas and liquid flows, pressure drops, heat transfer, and overall operational functionality [26]. This paper focuses on the mechanical design of the absorber and regenerator units in a typical TEG gas dehydration plant. The aim is to describe the design process, from designing criteria and developing process simulation models to equipment layout and detailed mechanical drawings, and finally, implementing quality control procedures to ensure compliance with industry standards.

The mechanical design of an industrial absorber and regenerator of the TEG dehydration plant which considers the best material suitable for equipment design, the minimum thickness of equipment and corrosion allowance, the minimum allowable internal pressure of the system/unit, design stress factor and also account for a welded joint element of equipment or unit which was achieved using the results and data got from HYSYS simulation of the dehydration plant [6,7]. Considerable research has been carried out on the TEG dehydration plant, and a few of them are cited: Gu & Liu [9] stated that dehydration by using TEG is the most convenient and economical method of removing water associated with natural gas. The stress on the body of the absorption tower results from heating in the welding process on the welded metal, which can cause lag formation, porosity, and incomplete welding defects [10,14]. They also considered the pressure on the absorber using strength and rigidity calculations. Dagde &Akpa [5] included that a liquid desiccant absorber is the most common method for dehydration in the natural gas industry. They developed the mathematical models of an absorber using the principle of mass and energy balance to predict the effectiveness of dehydration in an industrial absorber. Khan et al. [11] stated that the last 35 years have seen tremendous growth in the contribution of natural gas to the world's total energy demand and that most countries depend on it for economic growth and development.

Wosu et al. (2023) present a design model for the regeneration of lean triethylene glycol (TEG) in natural gas dehydration plants. The model was developed from the first principles of mass and energy balance and employs a heat exchanger to heat the rich TEG before introducing it to the regenerator column. The lean TEG is recovered from the column bottom and recycled. The design was carried out using HYSYS software, and the resultant specifications of regenerator volume, height, diameter, and column area were obtained as 18.857m3, 6.000m, 2.000m, and 3.143m2, respectively. The study demonstrated that the natural gas feed conditions, including temperature, pressure, and flow rate, significantly influence the performance efficiency of the regenerator and other units of the TEG dehydration plant. The developed model shows potential for improving the efficiency of TEG dehydration plants. In their study, Gajduk et al. (2019) [23] proposed a design of an absorption unit that incorporates baffles to enhance the gas and liquid contact surfaces, improving the TEG's absorption efficiency. Their results showed that this design improved the performance of the absorption unit by increasing the absorption rate of water in natural gas from 0.22 to 0.45 mol/s. Enhancement of TEG dehydration efficiency was also achieved in a study by Jing et al. (2018) [22], who proposed an improved configuration for the regenerator unit comprising a novel distribution tray paired with a packing bed. The authors found that the proposed design could reduce the TEG consumption rate by 14.6% compared to the conventional regenerator design. Mahmoud et al. (2021) [21] presented a simulation-based optimization approach for the design of TEG-based dehydration systems. The proposed model was used to simulate the performance of an absorption column and regenerator unit, and the optimization was conducted to reduce the system's energy consumption and cost. The results indicated that optimization decreased the annual operating cost of the system by 9.3%. Ghasemi et al. (2020) [20] proposed a design optimization of TEG regeneration columns in large-scale natural gas dehydration units using genetic algorithms. They reported a significant improvement in the column's efficiency and economic viability, quantified by a 26.5% reduction in the operating cost. Previous studies have focused on designing absorber and regenerator units that enhance absorption and regeneration efficiency in TEG-based dehydration units. These studies show that optimization of the mechanical design of these units can lead to reductions in energy consumption and operating cost and an overall increase in the system's performance.

In industrial processes, where precision and efficiency are paramount, the design and functionality of essential components play a pivotal role. A critical facet of industrial operations is gas processing, where removing moisture from natural gas is imperative for numerous applications [15,16]. In this context, Triethylene Glycol (TEG) dehydration plants stand as stalwarts, ensuring that natural gas is devoid of water vapour, preventing corrosion in pipelines and ensuring the quality of the end product [17,18]. At the heart of every TEG dehydration unit, the absorber and regenerator stand tall as the unsung heroes, responsible for the intricate task of absorbing water vapour from the natural gas stream and subsequently regenerating the TEG solution for continuous use [19]. This article delves deep into the mechanical intricacies of these indispensable components within a TEG dehydration plant, exploring the cutting-edge designs and engineering principles that govern their operation.

This work explores the mechanical design aspects of the absorber and regenerator, shedding light on the innovative technologies employed to enhance their efficiency, durability, and overall performance. By understanding the nuanced engineering behind these vital units, engineers and professionals in the field can glean invaluable insights, paving the way for advancements in gas processing technologies. This exploration will serve as a testament to the marvels of modern engineering and provide a platform for exchanging knowledge, fostering continuous improvement in the realm of TEG dehydration plants.

2. Materials and Methods

2.1. Materials

The mechanical design of an absorber and regenerator in an ethylene Glycol (TEG) dehydration plant involves using various materials to achieve optimal performance and efficiency in the dehydration process. The feed material in this research comprises the temperature, pressure, and flow rate of the characterized natural gas, which typically includes various components such as methane, ethane, propane, i-butane, n-butane, i-pentane, n-pentane, hydrogen sulfide, carbon dioxide, nitrogen, water, and TEG as an absorbent used in the dehydration process. To facilitate the efficient dehydration of natural gas, the design of TEG dehydration plants typically incorporates various units such as an inlet cooler, inlet scrubber, contactor/absorber column, flash valve, flash separator, filters, heat exchanger, regenerator/distillation column, stripping column, and circulation pump. The materials used in the construction and operation of these units must be carefully selected to ensure optimal performance, durability, and safety.

In addition to the selection of materials, mechanical design considerations in TEG dehydration plants also include the sizing and configuration of equipment, piping, and instrumentation, as well as the incorporation of safety features such as relief valves, alarms, and shutdown systems. The design of the absorber and regenerator units, in particular, must consider factors such as the flow rate and temperature of the TEG, the pressure drop across the units, and the efficiency of heat transfer between the TEG and the natural gas.

The mechanical design of an absorber and regenerator in a TEG dehydration plant requires careful consideration of various materials, equipment, and safety factors to ensure efficient, effective, and safe operation. Ongoing research focused on optimising the design and operation of these units through utilising new materials, technologies, and process improvements is crucial for the continued development and improvement of TEG dehydration processes.

2.2. Method

(a) Design and simulate the TEG natural gas dehydration plant using HYSYS:

The methodology for designing and simulating a TEG (triethylene glycol) natural gas dehydration plant using HYSYS (Hyprotech Simulation Software) involves several steps. These steps include data gathering, equipment selection, process design, and simulation. The first step is gathering all the necessary data to design and simulate the natural gas dehydration plant. This includes the composition of the natural gas, flow rates, operating conditions, and the required level of dehydration. Based on the data gathered, appropriate equipment for the dehydration process is selected.

The equipment is chosen to suit the operating conditions necessary and satisfy safety and environmental requirements. The primary equipment required for the TEG dehydration process includes a gas filter, glycol contactors, a re-boiler, and a condenser. After selecting the equipment, the process design is carried out. The design is based on the chosen equipment and the required level of dehydration. The design ensures that the TEG unit operates effectively and efficiently to remove water and other impurities from natural gas.

The final step is simulation. The process model is developed using HYSYS simulation software. The simulation involves entering all the equipment details and process conditions and selecting the most appropriate thermodynamic method for TEG dehydration. A sensitivity analysis is then carried out to ensure the chosen design is robust. Several parameters are monitored during the simulation, including compressor requirements, TEG circulation rates, pressure drop across the plant, and energy consumption. The simulation results are then analyzed, and adjustments are made if necessary to achieve an optimal design. The methodology for designing and simulating a TEG natural gas dehydration plant using HYSYS involves data gathering, equipment selection, process design, and simulation. The process is iterative and requires close collaboration between engineers and operators to ensure that the final design is accurate, efficient, and meets the required safety and environmental standards.

(b) Develop mechanical design models for the absorber and regenerator unit of the plant:

Developing mechanical design models for the absorber and regenerator unit of a natural gas dehydration plant involves several steps. Initially, design criteria such as required gas flows, pressure drops, and TEG concentration must be identified, followed by developing a detailed process simulation model using software programs such as HYSYS. This model is iterated until the optimal design is achieved. Equipment layout is created based on the P&ID, and detailed mechanical drawings of equipment are developed. Finally, quality control procedures are implemented to verify that the design meets the required specifications and industry standards. The entire process involves ensuring compliance with mechanical design standards, reviewing and analyzing design components, and implementing quality control procedures to ensure the successful completion of mechanical design for the absorber and regenerator unit of the plant.

2.3. Natural Gas Composition and HYSYS Simulation Operating Condition

Natural gas is a fossil fuel composed primarily of methane gas, with varying amounts of other gases such as ethane, propane, and butane. The exact composition of natural gas can vary depending on the location of its source and can contain trace amounts of nitrogen, carbon dioxide, and other gases (Table 1). HYSYS is a process simulation software used to design and optimize natural gas processing facilities.

Engineers use HYSYS to model natural gas under different operating conditions, such as pressure, temperature, and chemical composition. These simulations allow engineers to predict the behaviour of natural gas and optimize processing facilities to maximize efficiency and yield and reduce costs. HYSYS simulations have become standard in the oil and gas industry, where effective process modelling can significantly improve the overall operational performance of processing facilities. HYSYS Simulation for the Process Flow Diagram of the Natural Gas Dehydration Unit is shown in Figure 1.

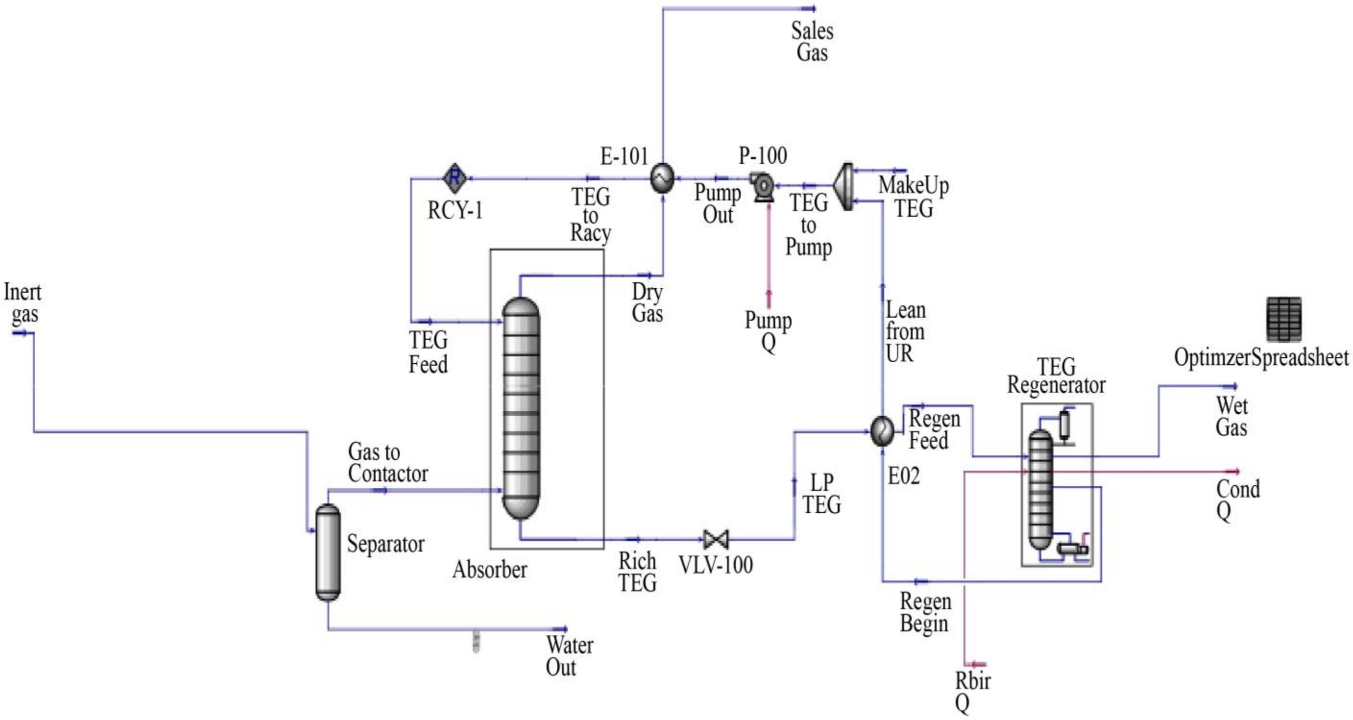

Fig. 1 Process flow diagram of natural gas dehydration unit

Table 1. Natural gas properties

Components	Composition	Molar Mass (g/mol)
C_1	0.8939	16.00
C_2	0.0310	30.00
C_3	0.0148	44.10
i-C_4	0.0059	58.12
n-C_4	0.0030	58.12
n-C_5	0.0005	72.15
i-C_5	0.0010	72.15
H_2O	0.0050	18.00
N_2	0.0010	14.00
H_2S	0.0155	34.10
CO_2	0.0284	44.00
TEG	0.0000	150.154
Total	1.0000	610.894
Operating Condition		
Pressure(kPa)	6205.2832	
Temperature (^{0}C)	29.4444	
Flow rate (kg/s)	768.6343	

2.4. Development of Mechanical Design Models

Consider the mechanical design schematics of the absorber/contactor column and regenerator/distillation column in Figures 2a and b,

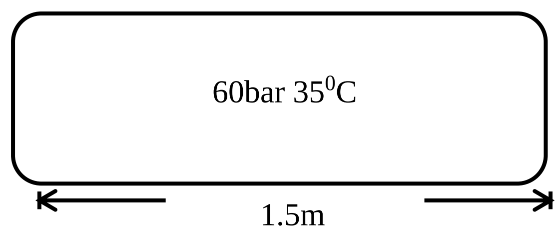

Fig. 2(a) Mechanical design of absorber column

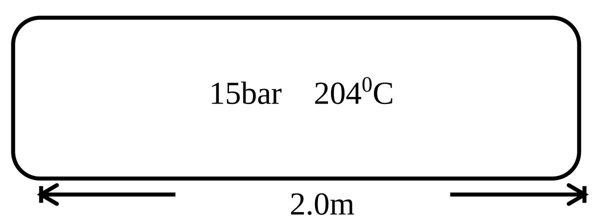

Fig. 2(b) Mechanical design of regenerator column

For absorber and regenerator (Figures 2a and b) columns with operating temperatures, pressures and column diameters.

2.4.1. Column Body (Cylindrical Type)

Determination of minimum thickness (e) is given as:

$$e = \frac{P_i D_i}{2JF - P_i} \quad \text{(Sinnott\&Towler, 2009)} \tag{1}$$

Where

J = welded joint efficiency

F = design stress

$$\text{Thickness (t)} = e + \text{Corrosion Allowance} \tag{2}$$

2.4.2. Doomed/Column Head

The column head will consider the following:

Standard Dish-Head (Torispherical)

Determination of minimum thickness(e) is given as:

$$e = \frac{P_i R_i C_s}{2JF - P_i(C_s - 0.2)} \quad \text{(Sinnott and Towler, 2009)} \tag{3}$$

Where

$R_s = D_i$

$C_s =$ Stress Concentration Factor

$$C_s = \frac{1}{4}\left[3 + \sqrt{\frac{R_c}{R_k}}\right] \tag{4}$$

Where P_k = knuckle radius = 6% R_c

Thickness (t) = e + corrosion allowance

Standard Ellipsoidal Head

Determination of minimum thickness (e) is given as:

$$e = \frac{P_i D_i}{2JF - 0.2P_i} \quad \text{(Sinnott and Towler, 2009)} \tag{5}$$

Thickness (t) = e + Corrosion Allowance

Flat Head

Determination of minimum thickness (e) is given as:

$$e = C_p D_c \sqrt{\frac{P_i}{f}} \quad \text{(Sinnott and Towler, 2009)} \tag{6}$$

Where

C_p = 0.4 (full face gasket)

D_c = Bolt circle diameter

Thickness (t) e + Corrosion Allowance

Table 2. Data for mechanical design evaluation

Parameters	Units	Absorber Column	Regenerator Column	References
Stainless steel material type (304)				
Operating temperature (T)	^{0}C	35	204	Kidnay& William (2006)
Operating pressure (P)	Bar	60	15	Kidnay& William (2006)
Design pressure (P_i)	N/mm^2	6.49	1.54	Calculated
Column diameter (D)	m	1.5	2.0	Calculated
Stress concentration (C_S)	Dimensionless	1.77	1.77	Sinnott& Towler (2009)
Stress factor (f)	N/mm^2	165	115	Sinnott& Towler (2009)
Welded joint efficiency (J)	Dimensionless	1	1	Sinnott& Towler (2009)
Atmospheric temperature	atm	1	1	Properties/ thermodynamics

The design, literature and properties/thermodynamics data were substituted and solved using the mechanical design models developed above.

3. Results and Discussion

Incorporating digital technologies, such as sensors and real-time monitoring systems, has revolutionized how absorbers and regenerators are managed. Predictive maintenance algorithms, enabled by data analytics, help anticipate potential issues before they escalate, ensuring continuous operation and minimizing downtime. Automation further enhances the precision of the dehydration process, reducing the likelihood of human errors.

In essence, advancements in the mechanical design of absorbers and regenerators have transformed TEG dehydration plants into highly efficient, durable, environmentally friendly, and technologically advanced systems. These outcomes benefit the industries directly involved and contribute to the broader goal of sustainable and responsible industrial practices, shaping a more efficient and eco-conscious future for gas processing technologies.

Table 3. Mechanical design results of absorber and regenerator column

Column Design	Absorber thickness (mm)	Regenerator Thickness (mm)
Column Body		
Cylindrical	31	15
Column Head (Doomed)		
torispherical head	55	25
Ellipsoidal head	30	14
Flathead	120	94

Table 3 shows the results obtained from the mechanical design model absorber and regenerator column, which shows that for economic purposes, the column body (cylindrical body type) and column head (standard ellipsoidal should have a minimum thickness of (31mm and 30mm) and (15mm and 14mm) for the absorber and regenerator column, respectively. The result also indicates that the design pressure or stress influences mechanical design for minimum column thickness determination during the TEG dehydration. TEG dehydration plants have witnessed a significant enhancement in efficiency. This results in improved mass transfer, allowing for a higher absorption rate of water vapour from the natural gas stream. Similarly, innovative heat exchange systems in regenerators optimize the regeneration process, ensuring swift and thorough removal of absorbed moisture from the TEG solution. The outcome is a highly efficient dehydration process, meeting stringent industry standards.

To ensure the lifespan of the TEG dehydration plant, the mechanical design aspect of the absorber and regenerator columns is crucial, given the pressure, stress, and corrosion involved during operation. HYSYS simulation design determined the absorber and regenerator's operating temperature, pressure, and column diameter. The most economical thickness of the column body and head for the absorber and regenerator columns was determined to be 31mm and 30mm and 15mm and 14mm, respectively, using stainless steel type (304) as the construction material. This research highlights the importance of properly designing and maintaining TEG dehydration plants to ensure longevity and efficiency. It provides useful insights into the mechanical design aspect of the absorber and regenerator columns using results obtained from the HYSYS simulation design.

Using durable materials, corrosion-resistant alloys, and coatings, coupled with intelligent design, will decimate wear and tear. This extends the lifespan of absorbers and regenerators and reduces maintenance downtime and costs. Enhanced durability ensures uninterrupted operation, a critical factor in industrial settings where continuous processing is essential. The evolution of TEG dehydration plants has led to environmentally conscious designs. Closed-loop systems and advanced pollution control mechanisms minimize the environmental impact. Reducing energy consumption due to improved heat exchange processes contributes to a lower carbon footprint, aligning with global sustainability goals. Modern designs are scalable and adaptable, catering to various gas processing capacities. Whether it's a small-scale facility or a large industrial plant, the mechanical design allows for seamless integration and operation. This flexibility is essential for industries experiencing varying demand levels, enabling them to optimize production based on market needs.

4. Conclusion

The mechanical design performance models for the absorber and regenerator column were developed to account for the best material type suitable for equipment design, minimum thickness of the equipment, corrosion allowance, minimum allowable internal pressure, design stress factor and welded joint factor for the smooth and safe operation of the absorber and regenerator column during TEG dehydration process. This ensures the safe operation and the lifespan of the natural gas TEG dehydration plant.

The mechanical design of the absorber and regenerator within a Triethylene Glycol (TEG) dehydration plant is an intricate and vital aspect of gas processing technology. The core components that drive the efficiency and reliability of the design principles, innovations, and operational intricacies have been explored in this work, providing a profound understanding of their crucial role in ensuring natural gas's quality and integrity. The absorber effectively removes water vapour from the gas stream with its structured packing and efficient mass transfer mechanisms. Simultaneously, with its smart heat exchange systems, the regenerator revitalizes the TEG solution, preparing it for another cycle. The synergistic operation of these two components optimizes the entire TEG dehydration process.

Furthermore, the emphasis on sustainability has led to the development of eco-friendly TEG dehydration plants that minimize environmental impact. The mechanical design of absorbers and regenerators will continue to evolve. Engineers will explore innovative solutions, incorporating digital technologies, automation, and artificial intelligence to enhance the performance of these units further.

The quest for energy efficiency and environmental responsibility will drive the development of greener, more sustainable TEG dehydration processes. Their mechanical design reflects the synergy between cutting-edge technology and the fundamental principles of gas processing. As we stand at the threshold of a new era in industrial engineering, the lessons learned from the mechanical design of these units will undoubtedly shape the future of gas processing technology, paving the way for cleaner, more efficient, and more sustainable energy solutions. This work emphasizes the importance of natural gas as a catalyst for development and industrialization in Nigeria. The study's findings can contribute to developing TEG dehydration plants in Nigeria and other countries faced with issues during natural gas processing and transmission. The study's results would also inspire future studies in natural gas processing and transmission, improving industry efficiency and productivity in the long run.

Declarations

Authors Contributions

W.C.O, E.M.E, and W.A.A: Conceptualization, Methodology, Original draft preparation, Performed experimental work, and Writing

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