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Mathematical Modelling and Dynamic Simulation of the Ethan Separation Unit in Natural Gas Liquefaction Plant

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ABSTRACT: Separation is one of the most important processes in all chemical industries, including the petroleum industry. Ethane gas separation is the simplest example of a gas mixture separation process. A mathematical model and dynamic simulation of the ethane gas separation unit at a natural gas liquefaction (NGL) plant were developed, focusing on developing an accurate mathematical representation that relies solely on temperature as the main dynamic variable, without introducing flow rate or pressure effects. This allows for a flexible and realistic simulation of the system's behaviour.

The mathematical model was built using first-order differential equations that describe the temporal relationship between the temperatures at the inlets and outlets of the system components using matrix algebra. Actual operational data recorded from the work site were used, providing the model with a high degree of reliability and validity in simulating the system's actual performance under both steady-state and unsteady-state operating conditions. The simulation was implemented using the MATLAB/Simulink environment to represent the thermal relationships and analyze the dynamic interaction between the system units.

The model results demonstrate good agreement with practical applications, making it possible to provide a ready-to-use simulation as a testbed for advanced process monitoring or operational decision support. Through system simulation, the model's ability to accurately and realistically represent system behaviour was demonstrated, matching the actual operational behavior with the help of gain factors. This work represents a qualitative contribution to the field of modelling industrial thermal systems and paves the way for further development toward building more comprehensive models for gas processing units.

KEYWORDS: Modelling, Simulation, Ethane, natural gas liquefaction, Separation, MATLAB

1. INTRODUCTION

Gas separation is one of the most important industrial processes in the petroleum and petrochemical industries, where mixed gaseous components are separated into their individual components for use in industrial or export purposes. Ethane (C_2H_6) is a gas of high economic value, given its widespread use as a raw material in the petrochemical industry, particularly in ethylene production, or as a fuel in turbine engines for some industrial plants and electricity generation [1].

In recent decades, the trend has shifted toward using computers to control operational systems in the industrial sector, particularly the petroleum sector, by designing a control system that allows engineers and specialists working in this sector to test their skills in applying control software to various types of devices and equipment [2]. These systems also outperform traditional systems in that they can be programmed in advance and according to the user's preferences, provide flexibility for the user to choose operating periods, and protect workers from exposure to high voltages or electrical shocks by working directly with the equipment. Not to mention the benefits of leveraging human expertise and translating it into software [3].

This research focuses on modelling the ethane gas separation system in a natural gas liquids separation unit (NGL plant). This unit produces ethane from the gas mixture entering the unit and passing through several heat exchangers and stripping towers. The separation process is carried out with the help of a catalyst, a very low-temperature gas, and another catalyst, a high-temperature gas [4]. This unit is modeled using a mathematical model based on the laws of thermodynamics and differential equations that describe the change in the concentration of ethane and its other components over time. This model is then converted into a state-space model to enable simulation in MATLAB/Simulink, enabling analysis of system performance under various operating conditions.

Real operating data extracted from an actual gas liquid separation plant was used to ensure the accuracy of the mathematical representation and the applicability of the results. This simulation is used to understand the complete dynamics of the system and verify its behaviour under steady-state and turbulent conditions, paving the way for the development of future control strategies that contribute to enhancing process efficiency and reducing waste [5].

2. LITERATURE REVIEW

This section discusses previous research on modelling industrial systems, including ethane gas separation systems. This paragraph aims to briefly summarize several surveys on this topic, placing current research within the context of the available literature..

Saffa Al-Naami et al. (2012) conducted a mathematical simulation study to design and implement a nonlinear observer-based control (NBOC) strategy for a continuous stirred reactor with a cooled jacket (CSTR). The system was mathematically represented using mass and energy balance equations, in addition to the Arrhenius model to represent the chemical reaction rate. Three control strategies were applied: cascade control, conventional feedback control (PI and PID), and fuzzy logic control. The model was built and simulated using the MATLAB/Simulink environment. The results showed that the fuzzy logic control strategy performed better in terms of reducing the squared integration error (ISE), reaching a value of 0.0084, compared to other methods. The diversity of the tested control strategies is one of the most important advantages of this study, and it demonstrates the effectiveness of applying fuzzy logic control to nonlinear systems without the need for a precise mathematical model. The study's drawbacks include its reliance on theoretical simulation without experimental support, and it does not provide a detailed analysis of the system's stability or sensitivity to environmental changes, which may limit its practical applications in complex industrial environments [6].

Sabrina Di Scipio et al. (2014) conducted a comprehensive analytical study of a natural gas liquefaction cycle using the PROII/8.1 simulation program to model the system under varying operating conditions, focusing on the coefficient of performance (COP) and the refrigerant flow rate required to achieve gas liquefaction. It was found that increasing the proportion of propane in the mixture improves the cycle efficiency. The advantages of this research include the high accuracy in representing the thermodynamic state using the Peng-Robinson equation of state. However, the disadvantages of the study are the lack of realistic design parameters such as heat losses or the interaction of time-varying pressures in operating compressors [7].

Mina Hoorfar et al. (2018) addressed the thermal separation process in natural gas processing systems, focusing on analysing the thermal performance of heavy gas separation processes using dynamic simulations using Aspen HYSYS. The system behaviour was analysed under the influence of changing inlet and outlet temperatures for each separation stage, with mathematical models presenting the effect of feed temperature on separation efficiency. The advantages of this research are that it reflects a deep understanding of the thermal mechanism of separation reactors. The disadvantages of this research are that it does not address the influence of pressure and flow rate as important dynamic factors in the design of industrial units [8].

Naved Siraj and A. Hakim (2018) developed a dynamic mathematical model to simulate the performance of a gas adsorption column using MATLAB/SIMULINK. Differential and algebraic equations were used to describe the column's behaviour over time. The model was applied to the adsorption of carbon dioxide and alcohol using water as an adsorbent. The advantages of the model include the use of a dual steady-state and dynamic model, which provides a comprehensive understanding of the system's behaviour. The disadvantages of the model are that it relies on only two components in the adsorption system (a binary system), which reduces its accuracy when generalizing the results to multicomponent systems. Furthermore, other variables such as gas pressure or flow rate were not incorporated into the model, with the primary focus being on molar composition and outlet concentrations [9].

Abdelkader Djelloul et al. (2022) developed a dynamic model of an ethylene separation column for ethane recovery using the MATLAB/Simulink platform. The dynamic interactions were modelled using material and energy balance equations. PID controllers were used to control temperatures and flow rates, and the system performance was evaluated under variable operating conditions. Real data were used, which gave the model high reliability, an advantage. Furthermore, incorporating dynamic simulation control increased the effectiveness of the proposed design and improved the accuracy of the results. The disadvantages include the lack of simplified models that rely solely on temperature, but rather include gas pressure and flow rates, which may be difficult to implement in resource-limited systems or educational settings [10].

Ibrahim (2022) presented a study aiming to create a mathematical model of a CSTR reactor that exhibits highly nonlinear dynamics, on the mathematical modelling and simulation of control strategies for a continuously stirred tank reactor (CSTR). A comparative study of various types of conventional and unconventional model-based controllers was conducted to control the reactor temperature. The research method included the development of various controllers such as Proportional (P), Proportional-Integral (PI), Proportional-Derivative (PD), Proportional-Integral-Derivative (PID), Two Degrees of Freedom (2-DOF-PID), and Model Predictive Controller (MPC). These controllers were simulated, tuned, and optimized using MATLAB /Simulink software. The response results of the different controllers were compared and analysed to evaluate their performance. The research highlights the comparison of a wide range of conventional and unconventional control strategies (including PID and MPC), providing a comprehensive overview of their performance. A disadvantage of the research is that it does not provide details about the size of the data used in the simulation or how to accurately represent nonlinearity in the mathematical model [11].

Jin Sun et al. (2023) conducted a study titled "Modelling and Simulation of an NGL Plant to Evaluate the Recovery of Ethane Gas Using ASPEN HYSYS." The researchers in this study relied on an analytical approach and numerical simulation. A simulation model of an NGL plant was built using Aspen HYSYS to evaluate the ethane recovery process. The methodology focused on inputting real operating data from a natural gas processing unit to design a dynamic simulation model of the system, which includes compressors, heat exchangers, and separation columns. A model based on flows, pressures, and temperatures was adopted as inputs to the system. The study relied on actual operating data, which gave the model a high degree of realism, a significant advantage of this research. Furthermore, the use of Aspen HYSYS enabled accurate simulation of system components, allowing for the study of the effect of thermal and pressure variables on the ethane recovery rate. One of the drawbacks of the research is that it does not represent the system mathematically (differential equations or an abstract mathematical model), but rather relies only on the modelling interfaces in the program without explicit derivation of the equations. It also does not integrate artificial intelligence tools or modern dynamic control methods such as Simulink or state-space modelling [4].

Adenubi et al. (2023) presented a study on modelling and simulation of a natural gas dehydration unit (NGDU) using the MATLAB/Simulink environment, to control the water content of the treated gas by focusing on the dynamic aspects of the system. Mathematical equations were used to describe the changes in chemical concentrations and temperatures within the system. Simulink was used to construct a time-lapse simulation of the dynamic state based on real industrial operating data. The advantages of this system include its effectiveness in implementing a simple automatic control system capable of ensuring the quality of the final gas. The disadvantages include that the modelling relies solely on temperature and concentration variables without incorporating the effects of pressure or flow, and the model is not designed for unstable or emergency operating conditions [12].

Studies have shown that modelling natural gas systems and their liquefaction or separation rely primarily on thermodynamic equations related to temperatures, pressures, and gas compositions. However, most work focuses on temperature and composition without fully considering flow and pressure variables. In this context, the current research contributes to the development of a thermal simulation model for an ethane gas separation system in a natural liquid separation plant, focusing on the thermal behaviour of the system based on the inlet and outlet temperatures across the separation stages. This enables the study of system behaviour and the identification of optimal opportunities for improving its efficiency.

3. MATERIALS AND METHODS

The mathematical model used in this research is based on analysing the thermal changes that occur across the various stages of the ethane separation system in an NGL plant, without introducing other influences such as flow rate or gas pressure. The system is represented by a series of functional blocks, each representing a unit in the system. The mathematical relationships between these blocks depend solely on thermal differences influenced by the catalyst. Linear equations are formulated to describe the relationship between the inlet gas temperature and the catalyst temperature to determine the outlet gas temperature. These equations are used to estimate the resulting temperature after each process, using correction coefficients or thermal functions determined based on actual data from the system. The model was built using the MATLAB/Simulink environment, using Gain, Sum, and Function Blocks to represent the thermal relationships. The blocks are arranged according to the sequence of operations in the separation plant, inputting actual inlet gas temperature values, connecting the outputs as inputs to the next stage, and comparing the model results with actual data to assess the accuracy of the model.

3.1. DATASET

The dataset used in this research was obtained from the actual work site, the North Rumaila NGL plant in southern Iraq. It was recorded during the operational periods of the ethane separation unit to ensure the availability of dynamic data that can be used to build a mathematical model and simulate the behaviour of the unit under real operating conditions. The data consists of actual readings from control panel instruments and includes the temperatures of the gas entering the various parts of the separation unit, as well as the temperatures of the gas exiting it after passing through the processes of cooling with cold gas, heating with high-temperature gas, or heat exchange within the heat exchangers. The advantages of this data are that it is continuous and realistic, and it can contain anomalous readings or noisy data resulting from operational factors or unstable sensors.

3.2 DATA PREPROCESSING

The data used in this research are digital and represent the inlet and outlet gas temperatures within the ethane gas separation unit at the (NGL) separation plant. Therefore, preprocessing steps were adopted to improve data quality and ensure its accuracy before using it in mathematical modelling and dynamic simulation. This preprocessing includes several steps, including cleaning the data of missing or outlier values, standardizing values using Z-Score standardization techniques to reduce variation between properties, and adjusting numerical dimensions, if necessary. This helps stabilize the mathematical model and improve simulation accuracy. This preprocessing helped uncover thermal patterns and identify the relationships between temperatures at the inlet and outlet points, enabling the construction of a mathematical model based solely on temperature changes as the primary dynamic factor in describing system behaviour. This preprocessing was necessary to reduce the impact of noise in the data and improve the accuracy of simulation results using MATLAB/Simulink tools.

3.3. PROCESS DESCRIPTION

This section defines and explains the process flow of the ethane gas separation system in the natural gas liquefaction plant to be represented, its processing stages, how it works, its benefits, and the changes that occur during operation. The ethane removal process, according to the basic design of the natural gas liquefaction plant, which includes an ethane gas separation unit, indicates that the estimated C3+ gas content, based on mole fractions, is 24.4 mol%, contained in the gaseous and liquid phase streams in the drying unit [13].

The ethane gas separation system (DeEthanizer) is one of the production systems that make up the natural gas liquefaction plant (NGL), which receives raw gas carrying some clay particles and quantities of water that accompany it during the process of extracting it from oil wells and compresses it in compression units to raise its pressure, so that it reaches the plant at a certain pressure and is entered into the plant to be treated in several production units, the purpose of which is to dry it from water, remove pollutants and produce a mixed gas free of impurities. Then it enters the ethane removal unit to separate the ethane from the rest of the gases. This means that the two production lines of the natural gas liquefaction plant are the first, the (C1 and C2) gas line, which is considered a light fuel used by industrial plants such as petrochemical plants, fertilizer plants, electric power turbines and other plants. The other line is a mixture of other gases that are pushed smoothly to another plant that separates these gases and produces the gas used in homes and buildings [14]. Figure 1 shows the layout of the main NGL plant units and the location of the ethane separation unit.

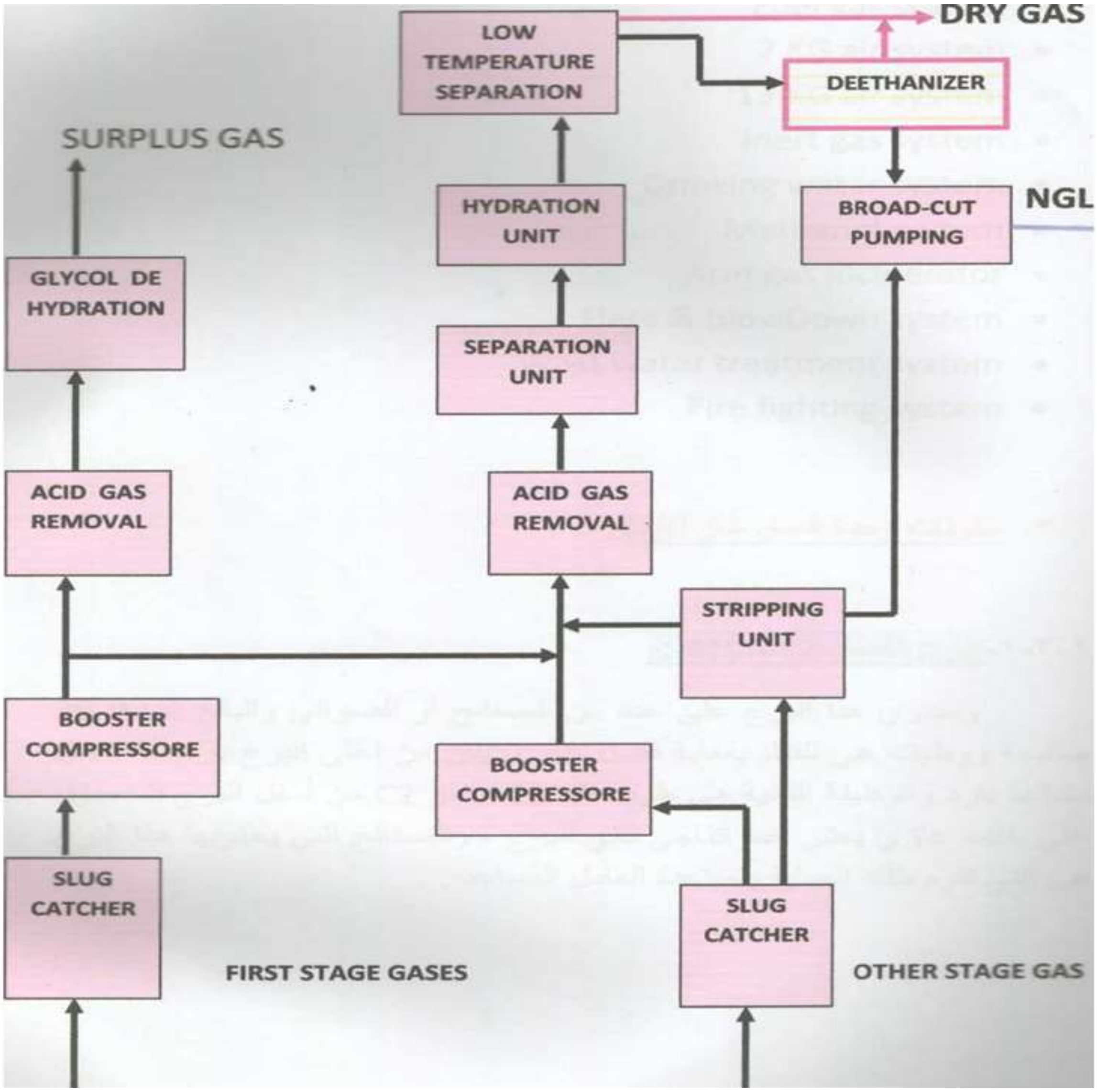

Fig. 1: Main units of the NGL plant [15].

The ethane gas separation unit consists of:
1. The 4100-C2 separation tower, which contains a number of plates or trays. Its function is to produce ethane gas from the top of the tower using a cold catalyst, and to produce C1 and C2 gas from the bottom of the tower.
2. Heat exchangers, which consist of two parts: the shell, which is the outer covering of the exchanger, and the core, which is a group of thin capillary tubes. The function of heat exchangers is to either raise the temperature of the incoming material using a hot feed gas, or lower it using a catalyst, which is a low-temperature feed gas.
3. Pumps, which push or pull the liquid into the ethane gas separation unit.
4. Valves, which control the flow of the material within the ethane gas separation unit.
5. Cooling fans, which cool the material fed to the ethane gas separation unit.
6- The storage vessel stores the gaseous material converted to a liquid at very low temperatures and high pressure, allowing it to be used in the cooling process of high-temperature gases.
Figure (2) shows the flow diagram of the gas feed to the ethane gas separation unit.

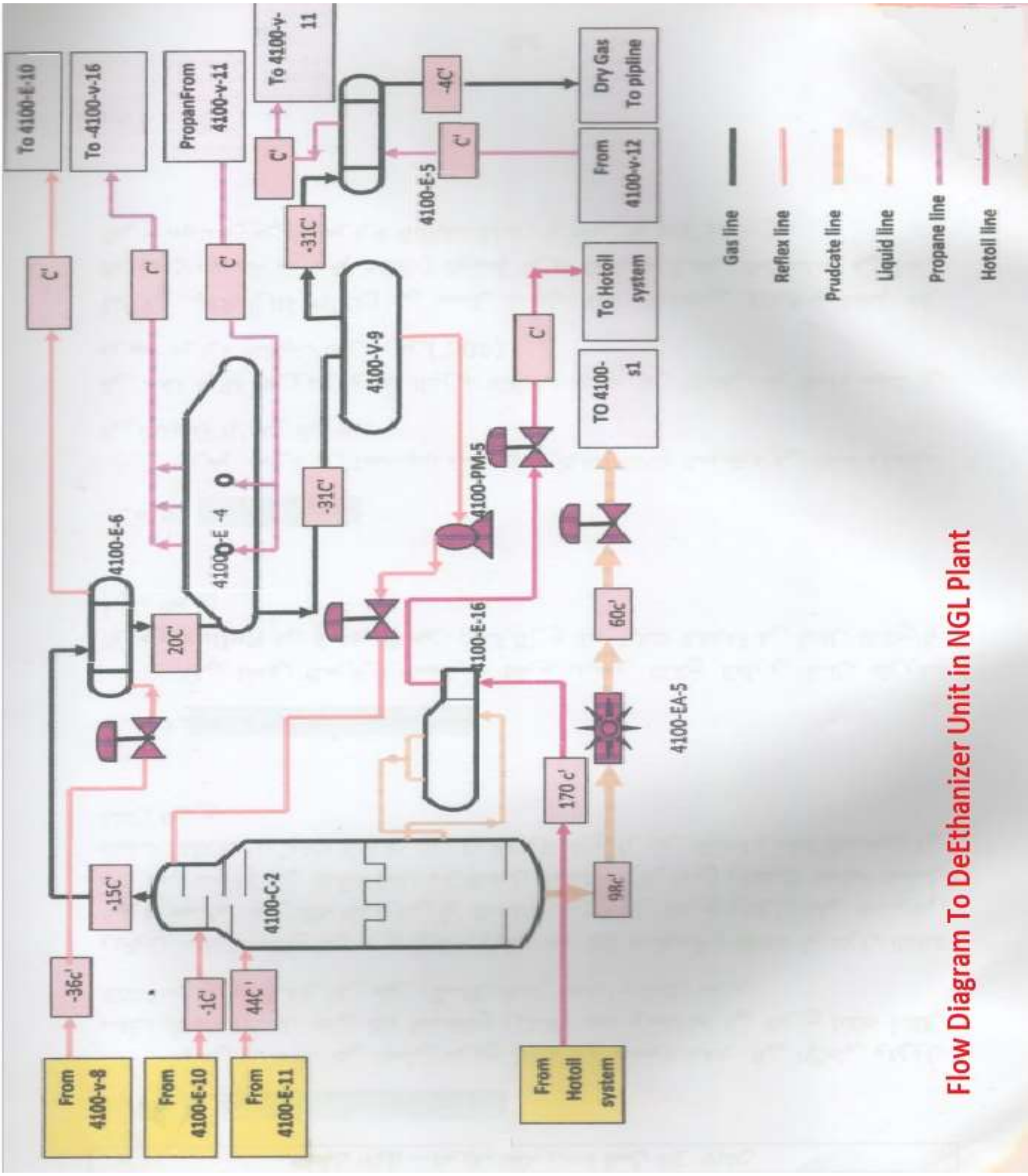

Fig. (2) Ethane gas separation unit flow diagram

3.4. DYNAMIC MODELING

Dynamic modelling is an essential tool for understanding and analysing the behaviour of industrial systems whose properties change over time, such as systems in which temperature is one of the variables used in separating ethane from a gas mixture, which is the focus of this research [16]. The thermal changes of the gas over time were modelled using mathematical equations that describe the temporal relationship between temperature evolution. The time-varying temperature was considered the only variable in the system, and other variables such as flow rate or pressure were not used, making the model more focused and closer to the actual application used in the operational control panel.

First-order differential equations were used to represent the dynamic modelling of the system. These equations describe the primary system inputs (feed gas temperatures) and secondary system inputs (catalyst temperatures). The temperatures are determined by the design specifications of the system, not the actual temperatures. This modelling enables accurate simulation of the thermal behaviour of the system and helps predict performance and improve system design in a realistic industrial environment. The mathematical modelling of the system can be divided into the following parts:

1- The 4100-C-2 separation column is divided into two sections:

4100 C-2a : it consists of three inputs (two feed gases + a catalyst). The first feed comes from the 4100-E-10 exchanger at a temperature of (-1°C). The second feed comes from the 4100-E-11 exchanger at a temperature of (44°C). The catalyst comes from the 4100-V-9 at a temperature of (-33°C). The mixing of the three inputs produces a single outlet from the top of the separation column at a temperature of (-15°C). When adding the temperature values of the three inputs into a mathematical equation, we do not obtain the design output temperature. Therefore, we need a gain factor of (-25°C) to complete the process correctly. The mathematical equation is as follows:

4100-C-2a= (-1) + 44+ (-33) + (-25) = -15 ………………….. Eq. (1)

If we substitute variables for the constants (design inputs), the equation becomes as follows:

4100-C-2a = X1 + X2 + X3 + (-25) = Z

4100 C-2b: it consists of three inputs (two feed gases + a catalyst). The first feed comes from the 4100-E10 exchanger at a temperature of (-1°C). The second feed comes from the 4100-E11 exchanger at a temperature of (44°C). The catalyst comes from the 4100-E16 exchanger at a temperature of (95°C). The mixing of the three inputs produces a single outlet from the bottom of the separation column at a temperature of (98°C). When adding the temperature values of the three inputs into a mathematical equation, we do not obtain the design output temperature. Therefore, we need a gain factor of (-40°C) to complete the process correctly. The mathematical representation of the equation is as follows:

4100-C-2b= (-1) + 44+ (95) + (-40) = 98 …………………….. Eq. (2)

If we impose variables instead of constants (design inputs), the equation becomes

4100-C-2b = X1 + X2 + X4 + (-40)= Z1

2- The 4100-E-6 heat exchanger is divided into two parts:

4100-E-6a: it consists of two inlets (feed gas + catalyst). The first gas comes from the top of the 4100 C-2a separation column at a temperature of (-15°C). The catalyst comes from the 4100 V-8 vessel at a temperature of (-45°C). Mixing the two inlets results in a single outlet at (-20°C). When adding the inlet temperatures in a mathematical equation, we do not obtain the design outlet temperature. Therefore, we need a gain factor of (40°C) to complete the process correctly. The mathematical representation of the equation is as follows:

4100-E-6a = (-15) + (-45) + (40) = -20 …………………….. Eq. (3)

If we impose variables instead of constants (design inputs), the equation becomes:

4100-E-6a = Z + Y1 + 40 = R

4100-E-6b: it consists of two inlets (feed gas + catalyst). The first gas comes from the top of the 4100 C-2a separation column at a temperature of (-15°C). The catalyst comes from the 4100 V-8 vessel at a temperature of (-45°C). Mixing the two inlets results in a single outlet at (-19°C). Adding the inlet temperatures in a mathematical equation does not give the design outlet temperature. Therefore, a gain factor of (41°C) is required to complete the process correctly. The mathematical representation of the equation is as follows:

4100-E-6b = (-15) + (-45) + (41) = -19 …………………….. Eq. (4)

If we impose variables instead of constants (design inputs), the equation becomes:

4100-E-6b = Z + Y1 + 41 = R1

3- The 4100-E-4 heat exchanger is divided into two parts:

4100-E-4a: it consists of two inlets (feed gas + catalyst). The first gas comes from the 4100-E-6a exchanger at (-20°C). The catalyst comes from the 4100-V-11 vessel, which is propane gas at (-38°C). Mixing the two inlets results in a single outlet at (-33°C). Adding the inlet temperatures in a mathematical equation does not give the design outlet temperature. Therefore, a gain factor of (25°C) is required to complete the process correctly. The mathematical representation of the equation is as follows:

4100-E-4a = (-20) + (-38) + (25) = -33 …………………….. Eq. (5)

If we impose variables instead of constants (design inputs), the equation becomes:

4100-E-4a = R +Y2 +25 =W

4100-E-4b: it consists of two inlets (feed gas + catalyst). The first gas comes from exchanger 4100-E-6a at –(-20°C). The catalyst comes from vessel 4100-V-11, which is propane at (-38°C). Mixing the two inlets produces a single outlet at (-38°C). Adding the inlet temperatures in a mathematical equation does not give the design outlet temperature. Therefore, a gain factor of (20°C) is required to complete the process correctly. The mathematical representation of the equation is as follows:

4100-E-4b = (-20) + (-38) + (20) = -38 …………………….. Eq. (6)

If we impose variables instead of constants (design inputs), the equation becomes:

4100-E-4b = R + Y2 + 20 = Y2

4- The 4100-E-5 heat exchanger is divided into two parts:

4100-E-5a: it consists of two inlets (feed gas + catalyst). The first gas comes from vessel 4100-V9 and is the result of the equation from the 4100-E-4a exchanger before entering vessel 4100-V9, which is at (-33°C). The catalyst comes from vessel 4100-V-12 and is propane at (10°C). Mixing the two inlets results in a single outlet at (-4°C). Adding the inlet temperatures in a mathematical equation does not give the design outlet temperature. Therefore, a gain factor of (19°C) is required to complete the process correctly. The mathematical representation of the equation is as follows:

4100-E-5a = (-33) + (10) + (19) = -4 …………………….. Eq. (7)

If we impose variables instead of constants (design inputs), the equation becomes:

4100-E-5a = W +Y3 +19 =N

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4100-E-5b: Consists of two inlets (feed gas + catalyst). The first gas comes from vessel 4100-V9 and is the result of the equation from the exchange 4100-E-4a before entering vessel 4100-V9, which is at -33°C. The catalyst comes from vessel 4100-V-12 and is propane at -10°C. Mixing the two inlets results in a single outlet at (-18°C). Adding the inlet temperatures in a mathematical equation does not give the design outlet temperature. Therefore, a gain factor of (5°C) is required to complete the process correctly. The mathematical representation of the equation is as follows:

4100-E-5b = (-33) + (10) + (5) = -18 …………………….. Eq. (8)

If we impose variables instead of constants (design inputs), the equation becomes:

4100-E-5a = W +Y3 +5 =M

5- The 4100-E-16 heat exchanger is divided into two sections:

4100-E-16a: it consists of two inlets (feed gas + catalyst). The first gas comes from the base of the 4100-C-2 separation column at a temperature of (95°C). The catalyst, hot-oil, comes from the hot-oil system at a temperature of (178°C) for heat exchange between them. Heat exchange between the two inlets results in a single outlet at a temperature of (150)°C. When combining the values of the two inlet temperatures in a mathematical equation, we do not obtain the design outlet temperature. Therefore, we require a gain factor of (-123°C) to complete the process correctly. The mathematical representation of the equation is as follows:

4100-E-16a = (178) + (95) + (-123) = 150 …………………….. Eq. (9)

If we impose variables instead of constants (design inputs), the equation becomes:

4100-E-16a = X4 + Z1 + (-123) = H

4100-E-16b: it consists of two inlets (feed gas + catalyst). The first gas comes from the base of the 4100-C-2 separation column, at a temperature of (95°C). The catalyst, hot-oil, comes from the hot-oil system, at a temperature of (178°C), for heat exchange between them. Heat exchange between the two inlets results in a single outlet at a temperature of (98)°C. When adding the values of the two inlet temperatures in a mathematical equation, we do not obtain the design outlet temperature. Therefore, we need a gain factor of –(-175°C) to complete the process correctly. The mathematical representation of the equation is as follows:

4100 E-16b = (178) + (95) + (-175) = 98 …………………….. Eq. (10)

If we impose variables instead of constants (design inputs), the equation becomes:

4100-E-16b = X4 + Z1 + (-175) = H1

6- Cooling fans: They consist of a single inlet, which comes from the equation 4100-C- 2b, which is a feed gas at a temperature of (98°C) degrees Celsius. The exhaust gas from the cooling fans is obtained at a temperature of (60°C) degrees Celsius. The design outlet temperature is not obtained. Therefore, a gain factor of (-38 °C) is required to complete the process correctly. The mathematical representation of the equation is as follows:

4100-EA-5 = 98 + (-38) = 60 …………………….. Eq. (11)

If we impose variables instead of constants (design inputs), the equation becomes:

4100-EA-5 = Z1 + (-38) = P

4. DYNAMIC SIMULATION RESULTS

Based on actual data (temperatures) from the operation of the ethane separation unit over a period of time, which did not correspond to the design temperatures, a simulation of the system was conducted. The experiment was conducted randomly in selecting data real-world temperature. We took three columns from Table)1(, which contains the temperatures recorded over a period of time. The first column is at 8:00 AM on February 17, the second column is at 24:00 PM on February 17, and the third column is at 20:00 PM on February 18. observed differences in the temperatures of the inputs and outputs of the design parts of the system comparison on actual, so entered the actual temperatures taken from the real world instead of the design temperatures, into mathematical equations representing the interactions for each part of the system. Then the values of the variables (gain) are calculated, which represent the true contributing factor be multiplied later by the design values to obtaining realistic results regardless of the inputs. Taking the temperatures from the table and

Date and time	/17 2 8:0 0	/17 2 12: 0	/17 2 16: 0	/17 2 20: 0	/17 2 24: 0	/18 2 4:0 0	/18 2 8:0 0	/18 2 12: 0	/18 2 16: 0	/18 2 20: 0	/18 2 24: 0	/19 2 4:0 0	/19 2 8:0 0	/19 2 12: 0	/19 2 16: 0	/19 2 20: 0	2/19 24:0
T1-33Dry Gas from (E-12)To P.L.	41	48	40	43	40	44	45	44	44	44	43	44	45	43	44	44	42
T1-92Liquid from (E-10)To C2	0.4-	4.6	2.6-	0.2-	2-	4.1	0.2	8.4	5	1-	1-	2-	0.1	0.2	2	0.5	0.4-
T1-41B.C. from (C2)To EA-5	101	101	100	102	101	100	99	100	101	101	100	101	102	101	100	101	101
T1-42 Liquid from (E-16)To C2	103	101	100	99	101	103	101	101	101	101	102	100	101	103	100	101	101
T1-45 Gas from (E-4)To V9	29-	27-	30-	28-	31-	21-	25-	24-	24-	31-	30-	29-	28-	29-	27-	24-	25-

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T1-94 Gas from (C2)To E-6	7-	6.1-	10-	5.3-	12-	3.5-	8-	1.2-	0.1-	13-	10-	6-	4.5-	7-	4.2-	1.4-	5.7-
T1-43 Liquid from (V-8)To E-6	45-	45-	47-	45-	45-	45-	45-	44-	42-	45-	46-	47-	44-	45-	47-	44-	45-
T1-44 Gas from (E-6)To E-4	17-	13-	18-	17-	21-	13-	17-	13-	13-	21-	17-	21-	18-	17-	14-	17-	13-
T1-38 Tray Temp No 29	83	74	79	82	80	85	76	75	76	80	79	80	82	83	77	79	85
T1-39 Tray Temp No 31	85	82	80	83	82	87	80	78	79	82	77	83	80	82	85	78	79
T1-40 Tray Temp No 35	95	93	92	93	95	92	94	94	94	95	95	94	93	92	95	93	93
T1-47 propane Temp from (v-12)To E-5	6	5.9	1.3-	0.2	5	3.5	1.5	3.6	3.1	5	1-	1-	1.3-	3.4-	1.5-	3.3-	3.1-
T1-48 Gas from (E-5)To K-4	1-	5	1-	1	1-	3	1	2	3	1-	1-	1	2	1	1-	1-	1-
T1-49 propane Temp from E-5 To V-11	2-	4.7	3-	1-	2-	1.8	0.5-	1.5	1	3-	2-	3-	1-	3	4.5	1.9	1
T1-37 Liquid from (E-11)To C2	36	34	37	35	37	35	37	36	36	36	36	37	35	34	35	37	36
propane Temp from (V-11)To E-4	38-	38-	37-	37-	37-	38-	37-	36-	36-	36-	38-	37-	37-	38-	36-	36-	37-
Liquid propane from (E-4)To V-16	38-	38-	37-	37-	38-	38-	37-	36-	36-	36-	38-	38-	37-	37-	38-	36-	37-
T1-46 B.C. from (EA-5)To S1	61	61	60	60	65	60	60	60	60	60	61	62	61	60	60	61	60
T1-HOT OIL from (F1)To E-16	169	167	169	160	169	163	166	168	170	170	171	173	170	169	168	170	171
From E-6-10-- To E-10	17-	16-	17-	17-	18-	18-	16-	17-	15-	16-	17-	17-	16-	18-	18-	17-	17-
From E-16 To - HOT OIL	140	141	140	139	138	139	140	141	140	140	138	137	140	140	139	139	140

1. The equation 4100-C-2a= (-1) +44+ (-33) + (-25) = -15

-0.4 X1 + 36 X2 + (-29) X3 =-7

-2 X1 + 37 X2 + (-31) X3 =-12

-1 X1 + 36 X2 + (-31) X3 =-13

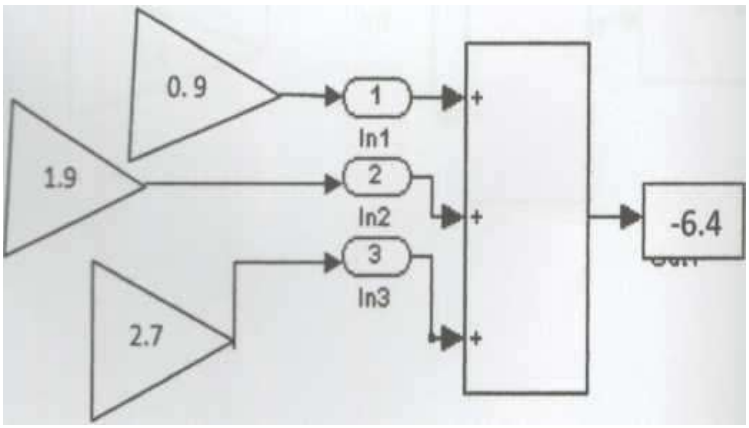
a= [-0.4 36 -29; -2 37 -31; -1 36 -31]

b = [-7; -12; -13]

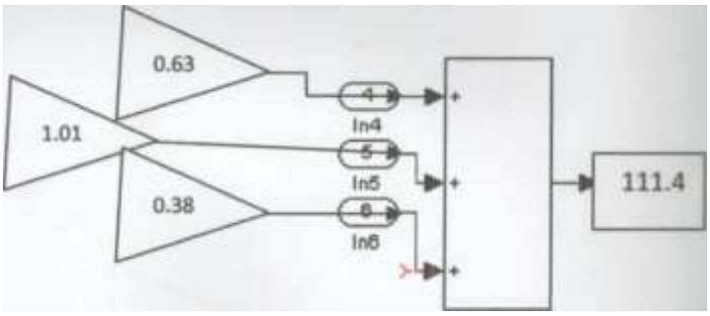
c= inv(a)*b = [0.9932 1.9932 2.7020]

X1=0.9 X 2= 1.9 X 3=2.7

4100-C-2a =0.9 * -1 + 1.9 * 44 + 2.7 * -33= -6.4



2. The equation 4100- C2b= (-1) +44 +(178) +(-123) = 98



-0.4 X 1 + 36 X 2 + (169) X 3 =101

-2 X 1 + 37 X 2 + (169) X 3 =101

-1 X 1 + 36 X 2 + (170) X 3= 101

a= [-0.4 36 169; -2 37 169; -1 36 170]

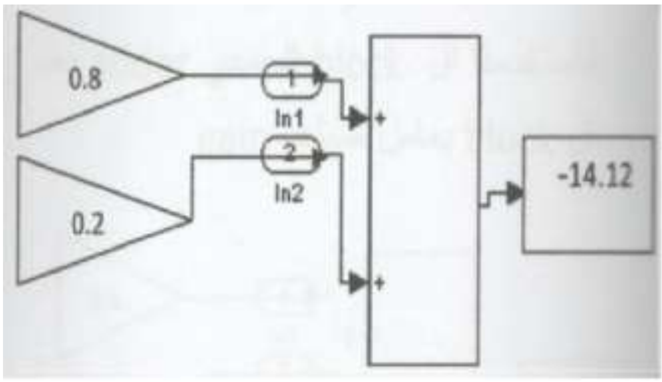
b=[101; 101; 101]

c=inv (a)*b= [0.6368; 1.0189; 2.3821]

X1=0.63 x2= 1.01 x3=0.38

4100-C2b= =0.63 * -1 +0.01 * 44 + 0.38 * 178= 111.4

3. The equation 4100-E6a= (-6.4)+(-45)+31.4 =-20



-7 X1 + (-45) X2 =-17

-12 X1 + (-45) X2 =-21

a= [-7 -45; -12 -45]

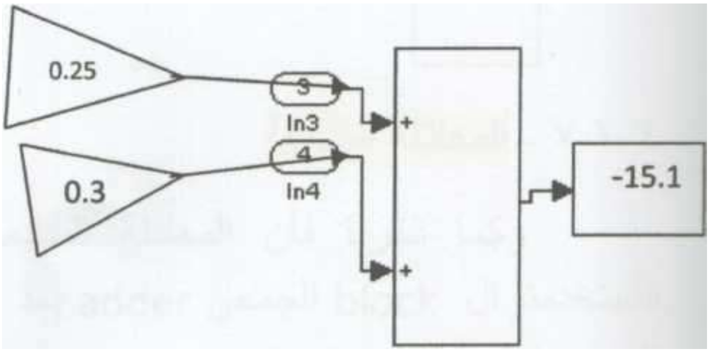
b=[-17; -21;]

c=inv (a)*b= [0.8000; 0.2533]

X1=0.8 x2= 0.2

4100-E6a = 0.8* -6.4 + 0.2*-45 = -14.12

4. The equation 4100- E6b = (-6.4) + (-45)+ (32.4)= -19



-7 X1 + (-45) X2 = -17

-12 X1 + (-45) X2 = -18

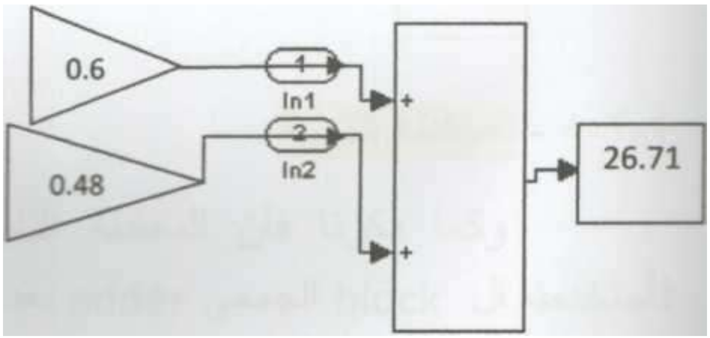
a= [-7 -45; -12 -45;]

b=[-17; -18;]

c=inv (a)*b = [0.2500; 0.3467]

X1=0.2 x2= 0.3

4100- E6b = 0.25* -6.4 + 0.3*-45 = -15.1



5. The equation 4100- E4a = (-14.12) + (-38) + (19.12)= -33

-7 X1 + (-38) X2 *1*=-29

-21 X1 + (-37) X2 =*-31*

a= [-17 -38; -21 -37;]

b=[-29; -31;]

c=inv (a)* b= [0.6213; 0.4852]

X1=0.6   X2= 0.48

4100- E4a =0.6* -14.12+ 0.48*-38 = -26.71

6. The equation 4100- E4b = (-14.12) + (-38) + (14.12) = -38

-17 X1 + (-38) X2 = -38

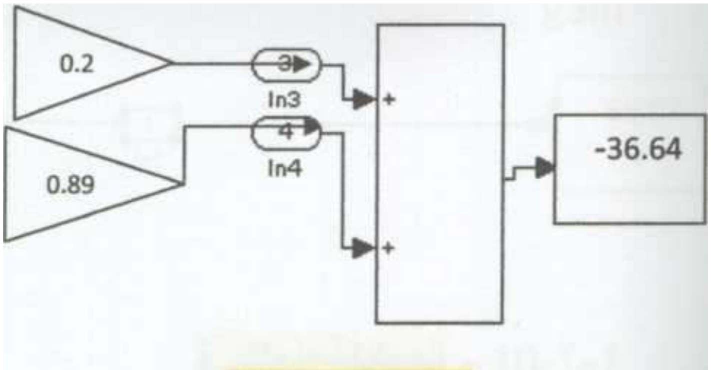
-21 X1 + (-37) X2 = -38

a= [-17 -38; -21 -37;]

b=[-38; -38;]

c=inv (a)* b= [0.2249; 0. 8994]

X1=0.2   X2= 0. 89



4100- E4b = 0.2* (-14.12)+ 0. 89*(-38) = -36.64

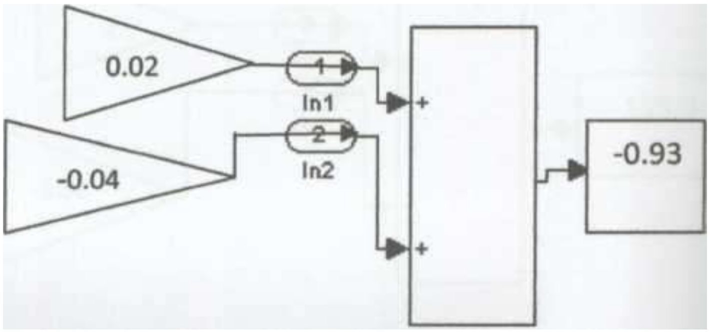
7. The equation 4100- E5a = (-26.71) + 10+ (12.71)= - 4

-29 X1 + 6 X2 =-1

-31 X1 + 5 X2 =-1

a= [-29 6; -31 5;]

b=[-1; -1;]



a =c

X1=0.02   X2= - 0. 04

4100- E5a = 0.02*(-26.71)+ (-0.04)*10 = -0.93

8. The equation 4100- E5b = (-26.71) +10 + (-1.29)= -18

-29 X1 + 6 X2 =-2

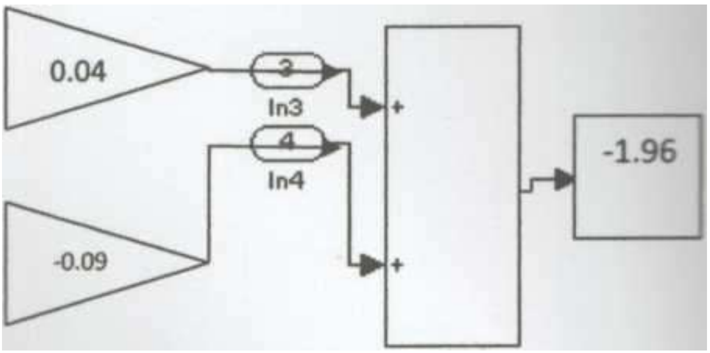
-31 X1 + 5 X2 =-2

a= [-29 6; -31 5;]

b=[-2; -2;]

c=inv (a)* b= [0.0488; - 0. 0976]

X1=0.04   X2= - 0. 09



4100- E5b = 0.04*(-26.71)+ (-0.09)*10 = -1.96

9. The equation 4100-E16a = 178 + 89 + (-117) = 150

170 X1+ 101X2 = 140

169 X1+ 101 X2 = 138

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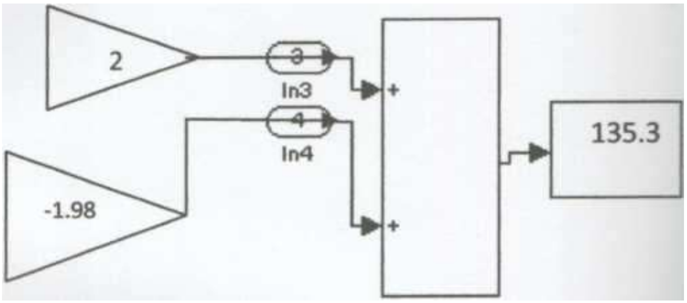
a= [170 101; 169 101;]

b=[140; 138;]

c=inv (a)* b= [2.0000; -1. 9802]

X1=2 X2= - 1. 098

4100-E16a = 2* 178+ (-1.98)*111.4 = 135.3



10. The equation 4100-E16b = 178 + 89 + (-169) = 98

170 X1+ 101 X2 =103

169 X1+ 101 X2 = *101*

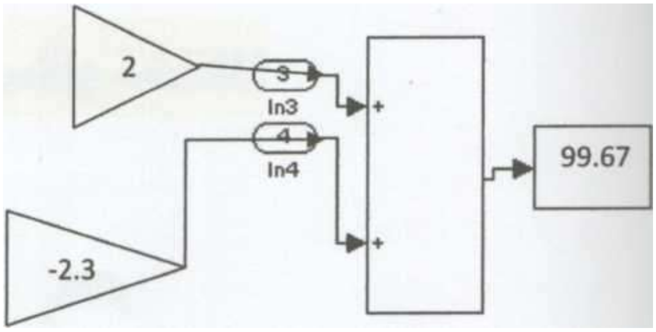
a= [170 101; 169 101;]

b=[103; 101;]

c=inv (a)* b= [2.0000; -2. 3465]

X1=2 X2= - 2.3

4100-E16b = 2* 178+ (-2.3)*111.4 = 99.67



11. The equation 4100-EA5 = 89 + (-29) = 60

101 *X1* = 61

X1=61/101=0.6

EA5 =0.6 * 111.4 = 66.87

After entering the actual temperatures taken from the real world instead of the design temperatures and representing them in mathematical equations that represent the interactions of each part of the system in order to calculate the values of (gain) that have a direct impact on the outputs of the equations that represent each part of the system, we find that some of the outputs of the system parts are inputs to other parts according to the sequence of the system parts. Table (2) shows all the details of the system equations and the impact of their outputs on each other .Figure (3) shows the flow of the system equations and its outputs.

Table (2) the details of the system equations and outputs

No. Eq.	Input 1 from	Input 2 from	Input 3 from	Output to
1	E-10 To C2	E-11 To C2	Output Eq. 5	From C2 To E-6
2	Output Eq. 10	E-11 To C2		From C2 To EA-5
3	Output Eq. 1	V-8 To E-6		From E-6 To E-4
4	Output Eq. 1	V-8 To E-6		From E-6 To E-10
5	Output Eq. 3	V-11 To E-4		From E-4 To V-9
6	Output Eq. 3	V-11 To E-4		From E-4 To V-16
7	Output Eq. 5	V-12 To E-5		From E-5 To K-4
8	Output Eq. 5	V-12 To E-5		From E-5 To V-11
9	Output Eq. 2	Hot oil To E-16		From E-16 To Hot oil
10	Output Eq. 2	Output Eq. 9		From E-10 To C2
11	Output Eq. 2			From EA-5 To S1

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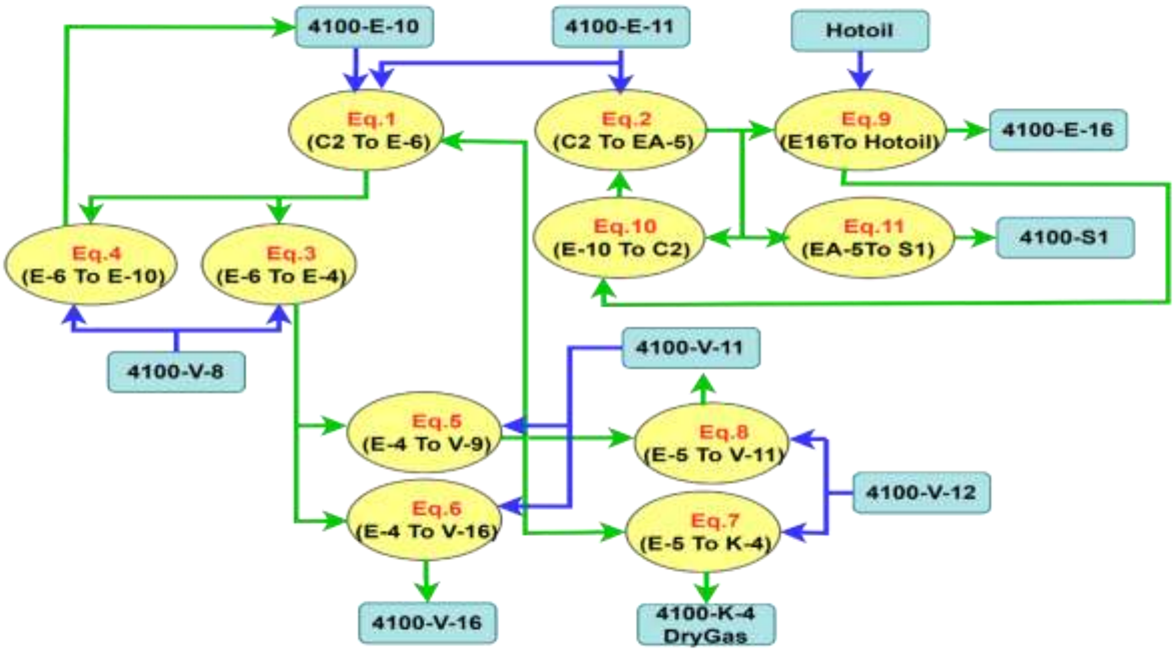

Fig. (3) the flow of the system equations and outputs.

When applying MATLAB/SIMULINK software to the ethane gas separation system to simulate it through a mathematical model to predict the steady state and dynamic behaviour and using the additive block tool to represent the system parts in addition to using the gain tool, a system was obtained that simulates the original system using actual variables, and Figure (4) illustrates this.

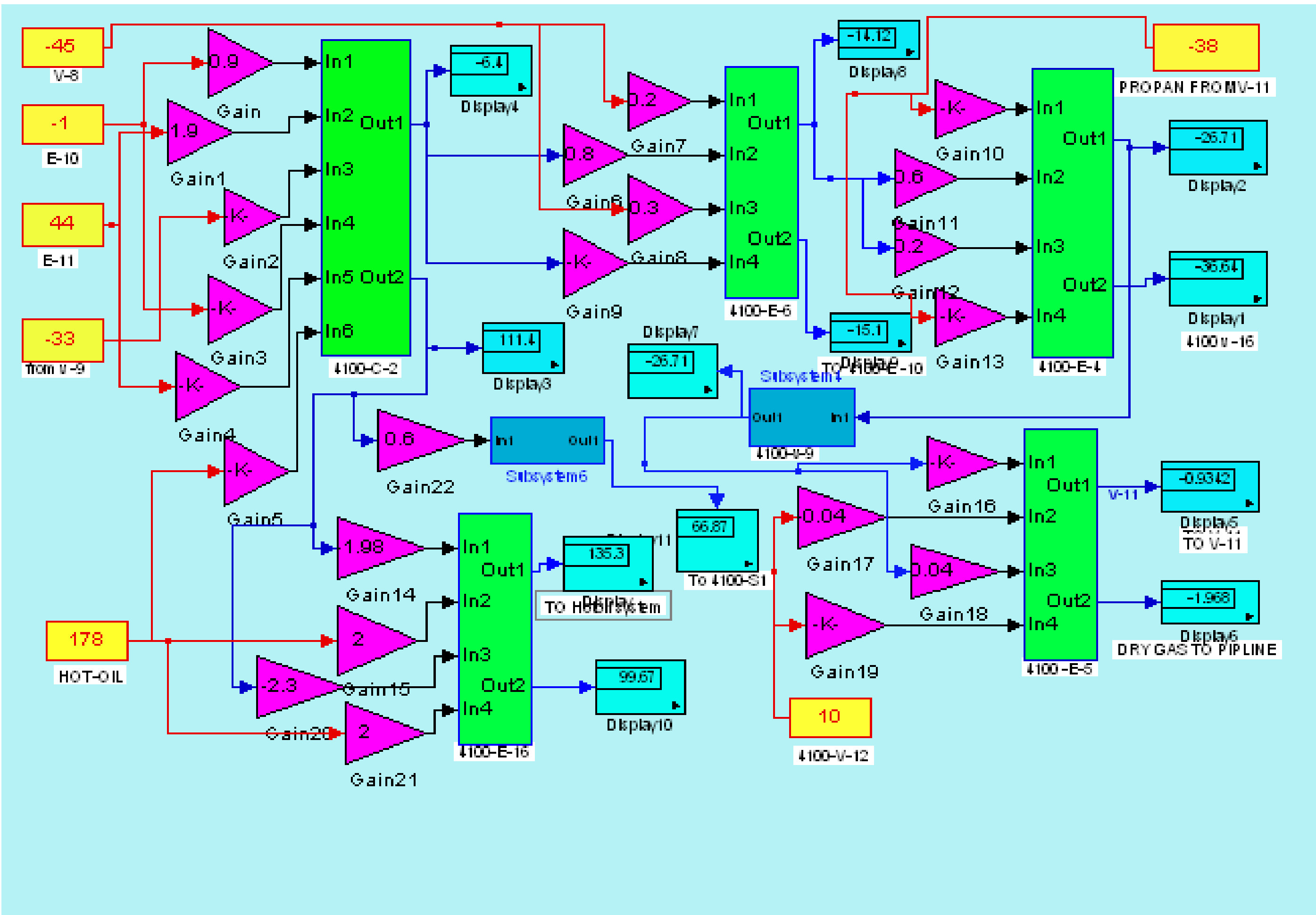

Fig. (4) System simulation using MATLAB/SIMULINK

5. CONCLUSIONS AND RECOMMENDATIONS

A dynamic model with temperature as the primary variable was developed to accurately represent the behaviour of the thermal system for mathematical modelling and dynamic simulation of an ethane splitter in a (NGL) plant. Simulation results demonstrated the model's ability to accurately predict thermal system behaviour using actual system thermal variables. The resulting temperature values demonstrated good agreement with the actual values recorded at the site. The model's reliability and applicability in real industrial environments were demonstrated by the use of realistic operating data and its adaptability to changing operating conditions or design requirements.

Based on the results of the simulation model, we recommend expanding system variables such as flow rate and pressure to improve the accuracy of the system simulation under unsteady operating conditions. We also recommend utilizing the MATLAB/Simulink environment to build an integrated model of the entire unit that can be linked to broader laboratory simulation systems. In conclusion, this model represents a powerful tool for analysing thermal system behaviour and supporting decision-making in the operation and maintenance of ethane splitter units, with clear opportunities for further development and improvement in future research.

DATA AVAILABILITY STATEMENT

All data, models and code generated or used during the study appear in the submitted article.

DECLARATION OF CONFLICTING INTERESTS

The author(s) declare(s) that there is no conflict of interest.

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