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DEVELOPMENT OF AN AUTOMATED SMART SYSTEM FOR AIR PURIFICATION IN AN URBAN ENVIRONMENT

Abstract

This article presents the development of an automated control system for the process of amine purification of polluted mixtures, a critical industrial process for removing hydrogen sulfide and other acid gases from gas streams. To emphasize the relevance and significance of this study, a preliminary analysis was conducted utilizing databases on pollution levels in the city of Almaty. The analysis provided valuable insights into the current environmental conditions and underscored the necessity of implementing effective purification technologies. The mathematical modeling of the amine purification process was carried out using the Simou method, resulting in an accurate transition function for the system. The parameters of the mathematical model were determined, and an in-depth analysis was performed to evaluate the stability, controllability, and observability of the system. These analytical procedures were executed using MATLAB software. To enhance system performance, PI and PID regulators were synthesized and evaluated. The simulation results guided the practical implementation of the automation system, utilizing the Modicon M340 programmable logic controller from Schneider Electric and the Harmony 6400 control panel. A visualization system for the amine purification process was developed using a mnemonic circuit that includes a control panel, an indicator panel, and graphical representations of key process parameters. The EcoStruxure Control Expert and EcoStruxure Terminal Expert software were employed to design and optimize this visualization system, ensuring user-friendly and efficient monitoring and control. In addition to addressing industrial process needs, a Smart City concept was developed as part of the research. This concept leverages the ARIMA (Autoregressive Integrated Moving Average) artificial intelligence method to analyze the concentration of harmful substances in the air. By integrating this analysis, the study aims to contribute to broader urban environmental management efforts. The outcomes of this work highlight significant advancements in industrial gas purification technology and its applications in environmental management, contributing to the development of sustainable and efficient solutions for modern industry.

Key words: Smart city, Artificial intelligence, Air purification, Carbon capture, Absorption column, ARIMA, Programmable logic controller.

Introduction

This article focuses on developing an advanced automated control system specifically tailored for the carbon capturing process. This process is based on chemical reaction of solvent and flue gas, that comes from industrial emission. The inception of this research was influenced by an in-depth study utilizing databases to analyze pollution levels in the city of Almaty. The objective was to evaluate the significance of implementing such a system in terms of its potential impact on reducing local pollution levels.

To accurately model the amine purification process, the Simou method was employed. This approach enabled the creation of a mathematical model that effectively describes the dynamic behavior of the process through a precise transition function. Utilizing MATLAB software, several key aspects of the mathematical model were analyzed. Parameters were derived and rigorously tested through analytical procedures that examined the system's stability, controllability, and observability. The work also involved the synthesis and assessment of both Proportional-Integral regulators. These regulators are integral for maintaining the desired level of control over the purification process, optimizing performance and efficiency.

Following successful simulation studies, the automation of the process was implemented using the M340 Programmable Logic Controller (PLC) from Schneider Electric. For operational control and monitoring, a sophisticated human-machine interface (HMI) was developed. This interface features a control panel that allows operators to interact with the system efficiently, an indicator panel that displays system statuses, and graphical representations of key process parameters and PI controller performance. The HMI software, EcoStruxure Control Expert and EcoStruxure Terminal Expert from Schneider Electric, were utilized to develop and integrate these visualization tools. Overall, this article exemplifies the integration of advanced modeling techniques, rigorous system analysis, and modern automation technology to enhance industrial purification processes, contributing significantly to environmental protection efforts.

At the 21st United Nations Climate Change Conference (COP21) in Paris, socio-environmental challenges like droughts and flooding from global warming were identified, and sustainable ecosystem management was highlighted as key to reducing greenhouse gas emissions (IPCC, 2021) [1]. The Kyoto Protocol, an international agreement aimed at reducing greenhouse gas emissions, identified six primary greenhouse gases that significantly affect the environment: CO2 (carbon dioxide), CH4 (methane), N2O (nitrous oxide), HFCs (hydrofluorocarbons), PFCs (perfluorocarbons), and SF6 (sulfur hexafluoride). Among these, carbon dioxide is considered the leading contributor to global climate change [2]. For example, carbon dioxide emissions rose from 22.15 Gt in 1990 to 36.14 Gt in 2014 [3]. Various efforts have been made to reduce the environmental impact of fossil fuels, including enhancing process efficiency, developing innovative energy conversion technologies, and advancing affordable renewable energy sources with minimal environmental effects, such as solar, wind, biomass, and geothermal energy [4]. Carbon capture and storage (CCS) has shown promising potential in mitigating global warming and combating climate change [5]. The Sleipner project in Norway, launched in 1996, and the In-Salah project in Algeria were pioneering CCS initiatives designed to test the feasibility of injecting CO_2 into saline aquifers, with Sleipner handling up to 0.9 million tons per year and In-Salah reaching a capacity of 1.2 million tons annually. In 2019 there were 22 large-scale ongoing CCS projects worldwide [6].

All carbon capture methods are generally classified into three main processes: pre-combustion, oxy-fuel combustion, and post-combustion, with other industrial approaches, whether low-carbon or carbon-free, being based on one or a combination of these core techniques [7]. In Qatar LNG CCS project has added cryogenic separation technology, where carbon dioxide is captured from industrial exhaust gas streams through cryogenic cooling [8], to their infrastructure [9]. Oxy combustion, implemented in UK, North Yorkshire [10] is a technique of burning fuel using pure oxygen, resulting in higher temperatures, lower fuel use, and higher CO_2 concentration [11]. In pre-combustion carbon capture, CO_2 is extracted from fossil fuels prior to combustion. Although pre-combustion capture offers higher efficiency, it is generally more costly than the post-combustion capture process [12]. The post-combustion CO_2 capture technique effectively removes CO_2 and other gases emitted from the combustion of fossil fuels, utilizing either physical or chemical adsorption and absorption mechanisms [13]. The amine-based carbon capture process is suitable for retrofitting existing power plants and other industrial combustion processes [14]. The scale-up and enhancement of amine-based carbon capture technology gained momentum in the mid-2000s due to increasing commercial interest in carbon capture. To accelerate CCS deployment over the next decade, CO_2 capture with amine-based solvents – currently the most effective and advanced technology – is critically important [15].

And now a lot of facilities are based on this method of CCS. The best examples are Petra Nova in USA[16], SaskPower's on Boundary Dam's Unit 3 in Canada [17], Al Reyadah in UAE [18]. In Kazakhstan there is Unit 300 in Tengizchevroil [19]. Unit 300 is a unit for cleaning hydrocarbon gases of separation and stabilization coming from the U-200 from acidic components ($_{H2S}$ and CO_2) with a circulating DEA solution [20].

1 Materials and Methods

1.1 Description of technological process

The technological process, that was described, involves carbon capturing and compressing, and does not include its further processing or storage, is shown in Figure 1.

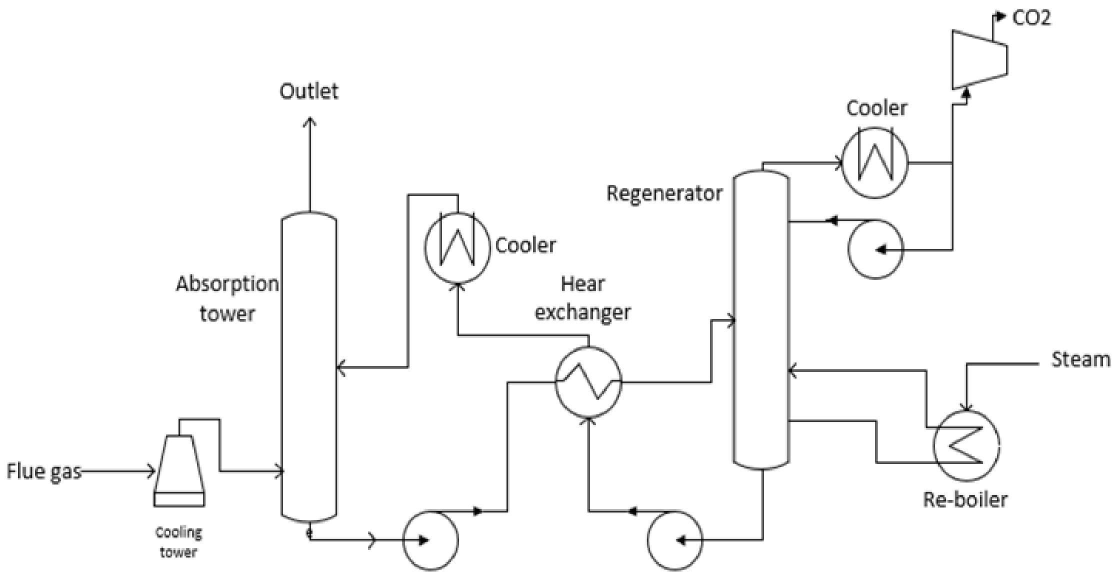

Figure 1 – Technological process scheme of capturing CO_2

Sequence of technological process of capturing CO2 shown in Figure 2. Firstly, the flue gas, that consist mainly of nitrogen, water, CO_2 and other impurities such as oxides of sulphury (SOx) or nitrogen (NOx) and dust [29], is cleaned of large particulates and contaminants, which prevents damage to the subsequent carbon capture system and affects its durability [22]. Within this tower, amine solutions Monoethanolamine (MEA) or Diethanolamine (DEA), are strategically deployed to effectuate the chemical binding of carbon, with a particular focus on carbon dioxide present in the flue gas. The interaction between the flue gas and the amine solution results in the absorption of CO_2, effectively entrapping it in the solution for further processing.

As the flue gas traverses through the amine solution, the CO_2 molecules become immobilized within the liquid medium, leading to a saturation point where the amine solution is replete with captured carbon. The formula of reaction:

$$C_2H_4OHNH_2 + H_2O + CO_2 \Leftrightarrow C_2H_4OHNH_3^+ + HCO_3^- \quad (1)$$

The concentration of MEA will be 30% and expected to capture 90% of CO_2. And in reinforced mode MEA will be 20% and capture 95% of CO2. However, the specific heat requirement as well as the costs are sharply decreasing with increasing MEA concentration from 15% to 20%. It can be explained that when using too low MEA concentration (e.g., 15% MEA), it will lead to a large solvent flow rate and thus expand the equipment dimension and higher CAPEX [30].

At this juncture, a vital facet of the carbon capture process unfolds, necessitating the regeneration of the saturated amine solution. The solvent is then recycled within the system. Subsequent cooling and recombination of the amines are performed to restore the solution's pristine condition, rendering it once again capable of efficiently capturing additional CO_2 from the incoming flue gas.

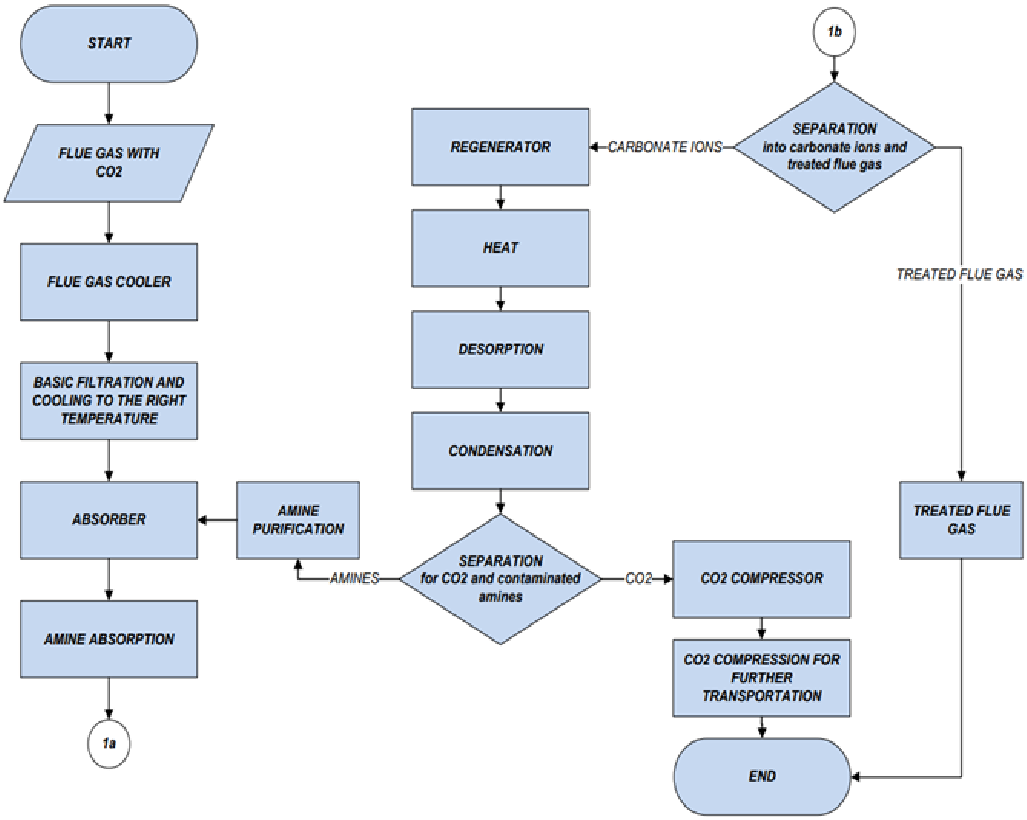

Figure 2 – Sequence of technological process of capturing CO_2

In the wake of the successful regeneration of the amine solution, the extracted CO2 is subjected to compression to attain the requisite pressure and concentration for its subsequent transportation and storage. Notably, a defining characteristic of this facility, constituting the essence of the overarching project, lies in the further utilization of the captured carbon dioxide. It is routed through an intricate network of pipelines, ultimately destined for injection into aged oil reservoirs. This innovative application serves to elevate reservoir pressure and augment oil recovery efforts by facilitating the expulsion of a larger volume of oil through the pre-existing wells, thereby bolstering oil production and recovery rates.

The control object in our technological process is the amine absorber. The separation unit system is subject to a three-level automated process control system model. The separation unit measures the temperature, and flow rate of amine, the concentration of CO_2 as an output. In Figure 3 its structural scheme is shown.

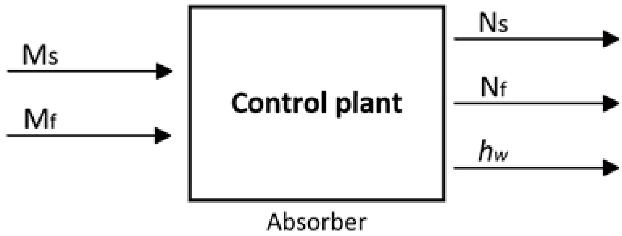

Figure 3 – Structural scheme of control plant

The diagram above shows which variables depend on our managed inputs. That were described in Table 1.

Table 1 – Main characteristics of control plant

Name of the parameter	Description	Input/Output signal	Discrete or Analog
Ms	Amount of solvent	I	A
Mf	Amount of flue gas	I	A
Ns	Amount of outlet flue gas	Q	A
Nf	Amount solvent containing dissolved CO_2	Q	A

1.2 Mathematical model

The transfer function is calculated based on the transition process curve using specialized programs for analyzing and synthesizing automatic control systems. Figure 4 displays the curve that best represents the actual transient process of reagent consumption into the absorber, which was obtained through experimental identification in at the complex gas Unit no. 9 of the Urengoy Gas Condensate Field. The researchers had access to the control plant during the experiments [24].

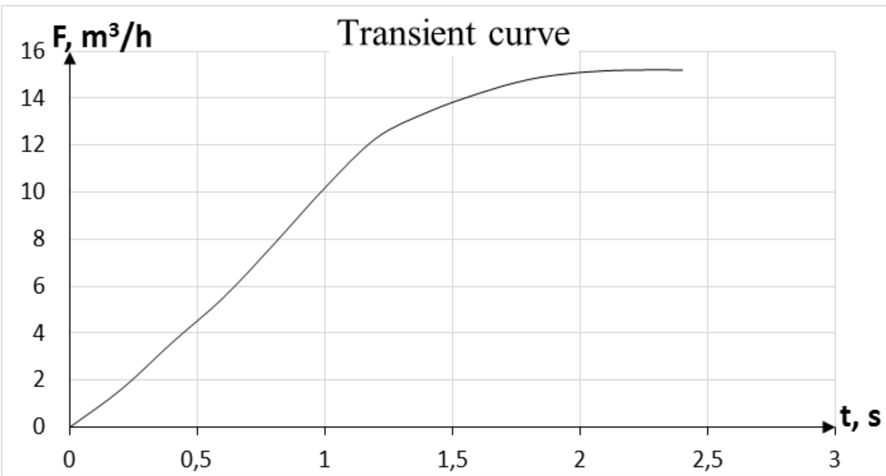

Figure 4 – Transient curve of solvent consumption into the absorber

Transfer function coefficients will be calculated by Simou "area" method [31]. The general view of the model for Simou method:

$$W(p)^{-1} = K\overline{W}_m(p)e^{-p\tau} = K\frac{1 + b_1p + b_2p + \cdots + b_mp^m}{1 + a_1p + a_2p + \cdots + a_np^n}e^{-p\tau}, \tag{2}$$

Selection of a functional model based by Simou in MATLAB. Transition curves of the models can be computed from the identified transfer functions utilizing the inverse Laplace transform method. The outcomes of the transient calculations performed on a computational platform are provided below. The coordinates of the transition points based on Model 4 and Model 5 roots are shown in Figure 5.

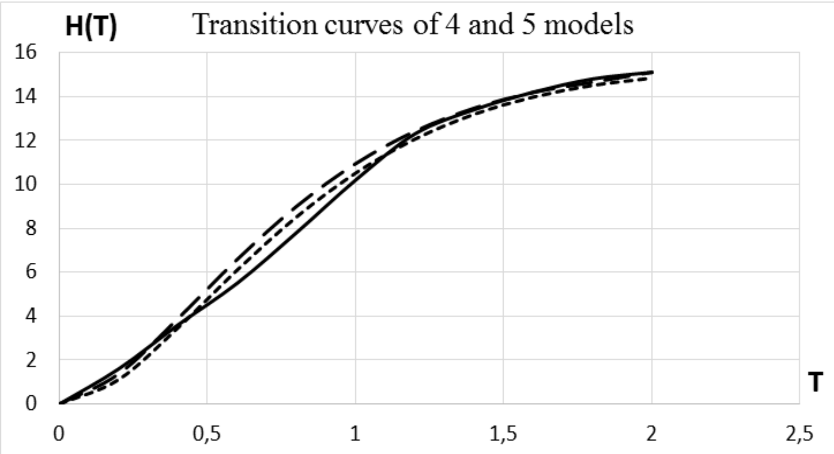

Figure 5 – Transition curves of 4 and 5 models

As can be seen from Figure 5, the 5th model turned out to be the closest to the object, the transfer function of which has the form:

$$W_m(p) = \frac{1 + 0.2p}{1 + 0.78p + 0.2p^2}, \tag{3}$$

This is the transfer function of CCS process that describes the Transient curve of Unit no. 9 of the Urengoy Gas Condensate Field, that shown in a Figure 5, derived by the Simou method in Matlab.

1.3 Selection of regulatory laws

To implement and chose regulator MATLAB was used. There is a tool PID Tuner, that can set proportion, integral and derivative modes and calculate all characteristics off step input. To simulate and see the result, the project that shown in Figure 6 was designed.

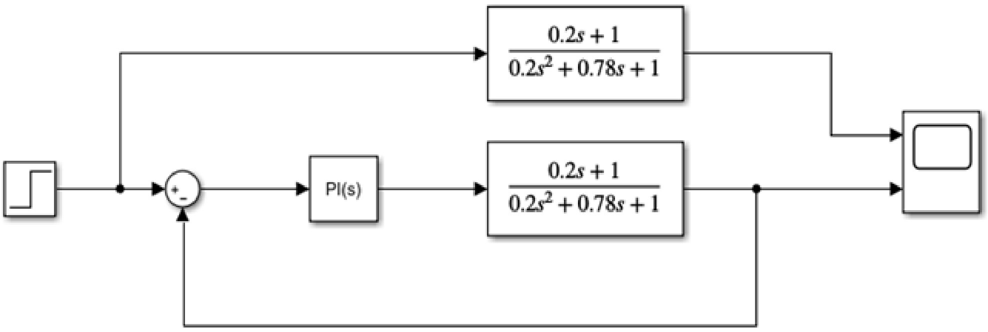

Figure 6 – Structural diagram of an open and closed system with a PI controller

In this structural diagram at the beginning “Step” block is used. This is the source of signal to see the process response. Then the “Transfer function” blocks are used. The first one goes to right to the “Scope”, that is needed to see result graphs. “PI(s)” goes after the second “Transfer function” block. Inside of this block the main part of controller. By this way there are two graphs: graph without controller and with controller, which are shown in a “Scope” in Figure 7 below.

The graph shows that the PI controller compensates for fluctuations in the early stages of the process and brings the system to the required level. The simulation results of a closed system with and without a PI controller clearly show that the quality of the transition process has changed - the regulation time has decreased. The transition process proceeds faster, the adjustment time is about one second, there are no overshoot phenomena and fluctuations of small amplitude. In Figure 7 dotted line graph show the transient process graph without PI controller and blue line shown transient process graph with PI controller. After that they can be compared, by characteristics taken in Matlab.

Figure 7 – Transient process graph without and with PI controller

The important controllers’ parameters and characteristics of system with and without controller are shown in Table 2 and Table 3.

Table 2 – PI controller parameters and characteristics of system

Characteristics	With PI controller	Without PI controller
Proportional gain	9.945	1
Integral coefficient	15.9594	0
Gain margin	Inf dB	Inf dB
Phase margin	77.4 deg	-180 deg
Peak	1.07	0.516
Overshoot	6.74%	3.12%
Rise time	0.151 seconds	0.598 seconds
Settling time	0.602 seconds	1.6 seconds
Steady-state error	0	0.4
Steady-state value	1	0.6
Closed-loop stability	stable	stable

To compare results Table 3 shows PID controller characteristics. In the left is the most suitable and in the right is controller with huge coefficients.

Table 3 – PID controller parameters and characteristics of system

Characteristics	With PID controller	With PI controller
Proportional gain	1.8328	9.945
Integral coefficient	4.5571	15.9594
Derivative coefficient	0.0976	0
Gain margin	Inf dB	Inf dB
Phase margin	69 deg	77.4 deg
Peak	1.08	1.07
Overshoot	8.83%	6.74%
Rise time	0.521 seconds	0.151 seconds
Settling time	1.63 seconds	0.602 seconds
Steady-state error	0	0
Steady-state value	1	1
Closed-loop stability	stable	stable

The results obtained with the help of the PI controller shows that the rise time and the settling time decrease. Overshoot is decreased because of Integrating part is included. The error decreases and reaches 0. Clear evidence for clear and accurate results of PI controller impact.

2 Results and Discussions

2.1 Controller Programming

Simulation of chosen Modicon M340 controller can be achieved in EcoStruxure Control Expert. In this software configuration of controller, code, operator screen can be done. The main idea of all simulation part is to connect real M340 controller with EcoStruxure Control Expert. In KBTU there are Schneider Electric stands with M340 and M241 controllers (Industrial Automation Lab), indicators, switches and terminals.

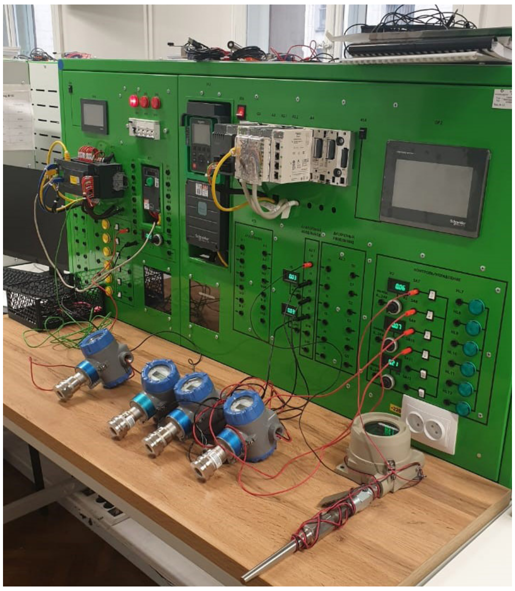

Figure 8 – Modicon M340 controller

In Figure 8 M340 controller is shown. With this controller all process was simulated and implemented in the next sections. In EcoStruxure Control Expert two HMI displays were made. The first is shown in Figure 9. This is a complete SCADA system where operator can monitor the entire simulation parameters, such as pressure, temperature and flow, as well as turn valves on and off.

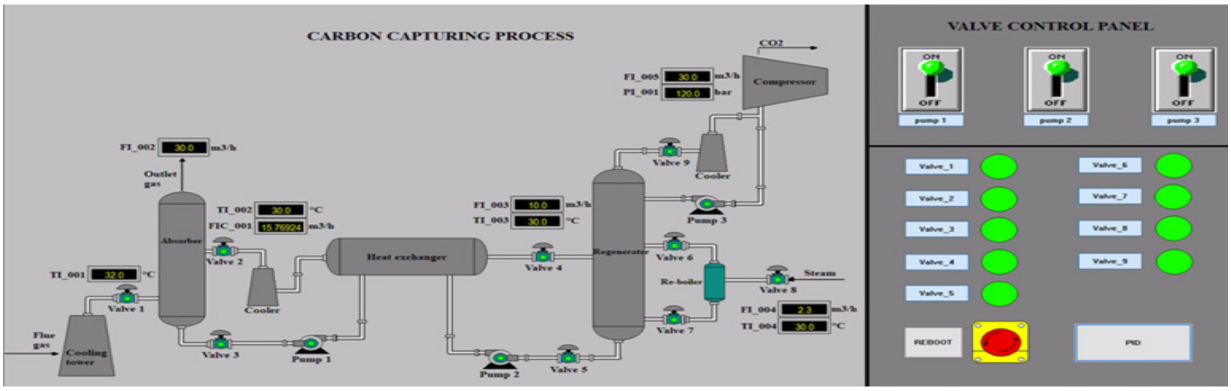

Figure 9 – HMI display for carbon capturing process

In the left there is a carbon capturing process, in the upright part there are animated switches designed for pumps. Below there are buttons with indicators for valves. Also, there is an emergency reboot button, that turn of all valves and pumps, for emergency situations. And in the left bottom there is a link to PID controller display, that is shown in Figure 10.

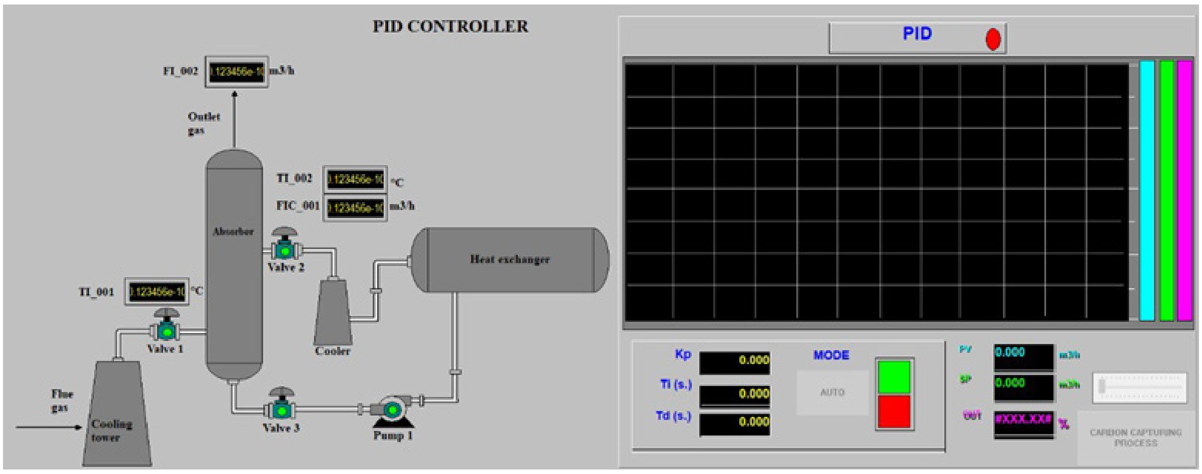

Figure 10 – PI controller display

PID controller display is also divided in two parts. In the left side there is our control object. In this display it's impossible to turn on or off them. It's only for monitor and set PI controller that shown in the right side. There process value, set point and PI out signal parameters with corresponding colors are shown. Set point can be changed. Changes in PV, SP and OUT can be observed on the graph. Also, in its right there are bar charts, that show corresponding values. In the bottom of PID window there are coefficients of PID controller. Moreover, there is a button for PI mode changing from automatically to manual. In the right bottom there is link back to the whole process. In Table 4 program variables are shown.

Table 4 – Program variables

Name	Type	Value	Address	HMI variable
1	2	3	4	5
All valve	EBOOL		%Q0.2.20	☒
Flow1_Q	INT		%QW0.1.0	☐
FlowSen_1	REAL			☒
FlowSen_2	REAL			☐
Mode	EBOOL			☐
Out	REAL			☐
PI_par	Para_PI_B			☐
PessureSens_1	REAL			☐
Pump_1	EBOOL		%QW.0.2.19	☐
Pump_2	EBOOL			☐
Pump_3	EBOOL			☐
PV	REAL			☒
PV_Q	INT		%QW.0.1.1	☐
sec1	EBOOL			☐
SP	REAL	15	%QW.0.1.2	☐
Temp1_Q	INT		%QW.0.1.3	☐
TempSen_1	REAL			☒
TempSen_2	REAL			☒
TempSen_3	REAL			☐
TempSen_4	REAL			☐
timer	EBOOL			☐
Valve_1	EBOOL		%QW.0.2.16	☒
Valve_2	EBOOL		%QW.0.2.17	☒
Valve_3	EBOOL		%QW.0.2.18	☒

There are variables for all valves, sensors, pumps, variables that used in PID controller. There the limits and coefficients of PID located. Valves are EBOOL, all sensors are REAL type variables will be used in HMI to open or close valves and indicate sensors reading. But in the BMX AMM 0600 only INT type of variable can be used. So that there are additional variables that were transformed from sensors and PI controller REAL variables to INT and sand to M340 controller. Not every variable was presented. To connect these variables with M340 several steps have been taken. First, it is just necessary to put HMI variable mark in every necessary variable. Next is addressing. In the I/O modules there are corresponding addresses that can be taken with variables. The process of writing code is divided into two stages. Connecting these two blocks is shown in Figure 11.

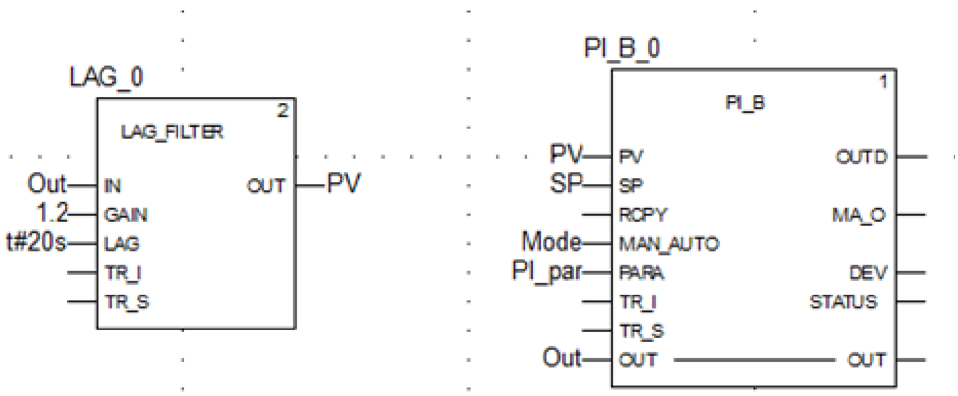

Figure 11 – PID regulator realization in PLC

The second stage of writing code is animation. To animate the entire process, it's necessary to configure and write the logic for all sensors. To do this, it is most convenient to create a section in the ST language. This code describes the logic of process animation in HMI. If the first valve opens and the other valves are also open, then the process starts, and the main reaction begins. It's possible see that the values change and FIC_001 shows the flow sensor on the PID controlled valve.

In the main HMI, shown in Figure 12, all the elements are presented: Cooling tower, Absorber, Coolers, Heat exchanger, Regenerator, Re-boiler, Compressor connected with tubes. They all designed using Ecostuxure Control Expert library, where there are a lot of figures and pattern for valves, pumps, tubes etc., that can be animated using code. In the pump and tubes there are some indicators, that change color depending of its status, ON of OFF. The background color is light grey, which is traditional for HMI display.

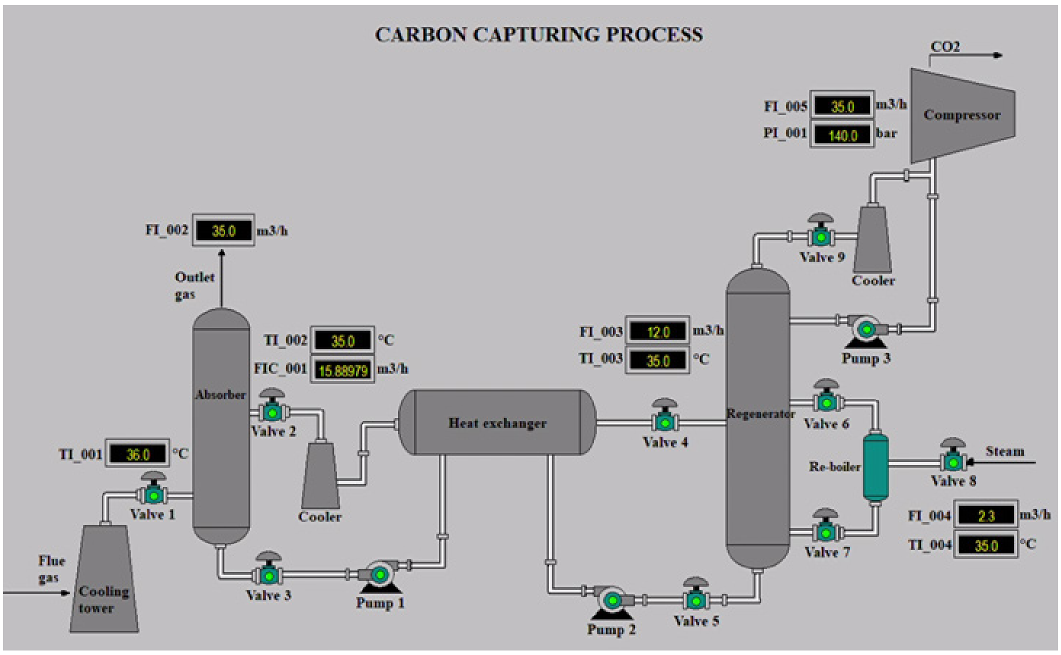

Figure 12 – HMI with animation

The whole process values were taken from real plant. The PID controller animation was visualized by trend diagrams and bar charts in Figure 13.

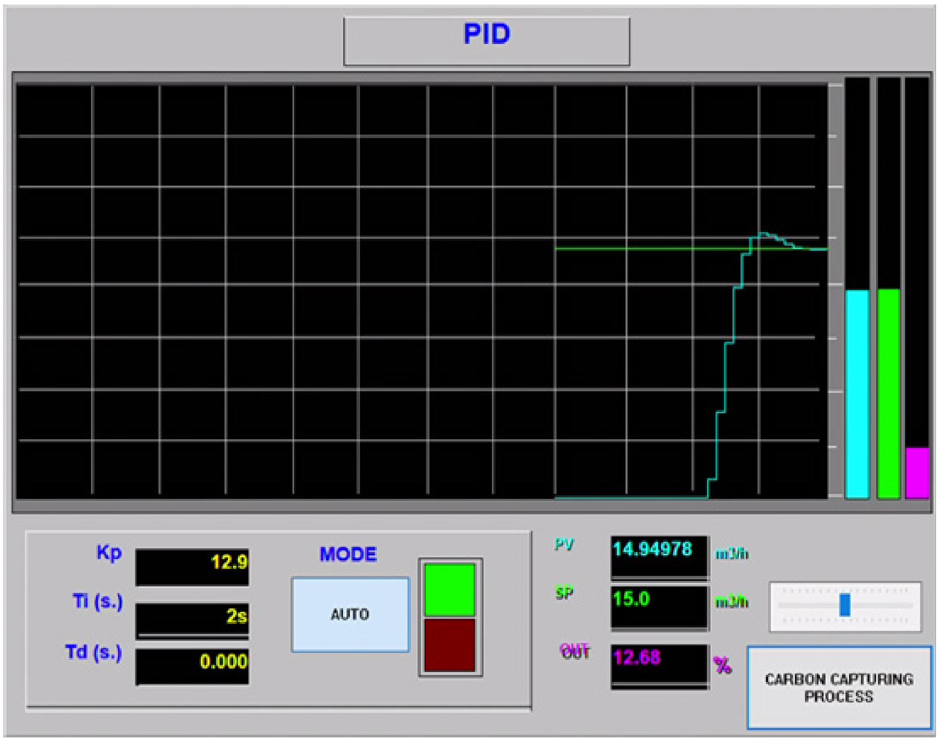

Figure 13 – PID display in run mode

If set point is changing the regulator signal "Out" start affect on process value. It's impossible to show HMI designed in EcoStruxure Control Expert in the terminal. That why it's required to design another HMI in EcoStruxure Operator Terminal Expert, which will be projected in the Schneider Electric terminal. By this HMI control object will be automated. In Figure 14 the designed HMI is shown. There are all variables are set. To see the result, it has to be simulated or downloaded to controller.

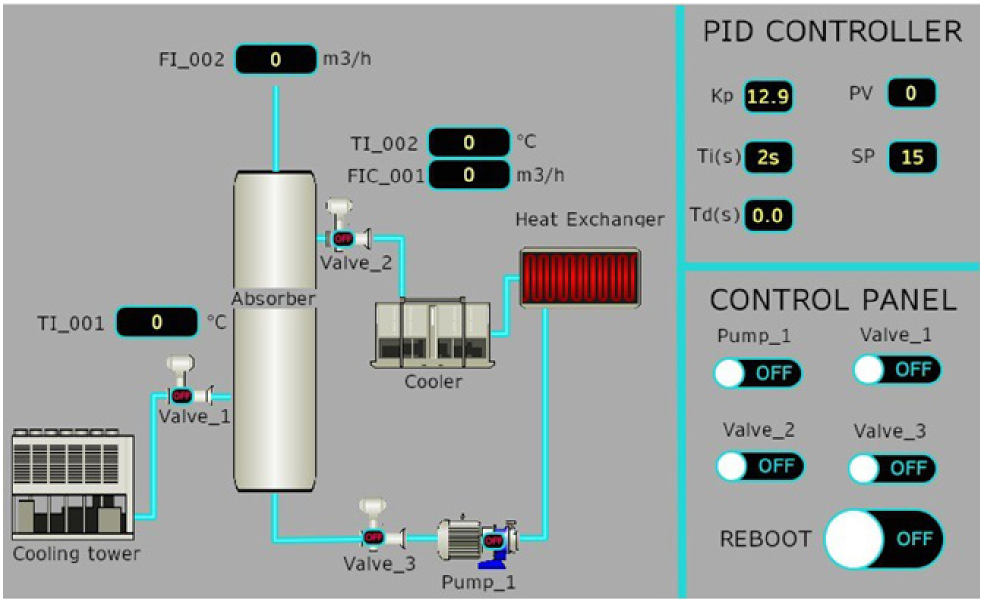

Figure 14 – Simulated screen (Panel Harmony)

There are no changings in variables. To see everything connected the Control Expert project and this project have to be downloaded. In Figure 15 connections of output and indicators are shown.

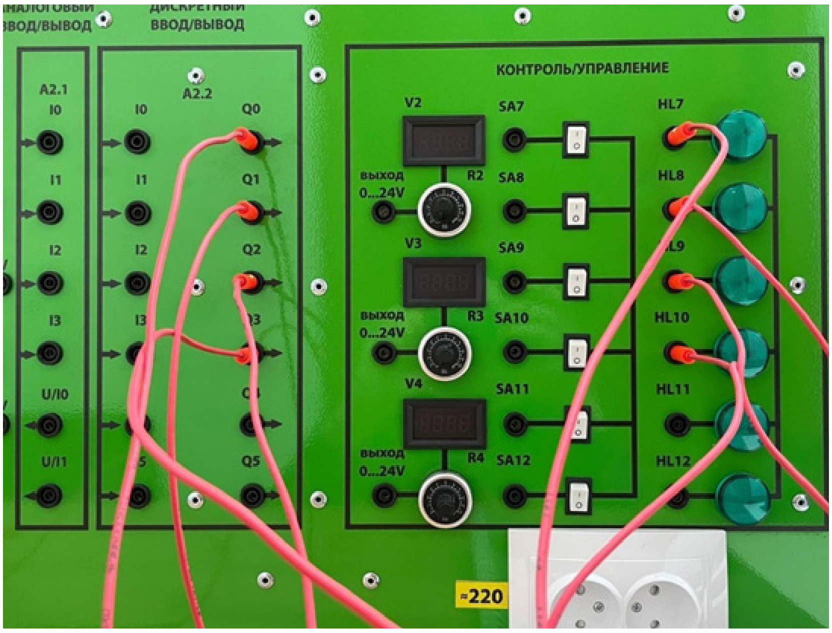

Figure 15 – Inputs and Outputs

In the Figure 16 simultaneous work of EcoStruxure Control Expert and EcoStruxure Terminal expert is shown. If there were no errors in connecting and transferring projects, then parallel changes in permanent animations should be observed.

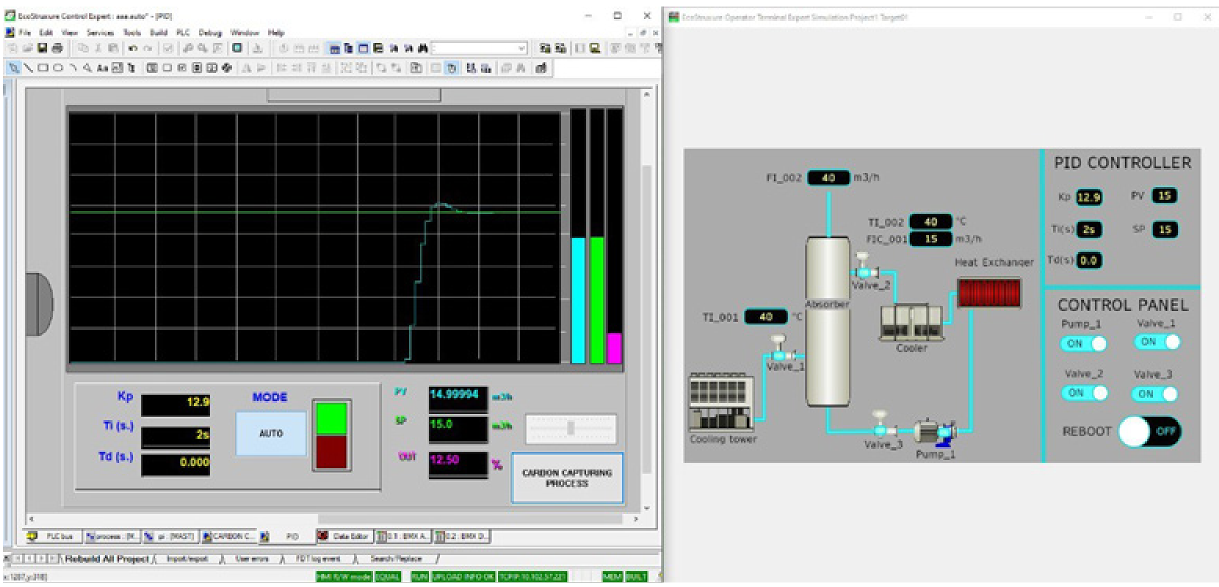

Figure 16 – Simulation in EcoStruxure Control Expert
and Operator Terminal Expert

In Figure 17 the simultaneous change of the corresponding variables like PV, pump and valves can be observed.

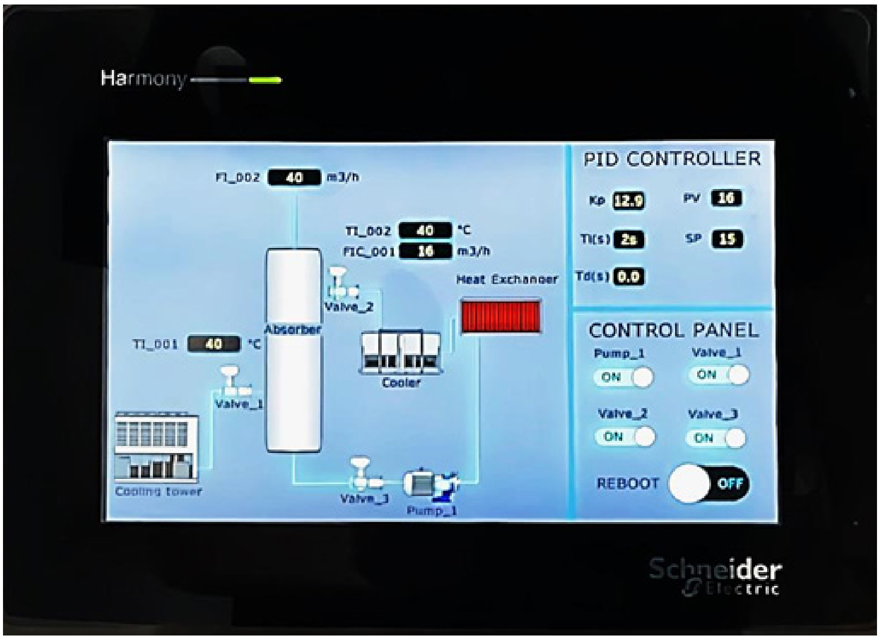

Figure 17 – Terminal Harmony 6400

And them can be changed and modified from Control Expert simulation, from Terminal Expert simulation and from programmed terminal in Schneider Electric stand's Terminal that sown in Figure 16.

2.2 Smart city application

To integrate the proposed purification system effectively into the smart city infrastructure, it is advocated for the utilization of artificial intelligence (AI) for air quality forecasting. In instances where unfavorable conditions are forecasted, an enhanced operational mode for the system is suggested. Given the availability of extensive historical data, the decision to utilize meteorological data for forecasting was driven by its free accessibility and rich dataset. Meteorological conditions have a significant impact on the level of air pollution. The distribution of pollutants is highly dependent on wind speed and direction, as well as atmospheric currents [25]. These factors contribute to the long-range transport of pollution from emission sources such as industrial plants and motor vehicles. If air masses are directed towards populated areas, this can lead to increased concentrations of pollutants at these locations.

Four primary meteorological parameters that significantly influence air quality conditions emerge: wind velocity, air temperature, soil temperature, and precipitation. Within the scope of the investigation, the Kazhydromet [27] meteorological database was utilized to procure data spanning from February 10, 2020, to November 30, 2023. Daily mean values of the selected meteorological parameters, sourced from the Almaty meteorological station, constituted the basis of the analysis. Air quality metrics were sourced from the AirKaz.org [28] platform, with particular emphasis on the CO concentration, owing to its comprehensive availability and indicative value. Consequently, forecasting endeavors were predicated upon projections of CO concentrations as the principal air quality indicator for specific dates. Accordingly, forecasting was made by this indicator. Air quality data were not available for some dates, so data preparation for analysis involved the following steps: data loading. handling missing values, addition of independent variable columns. The data preparation resulted in a dataset of more than 1300 rows ready for training the artificial intelligence model and shown in Table 7.

Table 5 – Dataset for training the AI model

Date	S1	S2	S3	S4	CO
30.11.2023	2,2	0,5	4	7,3	2
29.11.2023	0	0	3	9,6	14
28.11.2023	0	0,4	2	6,9	8
27.11.2023	0	0,5	2	4,7	11
26.11.2023	0	1	1	4	14
…	…	…	…	…	…
10.02.2020	0	0,9	0	8,1	19

Where S1 – precipitation, S2 – wind velocity, S3 – soil temperature, S4 – air temperature. This dataset will be used for further analysis and forecasting. The IBM SPSS Statistics tool was selected for forecasting due to its robust data analysis capabilities and powerful statistical modeling tools. Within the scope of the research, the collected data were imported into the SPSS Statistics, based on which a graph shown in Figure 18 was generated.

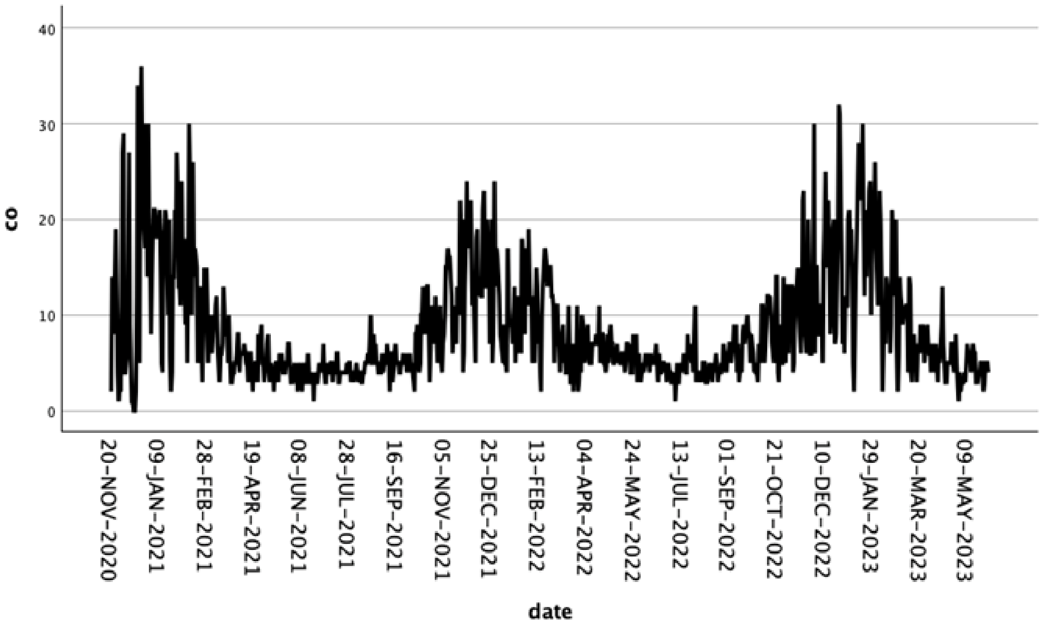

Figure 18 – CO concentration by date

The ARIMA (Autoregressive Integrated Moving Average) model is a statistical technique for forecasting time series. The ARIMA model's chosen because it's adapted at analyzing time series like collected air quality and meteorological data, capturing temporal trends and seasonal variations crucial for accurate air quality forecasting [33]. It is based on three main components: autoregression (AR), integration (I) and moving average (MA). Autoregression (AR): This component means that the value of a time series at a particular point in time depends on its previous values. ARIMA uses autoregression to predict the future values of a series based on its past values. The autoregressive parameter is denoted as «p». Integration (I): This component indicates the number of times a time series needs to be differentiated to make it stationary. A stationary time series is one in which statistical characteristics such as mean, and variance remain constant over time. Integration helps to convert a non-stationary series into a stationary series. The integration parameter is denoted as «d». Moving Average (MA): This component accounts for model prediction errors using a weighted sum of previous errors. This helps to account for the correlation between observations over time. The moving average parameter is denoted as «q». The combination of these three components allows ARIMA to account for different time series characteristics and provides flexibility for predicting different types of time series. The IBM SPSS Statistics tool enables model training and forecasting without the use of program code, simplifying the task for researchers. During model tuning, CO particle content data were specified as the predicted value and meteorological factors data as inputs to the forecast. The IBM SPSS Statistics tool automatically selects the best model to accurately forecast a particular data set, but an important adjustment when forecasting by independent variables is to select only ARIMA models. After the specified settings, a model of ARIMA type (1,0,2) was generated.

Time Series Modeler

Trainig data for forecasting

Model Description

			Model Type
Model ID	co_actual	Model_1	ARIMA(1,0,2)(0,0,0)

Model Summary

Model Fit

Fit Statistic	Value
R-squared	.806
RMSE	7.889
MAPE	3.095
MAE	5.679

Figure 19 – Model Description and Model Fit table

IBM SPSS Statistics automatically calculates statistical parameters to evaluate model validity. The assessment of model accuracy is crucial to validate the model's effectiveness in capturing the underlying data patterns and predicting future values. To conduct assessment of the model several statistical indicators were employed, namely R-squared (R^2), Root Mean Square Error (RMSE), Mean Absolute Percentage Error (MAPE), and Mean Absolute Error (MAE). These metrics provide insights into different aspects of model accuracy and error magnitude, facilitating a comprehensive understanding of model performance.

R-squared (R^2) measures how much variance in a dependent variable is predictable from independent variables, with values closer to 1 indicating better model predictions. Root Mean Square Error (RMSE) quantifies the differences between predicted and observed values, with lower RMSE values indicating smaller differences and thus, a better model. Mean Absolute Percentage Error (MAPE) is a percentage measure of prediction accuracy, where lower percentages (less than 10% is excellent, 20% is good, and over 50% shows inaccuracies) indicate a better fit. Mean Absolute Error (MAE) measures errors in the same units as the data, with values closer to 0 suggesting closer predictions to actual outcomes.

A good predictive model is generally characterized by high R-squared (close to 1), low RMSE, low MAPE, and low MAE values. This evaluation not only confirms the model's accuracy but also aids in identifying areas for improvement, ensuring effective forecasting and decision-making processes based on the model outputs.

Table 6 – Model Fit table from SPSS Statistics tool

Fit statistics	Value
R-squared	0,806
RMSE	7,889
MAPE	3,095
MAE	5,679

As evidenced by the results of the model estimation, R-squared is equal to 0,806. R-squared is a measure of model fit to real data. This means that the obtained model can explain 80.6% of the variability of the time series. At the same time, other indicators characterizing deviations are quite small. It is also necessary to take into account that the forecast did not consider the volume of emissions of harmful substances, as well as the factor of transfer of harmful substances from neighboring locations. In addition to the Model Fit analysis, graph that illustrate the comparison between predicted and actual values was built.

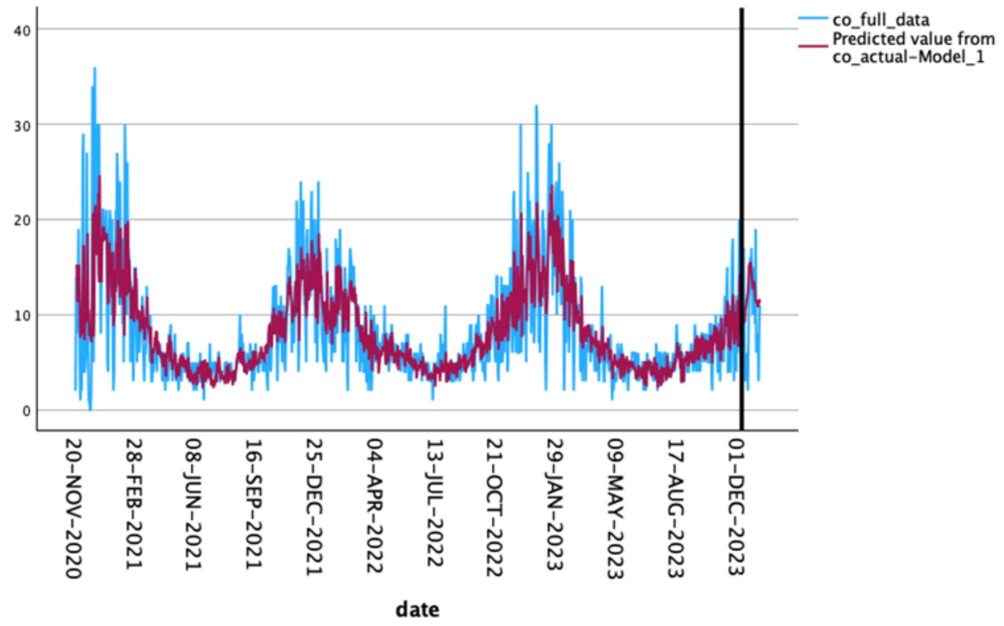

Figure 20 – Graphs of both predicted and actual values

Based on this graph, it is also evident that most of the values coincide. Apart from some sharp fluctuations in the measured values, the predicted line closely follows the trajectory of the graph. So, this result can be considered successful, and the obtained model allows to predict the level of air pollution from meteorological data with sufficient accuracy. It is assumed that if the CO value forecast reaches 20 units, the reagent concentration into the absorption tower will be decreased from

20% to 15%, enabling the retention of up to 95% of CO_2. This will allow timely transfer of carbon capture systems at urban and suburban production facilities in the enhanced mode to temporarily reduce air pollution and the burden on the respiratory systems of city residents.

Conclusion

This article presents the design and development of an automated control system for carbon capturing, focusing on its effectiveness and feasibility in reducing carbon emissions from industrial processes. The process algorithm was represented in a technological scheme and block diagram. The control object is the amine absorber, where the downflowing amine solution absorbs CO_2 from the upflowing sour gas, with the concentration of the solvent being regulated. A mathematical model was developed to describe the process, simulate its dynamics, and analyze the system's behavior. All necessary code scripts and results were produced using MATLAB software. The system's characteristics were compared under conditions without and with a customized PI controller to assess its performance. To maintain the desired system parameters, the regulator was configured, and its coefficients were obtained, enabling the implementation of a PI controller to regulate the flow rate of the amine-based solvent. The process was further investigated using the Modicon M340 programmable logic controller and Schneider Electric software. A Human-Machine Interface (HMI) was created using operator screens in EcoStruxure Control Expert and EcoStruxure Terminal Expert. The connection between the controller and software was established, allowing the process to be visualized and monitored on the actual controller, which was also programmed To align with the smart city concept, an analysis of the impact of meteorological factors was conducted. The necessary dataset parameters were prepared and analyzed using the Autoregressive Integrated Moving Average (ARIMA) method.

This work demonstrates the potential of automated control systems in advancing carbon capture technologies and contributing to environmental sustainability efforts.

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ҚАЛАЛЫҚ ОРТАДА АУАНЫ ТАЗАРТУДЫҢ АВТОМАТТАНДЫРЫЛҒАН АҚЫЛДЫ ЖҮЙЕСІН ЖАСАУ

Аңдатпа

Бұл мақала газ ағындарынан күкіртті сутек пен басқа қышқыл газдарды кетіру үшін өнеркәсіпте қолданылатын газдалған қоспаларды аминді тазарту процесін басқарудың автоматтандырылған жүйесін жасауға арналған. Зерттеу Алматы қаласының ластану деңгейі бойынша мәліметтер базасы негізінде жүргізілді. Симой әдісі арқылы алынған математикалық модельдің орнықтылығы зерттелді. Жүйеге арналған реттегіш синтезделіп, осы модель үшін ПИ және ПИД реттегіштердің тиімділігіне салыстырмалы талдау жүргізілді. Бағдарламалық іске асыру Schneider Electric компаниясының жабдығы негізінде ҚБТУ АҚ «Industrial Automation Lab» зертханасында жүзеге асырылды. Автоматтандыру жүйесі Schneider Electric компаниясының Modicon M340 контроллері мен Harmony 6400 басқару панелі негізінде құрылды. Жүйені бағдарламалау үшін EcoStruxure Control Expert және EcoStruxure Operator Terminal Expert бағдарламалық өнімдері пайдаланылды. Ауаның зиянды заттармен ластануын талдау ARIMA (Autoregressive Integrated Moving Average) жасанды интеллект әдісі арқылы жүргізілді.

Тірек сөздер: ақылды қала (Smart city), жасанды интеллект, ауаны тазарту, көміртекті ұстап қалу, абсорбциялық колонна, ARIMA, бағдарламаланатын логикалық контроллер.

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РАЗРАБОТКА АВТОМАТИЗИРОВАННОЙ ИНТЕЛЛЕКТУАЛЬНОЙ СИСТЕМЫ ОЧИСТКИ ВОЗДУХА В ГОРОДСКОЙ СРЕДЕ

Аннотация

Статья посвящена разработке автоматизированной системы управления процессом аминовой очистки загазованных смесей, применяемой в промышленности для удаления сероводорода и других кислых газов из газовых потоков. Исследование проводилось на основе базы данных об уровне загрязнения воздуха в городе Алматы. Осуществлено исследование математической модели, полученной методом Симоя, на устойчивость. Синтезирован регулятор. Проведен сравнительный анализ эффективности ПИ и ПИД регулятора для данной модели. Программная реализация осуществлялась на основе оборудования от компании Schneider Electric в лаборатории «Industrial Automation Lab» АО «КБТУ». Система автоматизации построена на базе контроллера Modicon M340 фирмы Schneider Electric и панели управления Harmony 6400 с помощью программных продуктов EcoStruxure Control Expert, EcoSructure Operator Terminal Expert. Анализ концентрации вредных веществ в воздухе осуществлялся на основе метода искусственного интеллекта ARIMA (Autoregressive Integrated Moving Average).

Ключевые слова: умный город (Smart city), искусственный интеллект, очистка воздуха, улавливание углерода, абсорбционная колонна, ARIMA, программируемый логический контроллер.

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