DOI: https://doi.org/10.33216/1998-7927-2025-290-4-72-77

UDC 681.5.015

STUDY OF THE IMPACT OF DISCRETE CONTROL OF THE COOLING AND CONDENSATION UNIT ON THE EFFICIENCY OF AMMONIA PRODUCTION

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ДОСЛІДЖЕННЯ ВПЛИВУ ДИСКРЕТНОГО УПРАВЛІННЯ ВУЗЛОМ ОХОЛОДЖЕННЯ ТА КОНДЕНСАЦІЇ НА ЕФЕКТИВНІСТЬ ВИРОБНИЦТВА АМІАКУ

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Optimisation of the ammonia synthesis process is about determining the most efficient parameters and operating conditions to achieve the desired goals or maximise productivity under limited resources and external factors.

Key areas where optimisation is critical for ammonia synthesis include

Rational use of resources - optimisation reduces the consumption of energy, raw materials and chemicals, which helps to reduce production costs and increase the efficiency of secondary resources.

Improved product quality - optimisation ensures consistent production of high quality ammonia, which is critical for its further use.

Improved process safety - optimal operating conditions contribute to a safe production environment, minimising the risk of accidents, fires and explosions.

Stability of equipment operation - optimisation reduces parameter fluctuations, which has a positive impact on process reliability and end product quality.

Reduced overall costs - optimisation can minimise the cost of equipment operation, energy consumption and maintenance.

Optimisation is an important tool for improving the efficiency, productivity and sustainability of the ammonia production process.

This article discusses the application of a discrete-time control system with a mathematical model of an air-cooled apparatus (ACA) and analyses the economic feasibility of implementing this system.

The analysis allows us to determine whether approximate solutions are acceptable for practical use or whether there is a need to apply more accurate methods of solving the problem.

The first step was to choose the optimal degree of discretisation, which allowed, on the one hand, to accurately take into account minor changes in values, and, on the other hand, to avoid an excessive increase in the number of possible states, which complicates calculations, especially when working with complex mathematical models. It has been established that the economic efficiency of the proposed discrete control system with a model of a cooling and condensation unit with a degree of discreteness of 0.5, since it allows to obtain up to UAH 2.7 million per year due to electricity savings;

Keywords: *air cooling apparatus, mathematical model, parameter optimisation, discrete control system, economic efficiency.*

Introduction. Stability issues in the ammonia synthesis process are caused by a mismatch between the operation of the automatic cooling and condensation (ACC) process and the dynamics of the synthesis itself. Process parameters, such as reagent consumption, inlet temperatures of the cooling unit and external temperature, vary for various reasons, including changes in the formulation or production conditions.

These changes can lead to fluctuations in the synthesis temperature regime and, as a result, in the temperature of the gas mixture at the column outlet and inlet to the APU. Operators may attempt to compensate for these changes by intervening and adjusting the ventilation of the APU. However, such interventions can lead to sudden changes in pressure and reagent flow rates, disrupting the stability of the ammonia synthesis process.

The problem is exacerbated when the ventilation is switched on haphazardly, leading to a sharp drop in temperature. This leads to an increase in pressure in the heat exchanger group, further increasing the pressure drop between the synthesis column and the compressor. This, in turn, increases the consumption of reagents and can provoke uncontrollable changes in the ammonia synthesis cycle.

In addition, irrational energy consumption can lead to significant financial costs for the company. For example, if the equipment is operating at excess capacity, this will result in overpayments for electricity. Electricity bills can account for a significant share of total production costs, so effective management of electricity consumption is an important economic objective.

In addition to financial aspects, irrational electricity consumption can also have a negative impact on the environment. Excessive energy consumption leads to emissions of pollutants into the air and water, which can cause environmental pollution and affect air quality. In addition, electricity generation can cause greenhouse gas emissions, contributing to global warming and climate change.

Statement of the problem. The task of implementing a discrete control system is to eliminate instability and (conduct an efficient process?) energy efficiency of the technological process of ammonia synthesis. The lack of consistency in the operation of the automatic cooling and condensation process (ACP) leads to fluctuations in process parameters, which can lead to increased energy consumption and reduced efficiency. Additionally, inappropriate blower activation can cause sudden changes in the pressure and flow rate of the target component, which can discoordinate the synthesis process.

Purpose. The purpose of this paper is to study the feasibility of implementing a discrete control system with a model of an ammonia cooling and condensation unit in terms of economic efficiency and ensuring the required product outlet temperature.

The developed discrete control system is based on a mathematical model of the cooling and condensation unit, which accounts for interdependencies among process parameters and responds dynamically to changes in heat transfer conditions. The system determines optimal operating modes for fans and cooling parameters to maintain a stable gas temperature at the outlet of the synthesis column and ensure efficient heat exchange in the air-cooled heat exchanger (ACHE).

$$\tau''\cdot\frac{d^2y1}{dt^2}+\tau'\cdot\frac{dy1}{dt}+y1=K_1\cdot(\tau_2\frac{dz1}{dt}+K_6\cdot z1)$$
$$+K_3\cdot(\tau_2\frac{dz3}{dt}+z3)+K_7\cdot z4 \qquad (1)$$

Taking into account the MM coefficients, the APO is as follows:

1) with the fan off:

$$3.76\cdot\frac{d^2y1}{dt^2}+19.27\cdot\frac{dy1}{dt}+y1=0.63\cdot(-79.79\cdot\frac{dz1}{dt}+z1)$$
$$+0.27\cdot(19.09\cdot\frac{dz3}{dt}+z3)+0.45\cdot z4 \qquad (2)$$

2) when the fan is on:

$$1.37\cdot\frac{d^2y1}{dt^2}+7.16\cdot\frac{dy1}{dt}+y1=-1.45\cdot(12.71\cdot\frac{dz1}{dt}+z1)$$
$$+0.27\cdot(6.97\cdot\frac{dz3}{dt}+z3)+1.88\cdot z4 \qquad (3)$$

3) when the irrigation system is on:

$$0.19\cdot\frac{d^2y1}{dt^2}+1.16\cdot\frac{dy1}{dt}+y1=-2.47\cdot(1.03\cdot\frac{dz1}{dt}+z1) \qquad (4)$$
$$+0.27\cdot(0.96\cdot\frac{dz3}{dt}+z3)+2.59\cdot z4$$

Discretization in Control System Design.

One of the key aspects in implementing a discrete control system is the selection of an appropriate discretization level. The discretization level defines how finely a continuous variable or domain is partitioned into discrete units. A smaller discretization step allows for more accurate representation of subtle variations in the process variables.

However, decreasing the discretization interval increases the number of possible states or combinations within the model, which can significantly raise computational complexity—especially when dealing with sophisticated mathematical models. Thus, choosing the optimal discretization level involves a trade-off between model accuracy and computational efficiency. It is crucial to balance the need for precise representation of physical phenomena with the constraints of data processing and resource consumption.

In particular, reducing the temperature measurement discretization step may hinder the system's ability to detect minor fluctuations. If the discretization step approaches the absolute measurement error of the temperature sensor (0.5°C in this case), most small variations in temperature may be perceived as noise rather than actual process changes.

To address this, incorporating temperature readings from the inlet of the cooling unit can enhance the system's ability to forecast changes in thermal conditions in response to variations in target component flow rate. The control algorithm can then dynamically adjust the operation of the fans at each air-cooled heat exchanger (ACHE) based on these input values, ensuring optimal cooling and condensation regimes for the gas mixture.

This approach helps prevent uncontrolled temperature spikes, pressure surges, and disturbances that commonly occur with manual fan operation. Instead, the system dynamically responds to changes in flow rate and continuously adapts the operation of the ACHEs to maintain process stability within the ammonia synthesis loop.

Impact of Contamination as a Disturbance in Discrete Control of the Cooling and Condensation Unit.

Considering contamination as a disturbance variable in the automated control scheme of the cooling and condensation unit, the application of a discrete control system offers the potential for more precise and efficient process regulation. This can lead to improved performance and the maintenance of optimal operating conditions.

The fundamental principle of a discrete control system lies in operating within a finite set of predefined states or modes. By transitioning between these states in response to contamination levels and other process variables, the system can effectively optimize the functioning of the cooling and condensation unit.

One practical approach to discrete control is to adjust the operating modes of fans and other cooling elements based on the measured degree of contamination. As contamination increases, the control system can automatically increase fan speed or modify cooling parameters to sustain optimal heat transfer efficiency.

Furthermore, the discrete control system can be enhanced with decision-making logic algorithms that take contamination levels and other relevant parameters into account. This enables the system to autonomously implement optimal control actions to ensure effective and stable operation of the cooling and condensation processes.

Monitoring and Control of Fouling in Air-Cooled Heat Exchangers Using a Discrete Control System

To monitor the fouling level of air-cooled heat exchangers (ACHEs), various sensors can be deployed on the heat exchanger surfaces and other components within the system. These sensors track parameters indicative of surface contamination, enabling the control system to respond in a timely manner and initiate corrective actions.

The proposed discrete control system, integrated with a mathematical model of the cooling and condensation unit, enables the estimation of the fouling coefficient of ACHE surfaces by continuously monitoring and analyzing key heat transfer parameters and the system's response to contamination.

The system includes sensors for measuring temperature, pressure, and heat flux, among others. The collected data are transmitted to the cooling and condensation unit’s model, which employs logical operators and analytical algorithms to process and interpret the information.

Based on this data analysis, the system can detect changes in heat transfer performance and assess the degree of fouling on the surfaces of heat exchangers and other ACHE components. For example, a decline in thermal efficiency may indicate the onset of surface fouling.

Using historical operational data or predefined threshold values, the system can approximate the current fouling coefficient by comparing real-time parameters against expected baseline values. This estimation supports proactive control measures.

By considering different combinations of fan activation and cooling settings, the discrete control system can implement optimal operational modes to maintain effective heat transfer and mitigate the adverse effects of fouling. This ensures the stable performance of the cooling and condensation processes and enhances the overall efficiency of the ammonia synthesis loop.

Energy Efficiency and Decision-Making in Discrete Control of the Cooling and Condensation Unit.

The proposed discrete control system not only enables the detection of fouling levels but also facilitates decision-making to optimize heat transfer performance and ensure efficient operation of the cooling and condensation unit.

When the estimated fouling coefficient reaches its maximum allowable threshold, the system triggers the self-cleaning mechanism of the air-cooled heat exchanger (ACHE). In parallel, an important objective of the control strategy is the minimization of energy consumption. Since the fans are activated only when necessary to compensate for temperature deviations, energy usage can be optimized, significantly reducing the operating costs of the ammonia synthesis process.

The economic feasibility of using a discrete control system for an air-cooling apparatus (ACA) is considered in detail

The following assumptions were used to calculate the economic feasibility:

1. Power of one fan N = 100 kW (according to the regulations).

2. Electricity cost C = 4.06 UAH per 1 kW (average value in Ukraine for enterprises).

3. The duration of the unit's operation in the warm season, H - 5000 hours/year (specified in the text).

4. Number of possible fan combinations, K - 256 (as discussed earlier).

To simplify the calculations, let us assume that the average difference in power consumption between fan combinations is 5/6 N (equal to approximately 83.33 kW).

Let's first determine the cost of electricity for each possible combination:

1. The cost of electricity for each combination, CC, is the cost of electricity per 1 kW multiplied by the power of the combination:

$C_C = C \cdot P_C$ (18)

We choose the combination that has the lowest power consumption among those that meet the temperature requirements (as described in Section 3).

Next, calculate the difference in power consumption between the standard operating mode and the selected combination.

Multiply the difference in power consumption by the number of hours of operation per year (in your case, 5000 hours) and the cost of electricity per 1 kWh (4.06 UAH).

Analysis of the data shows that among the combinations that give a given value of the temperature at the outlet of the APO ±1 °C in terms of energy efficiency is combination 248, i.e. we have achieved the maximum possible efficiency of electricity use for this process.

We have found a saving in the cost of electricity per hour when using the optimal combination compared to other combinations that give the set temperature at the outlet of the APO.

The minimum savings per hour are:

1082.7 - 947.3 = 135.4 UAH.

The maximum savings per hour are:

1488.7 - 947.3 = 541.4 UAH.

Accordingly, the minimum savings per year are:

$135.4 \cdot 5000 = 677{,}000$ UAH.

The maximum savings for the year is:

$541.4 \cdot 5000 =$ UAH 2,707,000.

Conclusion. The analysis of the discrete control system incorporating a model of the cooling and condensation unit under varying temperature conditions has demonstrated its significant potential in enhancing both energy efficiency and operational stability in ammonia production processes.

The proposed control strategy, employing a discretization step of 0.5, has been shown to achieve substantial economic benefits—yielding annual electricity savings of up to 2.7 million UAH. This result highlights the cost-effectiveness of the system and its practical value in reducing energy consumption without compromising process quality.

In addition to energy savings, the system addresses the critical issue of fouling on heat exchange surfaces within the air-cooled heat exchangers (ACHE). By monitoring the fouling coefficient, the system is capable of activating the self-cleaning mechanism once the critical threshold is reached—without the need to interrupt the synthesis stage. This feature enables in-process cleaning, which further minimizes energy losses and improves the efficiency of gas–ammonia mixture cooling and condensation.

Overall, the integration of a discrete control system with a model-based approach for the ammonia cooling and condensation unit significantly enhances equipment performance, reduces electricity consumption, and increases the overall stability and reliability of the ammonia synthesis process.

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Дуришев О.А, Кобзарев Є. В., Гурін О.М., Лорія М.Г. Дослідження впливу дискретного управління вузлом охолодження та конденсації на ефективність виробництва аміаку

Оптимізація процесу синтезу аміаку полягає у визначенні найбільш ефективних параметрів і умов роботи для досягнення поставлених цілей або максимізації продуктивності в умовах обмежених ресурсів і зовнішніх факторів.

Основні аспекти, в яких оптимізація має вирішальне значення для синтезу аміаку, включають

Раціональне використання ресурсів - оптимізація зменшує споживання енергії, сировини та хімічних речовин, що сприяє зниженню виробничих витрат і підвищенню ефективності використання вторинних ресурсів.

Покращення якості продукції - оптимізація забезпечує стабільне виробництво аміаку високої якості, що є критично важливим для його подальшого використання.

Підвищення безпеки процесу - оптимальні умови експлуатації сприяють створенню безпечного виробничого середовища, мінімізуючи ризик нещасних випадків, пожеж та вибухів.

Стабільність роботи обладнання - оптимізація зменшує коливання параметрів, що позитивно впливає на надійність процесу та якість кінцевого продукту.

Зниження загальних витрат - оптимізація може мінімізувати витрати на експлуатацію обладнання, споживання енергії та технічне обслуговування.

Оптимізація є важливим інструментом підвищення ефективності, продуктивності та сталості процесу виробництва аміаку.

У цій статті розглянуто застосування системи дискретного керування з математичною моделлю апарата повітряного охолодження (АПО) та проаналізовано економічну доцільність впровадження цієї системи.

В результаті аналізу можна визначити, чи прийнятні наближені розв'язки для практичного *використання, чи є необхідність застосування більш точних методів розв'язання задачі.*

Першим кроком був вибір оптимального ступеня дискретизації, який дозволив, з одного боку, точно врахувати незначні зміни величин, а з іншого - уникнути надмірного збільшення кількості можливих станів, що ускладнює розрахунки, особливо при роботі зі складними математичними моделями. Встановлено, що економічна ефективність запропонованої дискретної системи керування з моделлю вузлом охолодження та конденсації зі ступенем дискретності 0,5, адже за рахунок економії електричної енергії вона дозволяє отримати до 2,7 млн. грн/рік;

Ключові слова: *апарат повітряного охолодження, математична модель, оптимізація параметрів, дискретна система керування, економічна ефективність.*

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Стаття подана 25.04.2025.