LabVIEW- Based Leaching Tank Process Control System for Laterite Nickel Ore Processing on a Lab-Scale Basis

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ABSTRACT

This study successfully designed and implemented a LabVIEW-based nickel laterite ore leaching process control system on a laboratory scale. This system integrates key hardware components such as Arduino Mega 2560, temperature sensor, volume sensor, jet bubble reactor, and LabVIEW-based user interface that allows automatic and real-time monitoring and control of process parameters. The calibration results showed high accuracy, with temperature measurement error values of 0.04% and 0.015% compared to the calibrator. Volume measurements under five test conditions produced error values ranging from 0.023% to 0.066%, with the best accuracy shown by readings via the LabVIEW HMI. Leaching process testing was carried out using variations in citric acid concentrations. The resulting filtrate volume showed a decrease from 173 mL at a concentration of 0.5 mol to 8 mL at a concentration of 2 mol, indicating that the higher the solution concentration, the greater the viscosity of the solution, thereby inhibiting mass transfer. The application of jet bubble technology has been shown to increase the efficiency of mixing and contact between the leaching solution and the ore, which accelerates the leaching process. Overall, the system shows high stability, accuracy, and reliability for laboratory scale applications. This system is considered suitable for use as a learning medium, an initial simulation tool for the APAL (Atmospheric Pressure Acid Leaching) process, and a means of supporting research in the development of efficient, energy-saving, and environmentally friendly nickel extraction technology.

INTRODUCTION

Indonesia is one of the countries that has a key role in the world's current nickel needs where Indonesia is able to become a supplier of 29% of the world's laterite resources. According to data released by the Center of Mineral Resources, Coal & Geothermal, around 45% of laterite nickel deposits are in Indonesia, one of which is in the Sulawesi Islands[1] .

Nickel itself is a natural resource that is able to support the country's economy today [2], where one of the derivative applications of its processing results can be utilized in several industries such as medical tools, households, electronic casings, construction, automotive, and many more[3]. Especially in the automotive world, the development of electric cars today cannot be separated from the development of batteries. Several types of lithium batteries in electric cars can be categorized into several categories based on the cathode material they are made of.

In Indonesia, pyrometallurgy and hydrometallurgy methods remain the two main techniques for processing nickel laterite ore [4], [5]. Pyrometallurgical methods involve high-energy smelting processes that produce nickel matte or ferronickel [6], while hydrometallurgical approaches such as High Pressure Acid Leaching (HPAL) and Atmospheric Pressure Acid Leaching (APAL) offer the advantages of lower energy consumption and the ability to process low-grade ores more economically. In the APAL method, both inorganic and organic acids can be used as leaching agents [7]. Sulfuric acid is the most commonly used inorganic acid in industrial applications due to its availability and low cost [8]. However, sulfuric acid poses environmental concerns as it is non-recyclable and potentially hazardous. As a more sustainable alternative, researchers have explored the use of organic acids, particularly citric acid, as environmentally friendly leaching agents. Several studies have confirmed the effectiveness of citric acid in leaching lateritic saprolite and hematite nickel ores [9], [10].

Citric acid leaching is a heterogeneous process involving several steps, including: (1) external diffusion of reactants and products through the film layer, (2) internal diffusion through the ash layer, and (3) chemical reactions on the particle surface [9], [10]. To better understand the underlying physical phenomena, it is important to prepare and evaluate a kinetic model of the leaching process. Despite its many advantages, the APAL method faces challenges in large-scale applications, mainly due to its long processing time, which increases operational costs and the risk of inefficiencies when processing low-grade ores [11]. One potential

solution is to implement small-scale laboratory processing, which can serve as an educational tool and testing platform before industrial-scale operations. Various methods and technologies have been applied in nickel laterite leaching, especially for the mixing and dissolution processes [12], [13], [14], [15], [16]. Traditionally, this process is carried out using a mechanical stirrer driven by an electric motor. There are several disadvantages to this method. Because the initial reaction is strong enough, it can cause the stir bar connected to the driving motor to easily corrode. To overcome this, this conventional approach can be replaced with more efficient techniques, such as bubble jet technology, which uses air pressure to create turbulence and increase contact between ore particles and leaching agents [17], [18]. Previous studies have demonstrated the feasibility of developing a laboratory-scale leaching system that replicates industrial processes by incorporating a bubble jet reactor to enhance mass transfer during the leaching stage [19], [20].

Integrating bubble jet technology and an automatic control system, this study aims to develop a laboratory-scale trainer that can realistically represent industrial conditions and can also be used as an effective experimental education platform for students of mineral chemical engineering study programs. Based on this context, the current study focuses on the design and development of a leaching process control system that integrates Atmospheric Pressure Acid Leaching (APAL) technology and Bubble Jet Reactor, utilizing LabVIEW (Laboratory Virtual Instrumentation Engineering Workbench) software for automatic control of parameters such as temperature, fluid volume, and reaction time.

METHODS

This study uses a research and development (R&D) approach to design and build a laterite nickel ore processing trainer using the Atmospheric Pressure Acid Leaching (APAL) method equipped with an integrated LabVIEW-based control system.

Trainer Design Plan Build

Design of this trainer tool is needed to provide an overview of the shape of the tool to be made, the design of this trainer tool is made using the Solidworks application. To design the following trainer, of course, consider several technical conditions including the placement of parts, the thermal effects produced when operating the tool, the chemical effects produced from the nickel laterite processing process when the tool is running, and also the flexibility of the tool that can facilitate users when operating the trainer [10]. The size of the design tool is a trainer height of 90 cm, a trainer width of 120 cm, a trainer length of 80 cm. The design image can be seen in Figure 1.
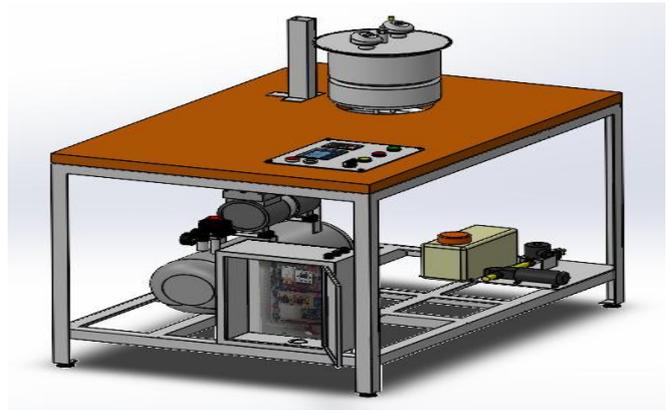

Figure 1. Leaching Tank Trainer Design.

General Architecture

The nickel laterite ore leaching process control system developed in this study is designed to work automatically and integrated, including the process of monitoring and controlling important parameters such as temperature, solution volume, and process duration. The general architecture of the system is arranged in the form of a block diagram to describe the relationship between functional components, both in terms of hardware and software.
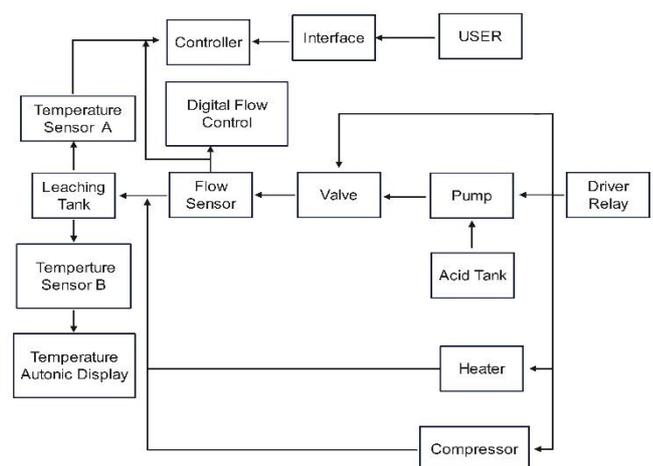

Figure 2. System Block Diagram

Generaly, the system diagram consists of four main parts, namely:

1. User Interface (HMI - Human Machine Interface)
   Is a visual and interactive part designed using LabVIEW software. This HMI allows users to monitor process parameters in real-time, set setpoint values (temperature, time, volume), and control actuators such as pumps, heaters, and air compressors. The HMI also displays sensor readings dynamically, including liquid volume and tank temperature.

2. Microcontroller (Arduino Mega 2560)
   Acts as the main controller that bridges communication between LabVIEW and physical devices in the field. Arduino receives commands from LabVIEW via serial communication and issues control signals to devices such as relays, heaters, and pump motors. In addition, Arduino also reads data from temperature and flow sensors, then sends it back to the HMI for display.

3. Sensors and Actuators

Sensors: consist of LM35 temperature sensors and thermocouples and YF-S201 flow sensors which are used to detect actual process conditions.

Actuators: include liquid pumps, air compressors for the jet bubble system, and heating elements controlled by signals from the microcontroller. This jet bubble system functions to create turbulence to increase the efficiency of mixing the solution and nickel ore.

4. Power and Security System

The entire system is powered through a protective circuit that includes MCB (Miniature Circuit Breaker), relay driver, and thermal protection system. Power distribution is designed to be safe and separate between control current and load current.

5. The block diagram of this system architecture shows an integrated workflow where the user provides input via the LabVIEW HMI, then sends commands to the Arduino. Furthermore, the Arduino controls the device in the form of a sensor to read the process conditions and the data is sent back to LabVIEW to be displayed.

This architecture allows the leaching process to take place automatically, accurately, and can be replicated in various experimental conditions on a laboratory scale. In addition, the integration of jet bubbles and HMI-based temperature controllers makes this system effective as a tool in research activities and learning laterite nickel ore processing techniques.

Controller panel design

The design of the control panel is a crucial part of the leaching process control system because it functions as the center of integration of all electronic and electrical devices that support the automatic operation of the system. This panel is designed with dimensions of 40 cm high, 30 cm wide, and 15 cm long, considering aspects of ergonomics, safety, ease of maintenance, and space efficiency. The design image of the tool can be seen in Figure 3.
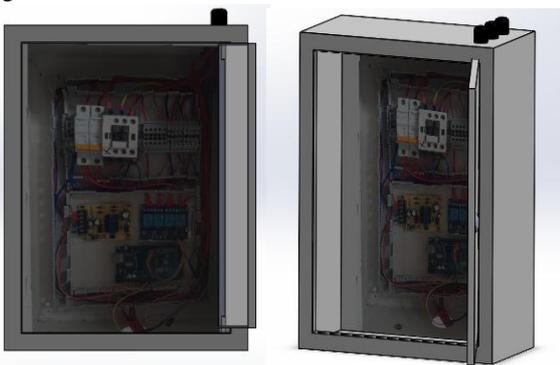

Figure 3. Control Panel Design

The control panel is placed on the front of the trainer in an upright position and is easily accessible to the operator. Its dimensions were chosen to ensure that all components can be installed safely without creating crowding that would complicate future operation or modification. This design ensures that the control system can operate optimally, safely and sustainably in a laboratory environment that simulates small-scale industrial conditions.

Wiring Circuit

To simplify the wiring process, a wiring diagram is needed as a reference in the next wiring process. The wiring diagram of the controller circuit can be seen in Figure 4.
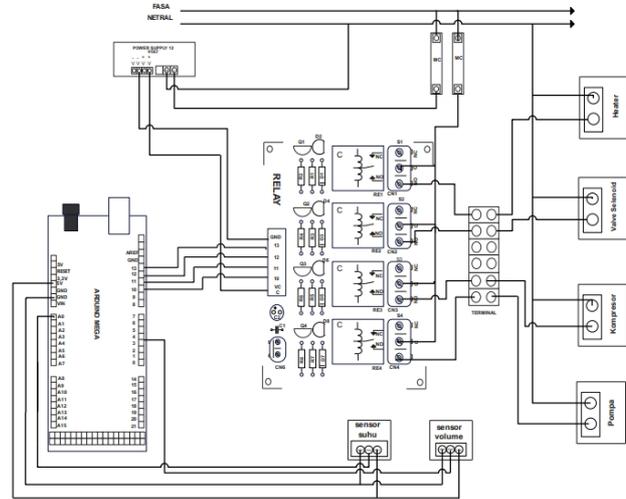

Figure 4. Schematic Circuit System

Wiring System

Wiring system generally refers to a series of cables and electrical components used to connect electrical devices to a system. The wiring system carried out on this tool is to create an installation design that ensures efficiency and safety of components in the distribution of electricity. In carrying out wiring systems, it is divided into two stages, namely wiring in the panel and wiring outside the panel, wiring in the panel is the wiring of controller components such as Arduino Maga, relays, power supplies, MCBs, and contactors, while wiring outside the panel is the wiring of the main components such as compressors, valves, pumps, heaters, flow sensors, temperature sensors, indicator lights, temperature controllers TCN4H-24R and water flow ZJ-LCD-M. The results of wiring in the panel and wiring outside the panel can be seen Figure 5.
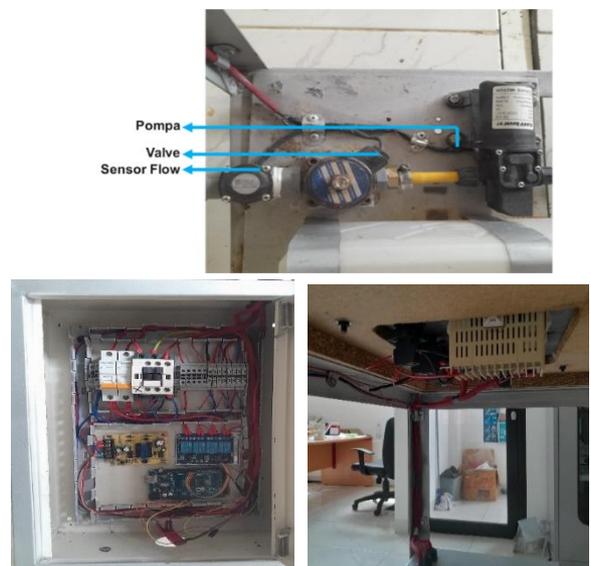
Figure 5. Wiring System Leaching Tank.

Human Machine Interface (HMI)

To facilitate the control and management of the tool, an HMI design is needed which will later be used to control the work process of the tool. The HMI in this study was created using programming software produced by National Instruments using a graphical programming language or block diagram while other programming languages use a text base. By using graphical programming, data acquisition on the system becomes more accurate. The following is Figure 6 of the HMI that has been created using LabVIEW.
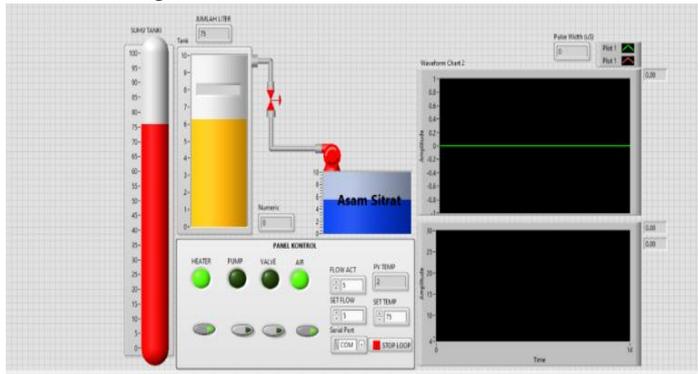

Figure 6. Human Machine Interface Design.

Procedure for operating system running system

All stages of the tool operation follow a systematic flow that has been designed and visualized in the form of a flowchart. The following figure shows the sequence of procedures from system initialization to completion of the leaching process, including parameter configuration, reagent filling, actuator activation (pumps, heaters, and compressors), monitoring process variables (temperature and volume), and stopping the process after the reaction time is met. This diagram is the main guideline in running the system safely, efficiently, and in a controlled manner, and ensuring that the process runs according to design specifications and experimental objectives.
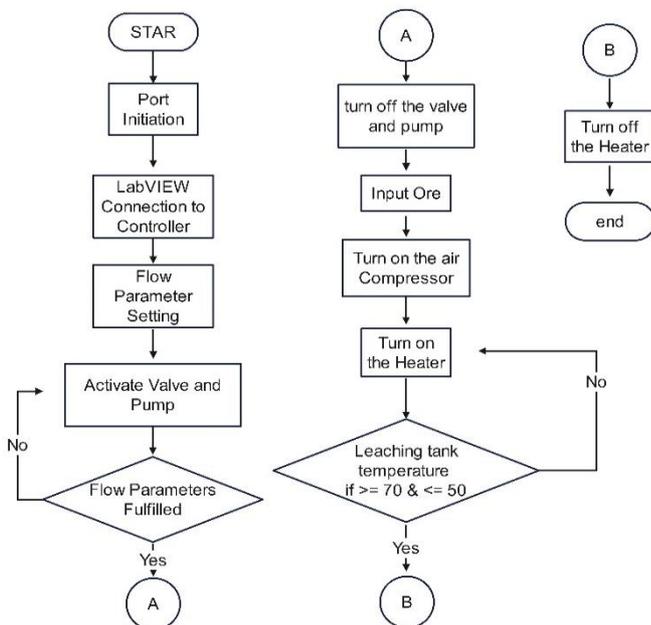

Figure 7. Flowchart Procedure for running an operating system

1. Port initiation sets the port used on the Arduino Mega
2. Connecting LabView to the Arduino Mega
3. The steps taken when you want to connect LabView to the Arduino Mega are as follows
   a. Opening the LabView program
   b. Setting the solution serial port
   c. Setting the read speed time
   d. Entering tools
   e. Selecting Makehub and Linx
   f. fSelecting Linxfirmware and selecting the type of Arduino used.
   g. Reselecting the Port series according to the previously selected Port series
   h. Next and finish
4. Flow parameter settings
5. Activating the valve and pump
6. Flow parameters are met
   If the flow parameters have been met, the valve and pump will turn off, while if the flow parameters have not been met according to the setting parameters, the valve and pump will remain active.
7. Insert Laterite Nickel Ore or Ore
   The ore will be inserted into the leach tank after the volume of citric acid in the leach tank is as specified.
8. Activate the compressor
9. The compressor is activated to create bubbles in the leach tank so that the solution in the leach tank will be stirred.
10. Activate the heater
    The heater is activated to heat the leach tank
11. Leach tank temperature ≥70°C
    The leach tank temperature is monitored using a temperature sensor, if the temperature is less than 70°C then the heater will remain active, if the temperature in the leach tank is more than 70°C then the heater will turn off and will turn back on if the temperature in the leach tank is less than 65°C.
12. Process duration 2 hours
    The setting process takes 2 hours, if the dissolution process takes less than 2 hours then the process will continue, while if the process takes more than 2 hours then the dissolution process is declared complete.

RESULTS AND DISCUSSION

This research produces an integrated trainer of laboratory-scale nickel laterite leaching process control system based on LabVIEW. This system is designed to simulate the atmospheric pressure acid leaching (APAL) process with the main control parameters including solution volume, reaction temperature, and process time, and is supported by jet bubble reactor technology for mixing efficiency.

Final Design

The following image shows the final result of the leach control system trainer that has been successfully assembled and tested in the Basic Electricity laboratory of the Electrical and

Installation Study Program of the Morowali Metal Industry Polytechnic. Figure 8 is an overall appearance of the tool
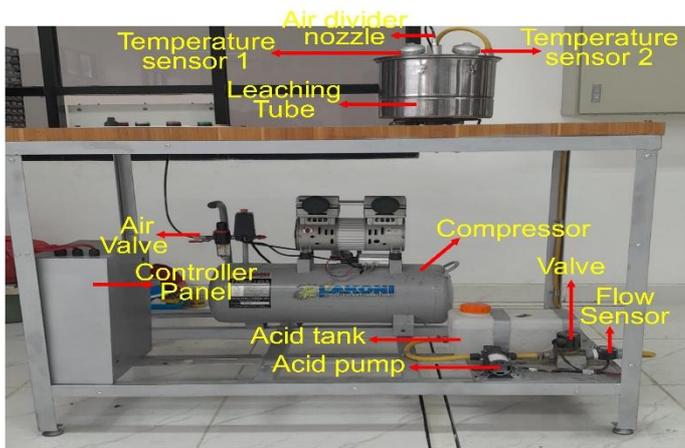

Figure 8. Lab Scale Leaching Tank Trainer.

Flow sensor and Temperature Sensor Calibration

Sensor calibration is carried out to ensure the accuracy of the measurement results on the system trainer that has been created. The calibration process is carried out by comparing the sensor reading results to standardized tools. The calibration process is carried out on two types of sensors, namely flow meter sensors, thermocouple sensors and LM35. In the calibration of the flow meter sensor, the reference value is obtained from a measuring scale in the form of a beaker as a definite reference value, for the comparative value itself it is obtained from the ZJ-LCD-M module as the standardization value of the industrial instrument, then the display value on the HMI that has been created is tested. While for the temperature sensor, an analog thermometer is used as the initial reference value, then for the comparative value it is obtained from the results of the thermocouple sensor measurements displayed on the autonic temperature display as an industrial standard device. Furthermore, the percentage and calculation of the error value are carried out with the average Error value listed in tables 1 and 2 of the sensor calibration results. To determine the presence of error, the following mathematical equation is used.

$$Error = \frac{Reference\ Value - measurement\ value}{reference\ value} \times 100\ \%$$

Table 1. Temperature sensor calibration values

Termometer (°C)	Autonik (°C)	Error %	Termometer (°C)	Labview (°C)	Error %
25	26	0.04	25	25,7	0.028
38	35	0.07	38	38,4	0.010
49	45	0.08	49	49,6	0.012
56	55	0.017	56	56,4	0.007
67	65	0.02	67	67,3	0.004
75	70	0.06	75	75,6	0.008
Average Error		0.04	Average Error		0.015

Table 2. Flow sensor calibration values with a volume of 1 liter

Comparasion of volume value readings				Comparasion of volume value readings			
Beaker (L)	ZJ-LCD-M	Time (s)	Error (%)	Beaker (L)	HMI LabVIEW (L)	Time (s)	Error (%)
1	0,97	18	0.03	1	0,95 Liter	18	0.05
1	0,98	18	0.02	1	0,96	18	0.04
1	0,98	18	0.02	1	0,96	18	0.04
1	0,98	18	0.02	1	0,96	18	0.04
1	0,97	17	0.03	1	0,95	17	0.05
Average Error		0.024	Average Error				0.044

Table 3. Flow sensor calibration values with a volume of 2 liter

Comparasion of volume value readings				Comparasion of volume value readings			
Beaker (L)	ZJ-LCD-M (L)	Time (s)	Error (%)	Beaker (L)	HMI LabVIEW (L)	Time (s)	Error (%)
2	1,95	36	0.025	2	1,92	36	0.04
2	1,96	35	0.02	2	1,92	35	0.04
2	1,96	36	0.02	2	1,93	36	0.035
2	1,95	35	0.025	2	1,92	35	0.04
2	1,97	36	0.025	2	1,92	36	0.04
Average Error		0.023	Average Error				0.039

Table 4. Flow sensor calibration values with a volume of 3 liter

Comparasion of volume value readings				Comparasion of volume value readings			
Beaker (L)	ZJ-LCD-M (L)	Time (s)	Error (%)	Beaker (L)	HMI LabVIEW (L)	Time (s)	Error (%)
3	2,90	52	0.033	3	2,88	52	0.04
3	2,91	54	0.03	3	2,89	54	0.03
3	2,90	53	0.033	3	2,88	53	0.04
3	2,90	52	0.033	3	2,88	52	0.04
3	2,90	53	0.033	3	2,88	53	0.04
Average Error		0,98	Average Error				0.038

Table 5. Flow sensor calibration values with a volume of 4 liter

Comparasion of volume value readings				Comparasion of volume value readings			
Beaker (L)	ZJ-LCD-M (L)	Time (s)	Error (%)	Beaker (L)	HMI LabVIEW (L)	Time (s)	Error (%)
4	3,88	70	0.03	4	3,86	70	0.035
4	3,87	70	0.032	4	3,86	70	0.035
4	3,88	70	0.03	4	3,86	70	0.035
4	3,88	69	0.03	4	3,85	69	0.037
4	3,88	70	0.03	4	3,86	70	0.035
4	3,88	70	0.03	4	3,86	70	0.035
4	3,88	70	0.03	4	3,86	70	0.035
4	3,87	68	0.032	4	3,85	68	0.037
4	3,87	69	0.032	4	3,85	69	0.037
4	3,88	69	0.03	4	3,86	69	0.035
Average Error		0.036	Average Error				0.0356

Table 6. Flow sensor calibration values with a volume of 5 liter

Comparasion of volume value readings				Comparasion of volume value readings			
Beaker (L)	ZJ-LCD-M (L)	Time (s)	Error (%)	Beaker (L)	HMI LabVIEW (L)	Time (s)	Error (%)
5	4,78	86	0.044	5	4,67	86	0.066
5	4,79	86	0.042	5	4,67	86	0.066
5	4,79	87	0.042	5	4,68	87	0.068
5	4,78	86	0.044	5	4,67	86	0.066

5	4,77	85	0.046	5	4,66	85	0.068
5	4,79	86	0.042	5	4,67	86	0.066
5	4,78	86	0.044	5	4,67	86	0.066
5	4,77	85	0.046	5	4,66	85	0.068
5	4,78	85	0.044	5	4,66	85	0.068
5	4,78	85	0.044	5	4,67	85	0.066
Average Error			0.0438	Average Error			0.0668

Based on the data that has been obtained at the time of collecting volume monitoring system data, it can be seen that the calibration process is very influential for error resistance. The difference in sensor reading before calibration is carried out and after calibration is greatly affecting the average error.

Test results

In this process the designs trainer that has been through system testing first, is tested directly in leaching on the processing of laterite nickel seeds. This process is carried out 12 times with different comparison variations. The following is the data from the processing of laterite nickel seeds that have been done with different ratio.

Table 7. Test results with material comparison

Comparison	Concentration (mol)	Nickel ore (Solid) (gr)	Sulution (*Liquid*) (ml)	Citric Acid (gr)	Filtrate Result (ml)
0,5:12	0,5	83,3	2000	192	173
1:12	0,5	166,6	2000	192	167
1,5:12	0,5	250	2000	192	149
2:12	0,5	333,33	2000	192	136
0,5:12	1	83,3	2000	384	27
1:12	1	166,6	2000	384	24
1,5:12	1	250	2000	384	22
2:12	1	333,33	2000	384	21
0,5:12	2	83,3	2000	768	10,4
1:12	2	166,6	2000	768	9,7
1,5:12	2	250	2000	768	8,9
2:12	2	333,33	2000	768	8

CONCLUSION

This study successfully designed and implemented a LabVIEW-based nickel laterite ore leaching process control system on a laboratory scale. This system combines hardware such as Arduino Mega 2560, temperature sensors, volume sensors, and jet bubble reactors, as well as a LabVIEW-based user interface that allows automatic and real-time control and monitoring of process parameters. The test results showed that the system has high accuracy. In temperature measurements, an average error value of 0.04% and 0.015% was obtained when the sensor was compared to the calibrator. While in volume measurements, the error values from 5 test conditions were obtained with varying values as follows. At a volume of 1 liter, the measurement error was 0.024% and 0.044%. At a volume of 2 liters, the error was 0.023% and 0.039%. At a volume of 3 liters, an error of 0.98% and 0.038% occurred. At a volume of 4 liters, the error was recorded at 0.036% and 0.035%. At a volume of 5 liters, the error was 0.0438% and 0.066%.

Process testing was also carried out on leaching of laterite nickel ore using leaching regen with the results obtained in the form of filtrate. At a concentration of 0.5 mol, 173 ml of filtrate was obtained, while at a concentration of 2 mol, 8 ml of filtrate was obtained. From the dissolution process carried out, it can be concluded that the higher the concentration of the solution, the smaller the filtrate produced, because the higher the concentration of the solution, the more concentrated the solution and the more difficult it is to distribute in the solvent tank and heating tank.

Overall, the system shows high stability and accuracy in controlling temperature and volume parameters. The relatively small error value, especially in readings by HMI LabVIEW, indicates that this system is suitable for use as a learning medium, initial simulation of the APAL process, or a research tool in laboratory-scale laterite nickel processing. The integration of jet bubble reactor technology into the system also provides increased mixing and contact efficiency between the leach solution and ore, which has the potential to accelerate the dissolution process. This system is expected to be an initial prototype in supporting research and development of efficient, energy-saving, and environmentally friendly nickel processing technology.

ACKNOWLEDGMENT

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