Energy and Power Engineering, 2023, 15, 443-456
https://www.scirp.org/journal/epe
ISSN Online: 1947-3818
ISSN Print: 1949-243X

Modeling of an Automatic Optimization System of Cyanide Concentration in Carbon in Leach for Optimal Ore Processing in a Mining Company

Madjoyogo Herve Sirima[1*], Betaboale Naon[2], Issa Compaore[3]

[1]Institute of Industrial and Textile Systems Engineering, Polytechnic High School of Ouagadougou, Ouagadougou, Burkina Faso
[2]Group of Studies and Research in Mechanics, Energy and Industrial Techniques, University Institute of Technology, Nazi Boni University, Bobo-Dioulasso, Burkina Faso
[3]Cooperative Mining, Gaoua, Burkina Faso
Email: *madjoyogoherves@gmail.com

How to cite this paper: Sirima, M.H., Naon, B. and Compaore, I. (2023) Modeling of an Automatic Optimization System of Cyanide Concentration in Carbon in Leach for Optimal Ore Processing in a Mining Company. *Energy and Power Engineering*, **15**, 443-456.
https://doi.org/10.4236/epe.2023.1511024

Received: July 11, 2023
Accepted: November 27, 2023
Published: November 30, 2023

Abstract

The optimization system, which was the subject of our study, is an autonomous chain for the automatic management of cyanide consumption. It is in the phase of industrial automation which made it possible to use the machines in order to reduce the workload of the worker while keeping a high productivity and a quality in great demand. Furthermore, the use of cyanide in leaching tanks is a necessity in the gold recovery process. This consumption of cyanide must be optimal in these tanks in order to have a good recovery while controlling the concentration of cyanide. Cyanide is one of the most expensive products for mining companies. On a completely different note, we see huge variations during the addition of cyanide. Following a recommendation from the metallurgical and operations teams, the control team carried out an analysis of the problem while proposing a solution to reduce the variability around plus or minus 10% of the addition setpoint through automation. It should be noted that this automatic optimization by monitoring the concentration of cyanide, made use of industrial automation which is a technique which ensures the operation of the ore processing chain without human intervention. In other words, it made it possible to substitute a machine for man. So, this leads us to conduct a study on concentration levels in the real world. The results show that the analysis of the modeling of the cyanide consumption optimization system is an appropriate solution to eradicate failures in the mineral processing chain. The trend curves demonstrate this resolution perfectly.

Keywords

Modeling, Automatic Optimization, Cyanide Concentration, Optimal Ore Processing

1. Introduction

The gold recovery process after treatment through the crushing, grinding and settling circuits is done in reservoirs or tanks according to the Carbon in Leach (CIL) method. This recovery process requires the addition of chemicals including cyanide. The latter has the role of dissolving the gold contained in the ore in order to allow the fixation on the activated carbon [1] [2]. The addition of cyanide is done according to desired ppm in the tanks.

However, a great variability of the ppm is observed either in excess or in less. As a result, cyanide consumption is not optimized and the consequence is poor gold recovery in addition to cyanide waste [2] [3] [4]. The findings on the variability are corroborated by the trend line of **Figure 1** below over a two-week period. On this curve, we have the desired ppm setpoint in blue and the ppm value in the tank in red.

From the curve, we see huge variations and huge overruns with respect to the setpoint. For a setpoint of 275 ppm, we end up with 367 ppm max and 141 ppm min. That is an excess of 92 ppm and a lack of 134 ppm.

Now let's bring the curve back to 48 hours by adding some parameters such as the solid mass and the addition of cyanide. We get the curve of **Figure 2**. The set point is always in blue and the CIL A ppm value in red.

When analyzing the curves of **Figure 1** and **Figure 2**, we find that when the setpoint is exceeded or not reached, the value takes a long time to catch up with the setpoint. Once the setpoint has been caught, the value does not stabilize but it continues in the direction it is following.

Moreover, we observe that the reaction of the adjustment of the consumption of cyanide is very slow in time and of lesser extent. This could justify the time taken by the ppm value to rise or fall towards the setpoint.

Additionally, we see a large variability in the flow rate of cyanide to be added to the leach tank [3] [4] [5]. The solid mass which is the quantity of material sent to the CIL A is also very variable. This observed situation is considered as a failure and could be resolved by automatic reprogramming of the system [5] [6]. Industrial automation is the process of integrating machinery and industrial equipment could perform automatically such task with the use of automation or automation hardware and software [7] [8] [9]. This will improve productivity, safety and profitability by automatically optimizing cyanide consumption. It should be noted that industrial automation is the use of a technique that ensures the operation of a machine or a group of machines without human intervention [8] [9] [10] [11].

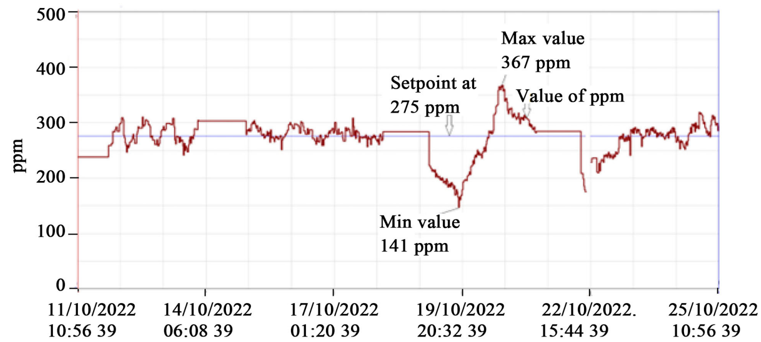

Figure 1. ppm curve over two weeks.

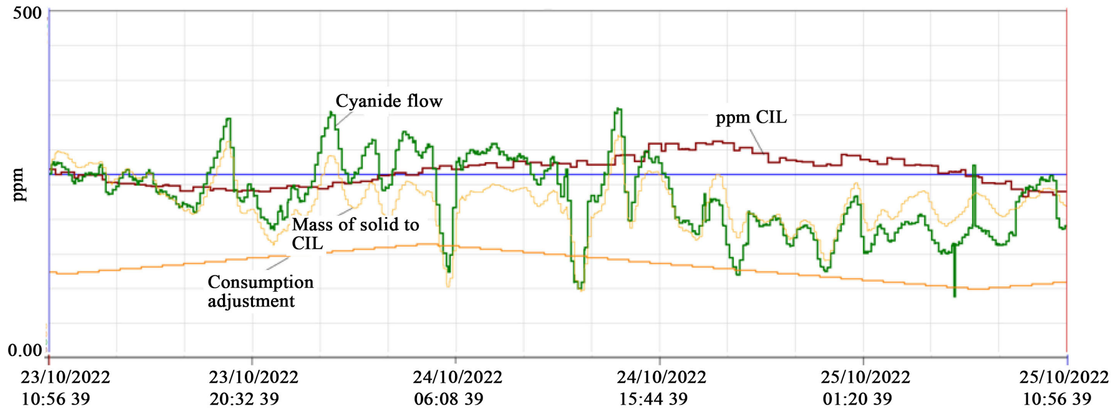

Figure 2. Curve over 48 hours.

The programming software used for the PLC as part of this optimization is equipped with a new multitasking version offering several characteristics. The language used in the framework of the optimization allows the graphical programming of function blocks [10] [11] in accordance with the IEC 61131-3 standard as illustrated in **Figure 3**.

2. Methodology

The function block monitors the overshoot of an upper limit as well as the crossing of a lower limit value of an input variable. This is a kind of hysteresis block as listed in **Figure 4**.

Regarding the operation of our modification, we have five inputs, as illustrated in **Figure 5**, on the side of the "Indlim_Real" block and 02 outputs. The outputs of "IndLim_Real" are linked to two selection FBD blocks "SEL". At the "Out" outputs of the "SEL" blocks, we have two variables. The "SEL" blocks have 03 inputs and 01 output.

In our logic, when the pressure at the X input of Indlim_real is greater than or equal to 86 kPa, the Mx_Ind output is activated. The value −1.5 at the input of the first "Sel" block is selected. The output of this block therefore takes the value −1.5. This has the effect of reducing the density setpoint by 1.5. The pumps will then speed up to lower the pressure. The output flow to the CILs will increase. When the pressure drops to 85 kPa or less, the Mx_Ind output goes to 0 and the

"SEL" block applies 0.0 to the output. So we stay at this density setpoint. Conversely, when the pressure is less than or equal to 83 kPa, the MN_IND output is activated. The value 1.5 at the input of the second "SEL" block is transferred to the output. In doing so, the density setpoint is increased by 1.5. The effect will be a drop in the speed of the pumps so that the % solid goes up. Speeds to CILs will drop. When the pressure reaches 84, the output of the second "SEL" block becomes 0.0.

Mathematically, we write:

E304_DIC_0268_SP_SUB = -1.5 if $X \geq 86$

E304_DIC_0268_SP_ADD = 1.5 if $X \leq 83$

E304_DIC_0268_SP_SUB = 0.0 if $84 \leq X \leq 85$

E304_DIC_0268_SP_ADD = 0.0 if $84 \leq X \leq 85$

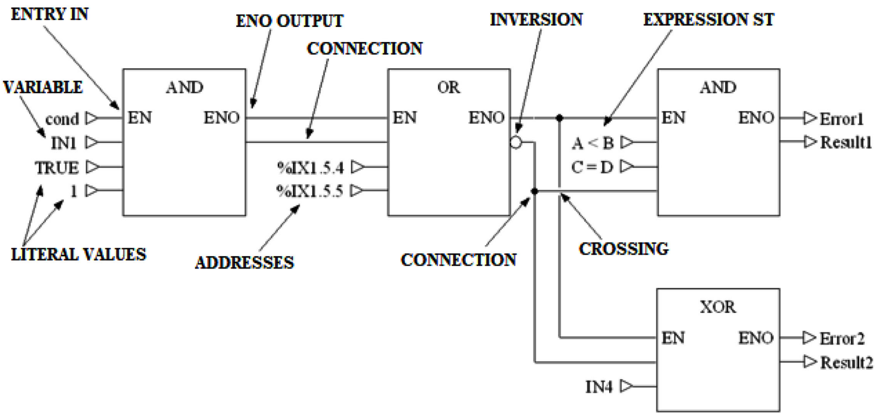

Figure 3. Representation of an FBD section.

Figure 4. Function block and hysteresis diagram representation.

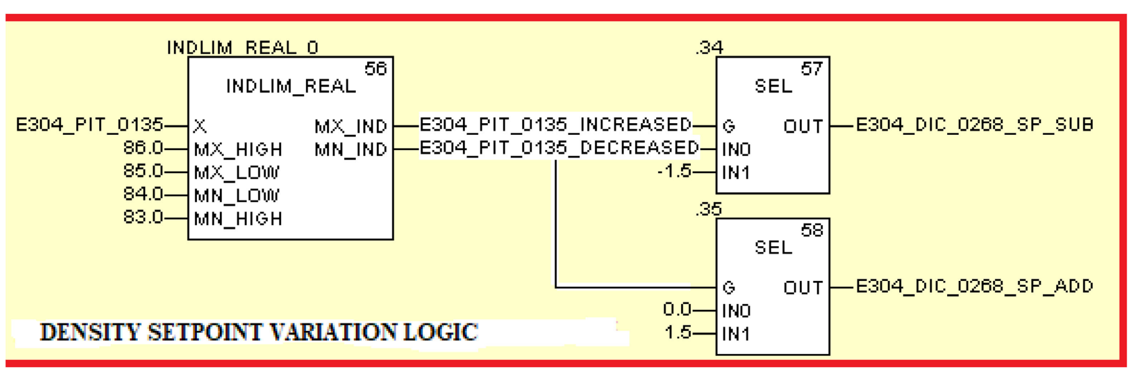

Figure 5. Density setpoint variation logic.

2.1. Description of Changes Made to the Cyanide Addition Control

The situation before the changes observed on the curves in Figure 6 denotes a slow adjustment of consumption. The cyanide flow rate is very variable and the mass flow rate is unstable. The data is taken over 24 hours.

The following changes have been made:

- Calculation of new set point every 15 minutes. The well-calibrated Mintek analyzes the ppm and transmits the values every 15 minutes.
- Programming of a deadband logic when the ppm reaches ±10 of the setpoint: the adjustment of the cyanide consumption value is stopped. The flow of cyanide then varies as a function only of the mass flow to the CIL.
- Change of the correction value from 0.01 to 0.025 which allows deviations to be corrected fairly quickly: reduction of the overshoot amplitudes and the time taken for the correction.
- Tuning of the cyanide control loop to make it less aggressive since we are working on a slow system such as perceptible change after at least 15 minutes.
- Disabling the manual correction performed by the operator.
- Maximum cyanide limit set at 3 m^3/h instead of at 5 m^3/h. This limit is adjustable by programming after analysis of the parameters.
- Max limit automatically decreases to 2.9 if the max flow is reached and the ppm is higher than the set point and growing. It returns to 3 when everything becomes stable again.
- Minimum consumption adjustment limit increased from 0.4 to 0.55 in order to maintain a minimum flow at all times.
- When the max flow −0.10 is reached, the increase of the cyanide consumption correction value is prohibited. The variation is made only according to the mass flow.
- We force the consumption adjustment value to decrease when the ppm is at +10 of the setpoint and we have reached the maximum flow rate of cyanide.

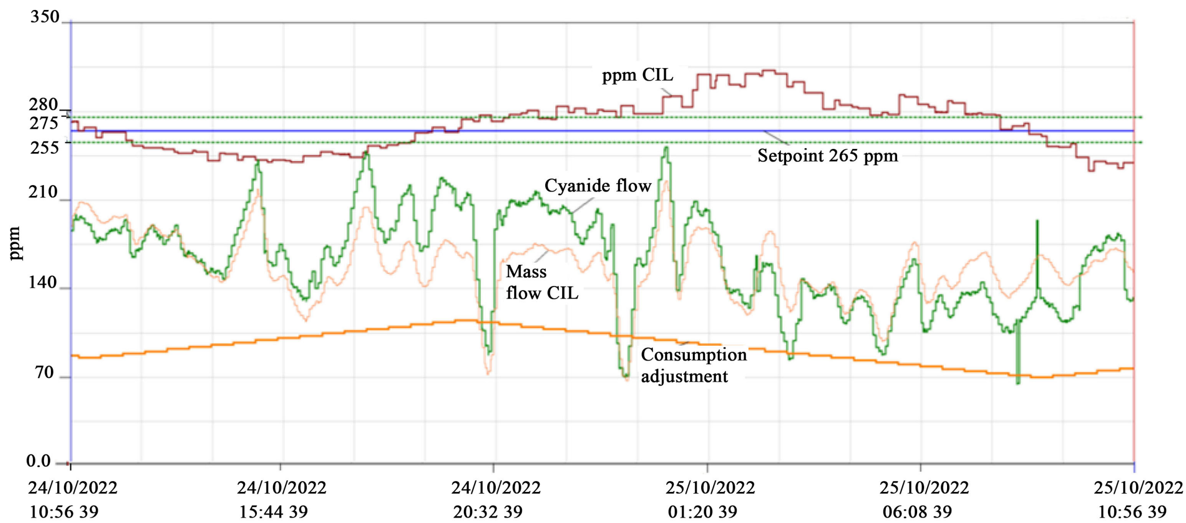

Figure 6. Behavior of cyanide flow, consumption and flow.

2.2. Setpoint Calculation Program

This setpoint is recalculated every 15 minutes and slightly increases the kg/t if the ppm is low and vice versa. This logic is used to calculate the time for adding or decreasing the cyanide setpoint as shown in Figure 7. This time is calculated every 15 minutes with the "Execut Time" DFB block. This block executes the actions at given frequencies.

Then we proceed to the adjustment of the specific consumption every 15 minutes according to the ppm as illustrated in Figure 8. Depending on the conditions of the "DBAND_MIN_MAX" blocks and the AND blocks, the setpoint will either be increased (ADD output block) or decreased (SUB output block). The decrease or increase is done according to the value of the variable "E311_CN_CONS_SP" which is a constant. We adjusted it from 0.01 to 0.025.

The "DBAND_MIN_MAX" DFB block that we have programmed makes it possible to determine the evolution of the ppm and affects the decrease, increase or stability according to the internal logic. It determines a deadband which is the point where the ppm value falls within the desired range. If the ppm setpoint is 300, the range will be between 310 and 290.

Force to decrease when the ppm is stable around the setpoint and the flow increases or when the flow is high for more than 30 minutes as shown in Figure 9.

<u>Calculation of the target in m³/h and calculation of the specific consumption</u>

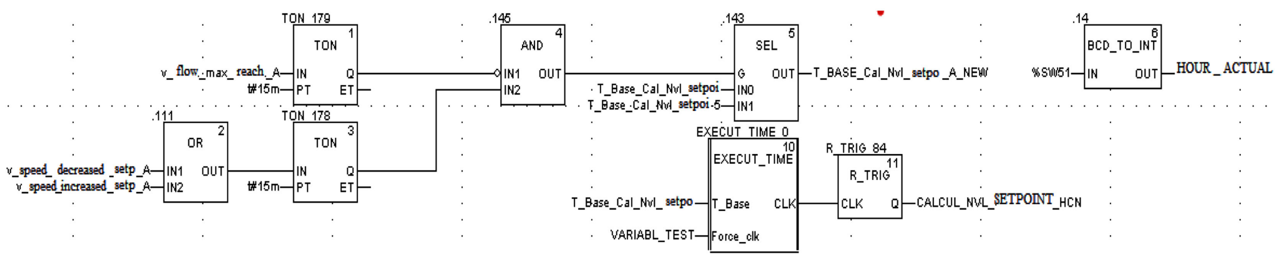

Figure 7. Time base calculation program.

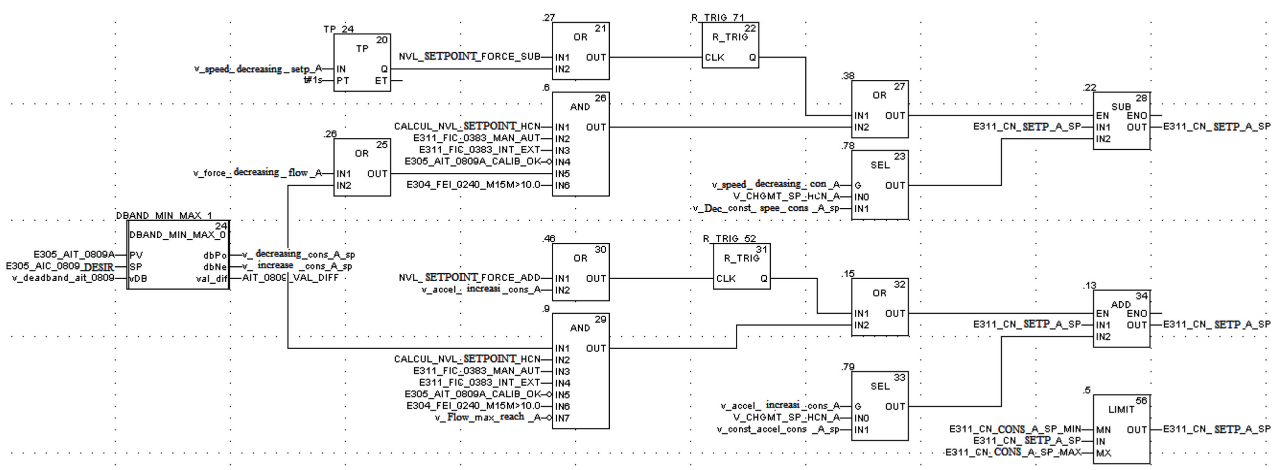

Figure 8. Specific consumption adjustment program.

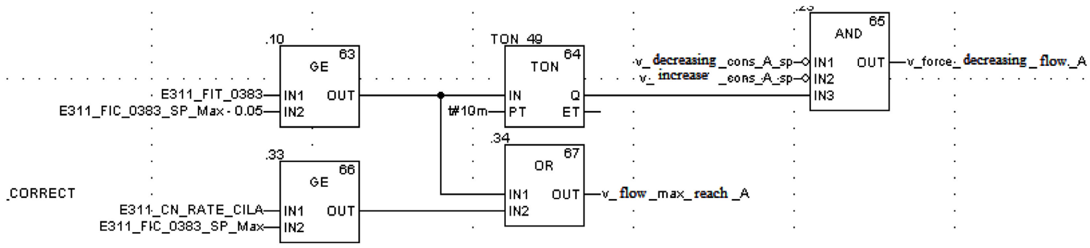

Figure 9. Program to force the increase or decrease.

Specific consumption: It is a constant determined by metallurgy. This is the amount of cyanide it takes to process 1 ton of ore. It is equal to 13/47.35 = 0.27. The "Move" block transfers the input value.

Calculation of the level of cyanide necessary according to the solid mass of pulp towards the CIL is shown in Figure 10.

We replaced the old calculation which was done with the mass flow by the solid mass based on the density. Its calculation is programmed, as shown in the Figure 11 as follows according to the formula:

$$Ms = \text{flow rate} \times \%\ \text{solid}$$

For operational purposes, we have created a DFB block which averages over 1 hour the solid masses over a period of 15 minutes. Indeed it takes time to measure the ppm contained in the tank.

<u>**Cyanide flow controller sent to cilium tank**</u>

This is the regulation loop that controls the flow of cyanide to be added based on data from previous programs. The PID parameters change according to the operation mode of the loop as shown in Figure 12.

With the following PID parameters:

Kp = 2.0

The gain is varied to the point of oscillation close to the setpoint.

Ti = 20

Td = 0.0

Our parameters configured in this way will allow the control loop to be less aggressive in the event of an error.

<u>**Management of the max and min limits in order to avoid any excessive excess of the ppm**</u>

The logic is entirely based on function blocks (FBD).

When the cyanide flow is above the max limit for more than 30 minutes, the output E311_FIC_0383_SP_MAX takes the value of V_0383_NEW_VALUE_MAX which is to decrease the cyanide flow set point as shown in Figure 13. When the cyanide flow value is below the max limit and there is a request to ramp up, the output resumes the normal flow setpoint.

When the difference between the measured ppm value (E311_AIT_0809) and the ppm set point is greater than 15.0 ppm, the maximum cyanide flow rate limit is lowered to 1 m^3/h. The result will be a rapid drop in ppm.

And conversely when the difference is less than −15.0, the minimum throughput limit is increased.

The control loop opens as a popup when the control room clicks the control ppm button. The screen appears as shown in Figure 14 with all the identifications on Table 1.

In this kind of configuration, we are dealing with a cascade control loop. The output of the first control loop becomes the setpoint of the second control loop.

3. Results and Discussion

Before the modifications, we observe the following trends: a large variation in the density instructions with each variation in pressure, a variation also in the

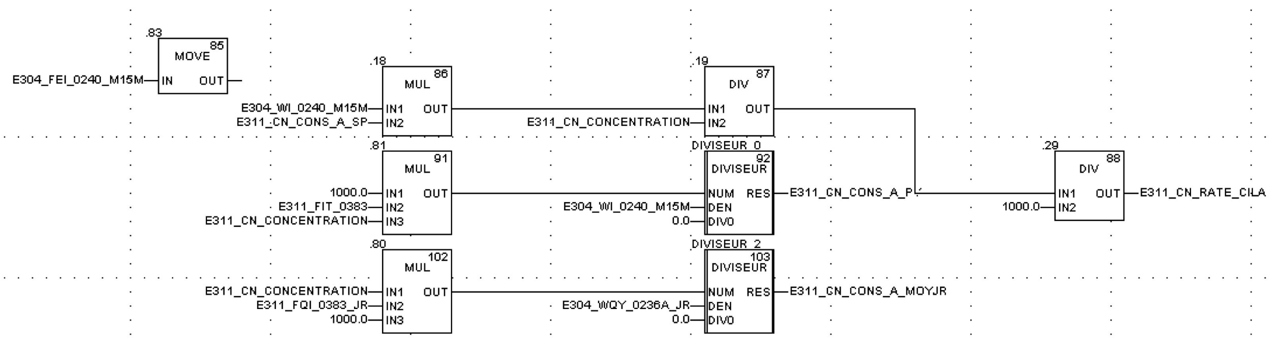

Figure 10. Cyanide rate calculation program (E311_CN_RATE_CILA).

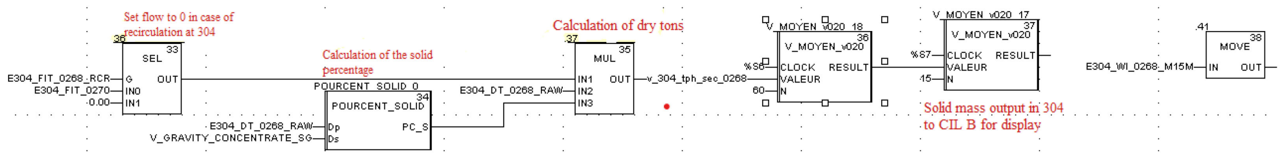

Figure 11. Solid mass calculation program.

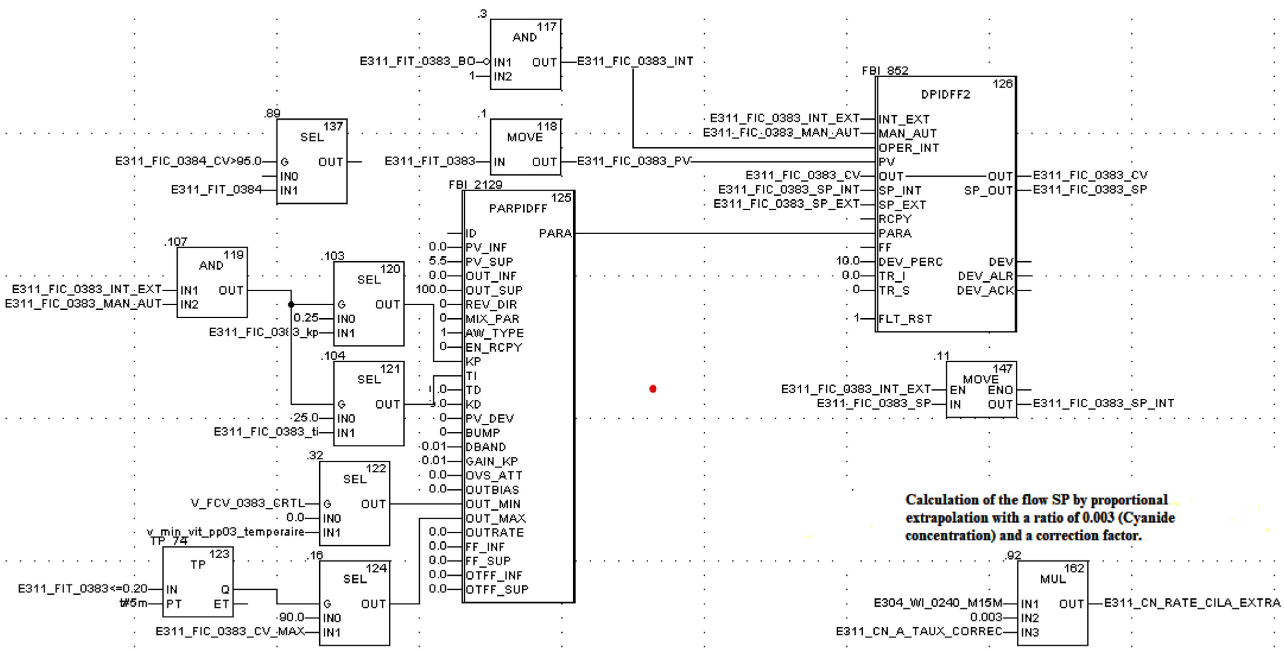

Figure 12. Control loop program.

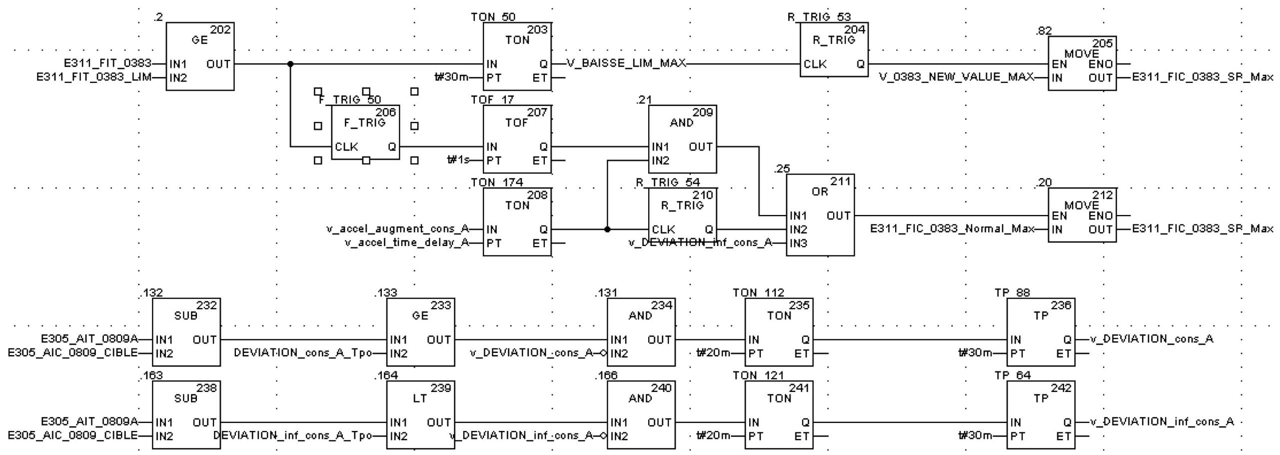

Figure 13. Program for adjusting the MAX and MIN limits in order to avoid excessive excess of the ppm.

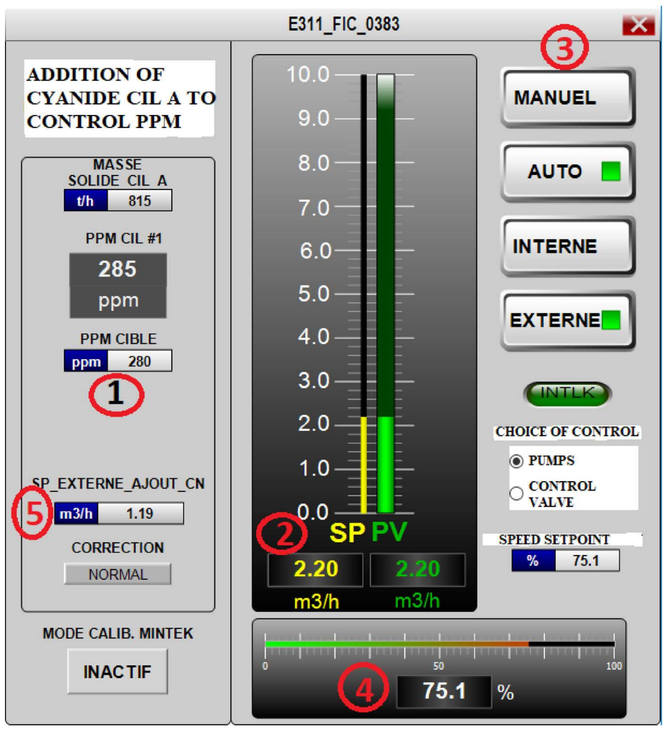

Figure 14. Control loop window.

Table 1. Control loop window elements.

Numbers	Designations
1	Value of the ppm setpoint: this is the target
2	SP: flow setpoint. PV: measured flow value
3	Operating mode: internal or external automatic, manual
4	Output value of the regulation loop applied to the pre-actuator (speed variator in our case)
5	SP_EXTERNE: external setpoint when the controller is in auto and external mode

flow rate of the pulp. The trend is over a period of 8 hours as shown in Figure 15. The operators and the programmed logic reacted this way because they did not want to fall into alarm and be challenged by their hierarchy. The blue curve represents density and the red curve represents flow. Variations in the pressure under the silo have the effect of varying the density setpoint in blue. We observe multiple density setpoint variations at very low frequencies.

Subsequently, the following changes were made to the program and to the interfaces:

- 1st case: when the pressure is greater than 86 kPa, the SP of % solid is reduced by 1.5 until the pressure is less than 85 kPa.
- 2nd case: when the pressure drops below 83 kPa, the SP of % solid is increased by 1.5 until the pressure reaches 84 kPa.
- 3rd case: when there is none of the above cases, the pressure is between 83 and 86 without having reached them. The density setpoint is applied without addition or subtraction.
- Addition of a filter on the output values of the density control in order to avoid the strong reactions of the flow control loops.

3.1. Results Pressure under the Thickener Cone

The trend is taken over 8h. We observe that the fluctuations of the density setpoint have ceased such as 2 variations in 8 hours. This results in a stabilization in the pulp feed rate to CIL in red as shown in Figure 16 Which will subsequently allow the addition of cyanide at an equally stable rate. No adjustment is necessary. Density variation and pulp flow problems are corrected.

3.2. Results Addition of Cyanide and Variation of ppm

Trends are taken over 24 hours as shown in Figure 17. The ppm values are within the desired range. With a setpoint of 200 ppm and an objective of ±10, we find that most of the time the value is within this target. This avoids over-consumption or under-consumption of cyanide, thus optimizing variability.

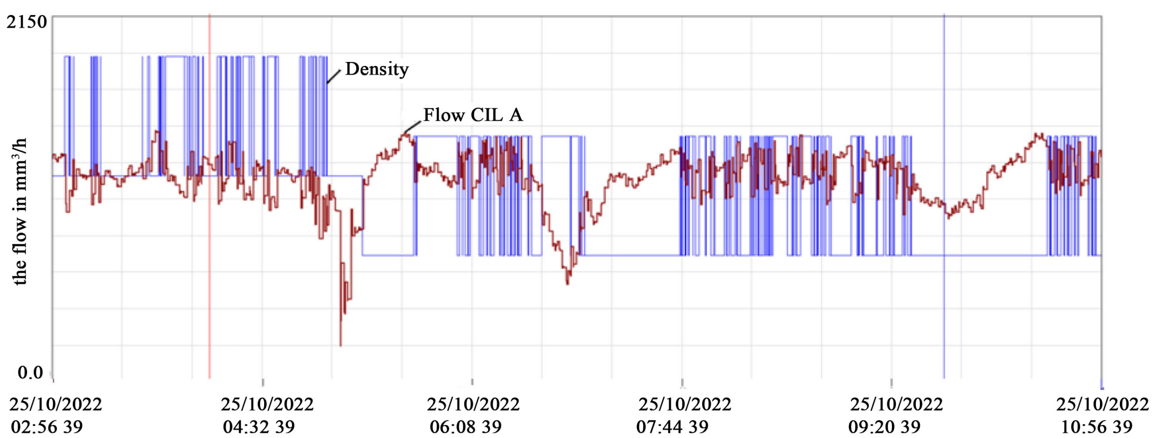

Figure 15. Trend of density variations.

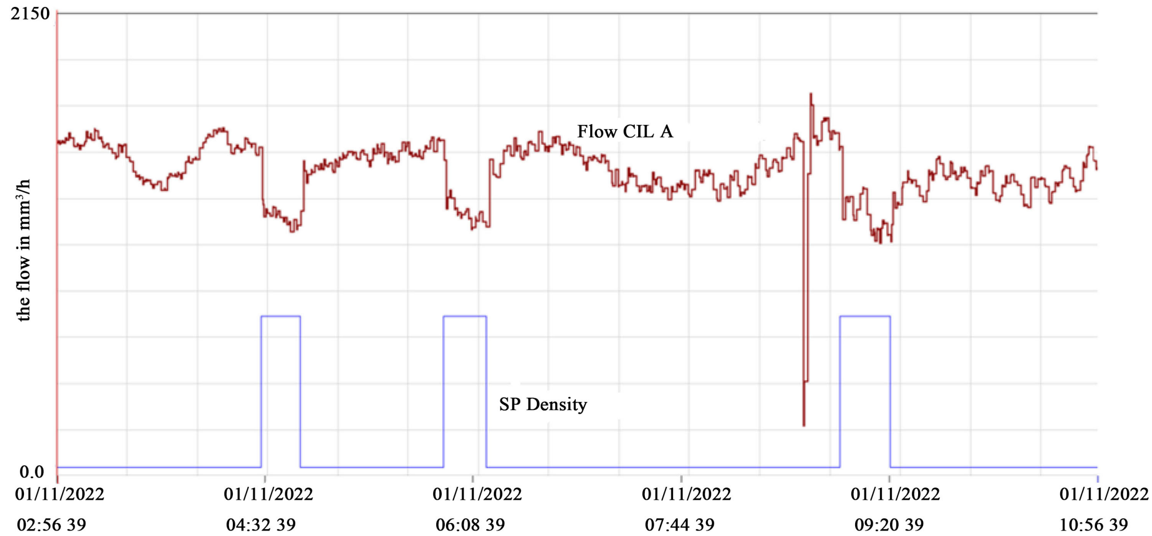

Figure 16. Curves after modification of the program.

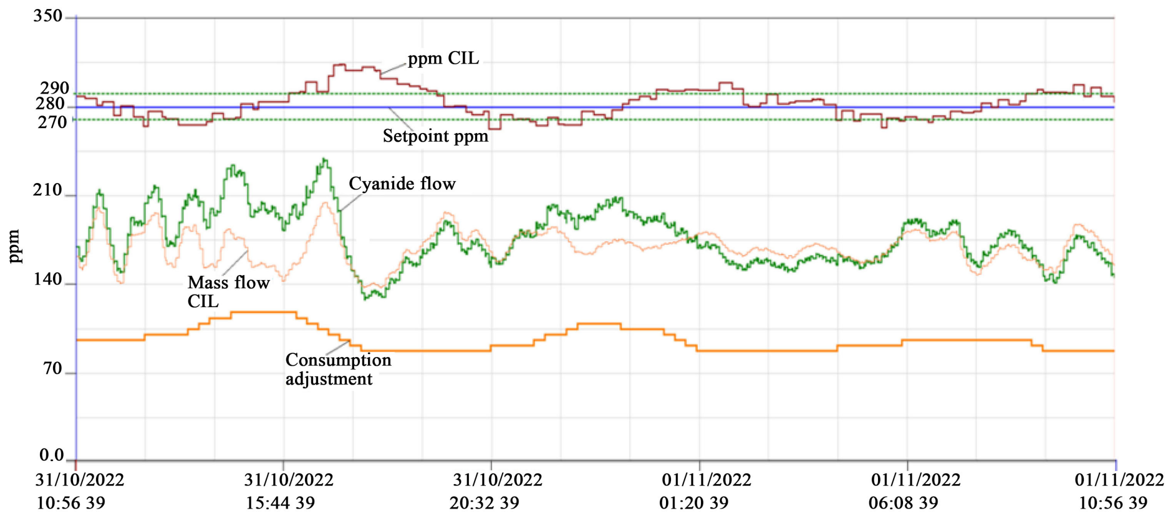

Figure 17. Cyanide addition curve, flow rate and consumption.

Also, the cyanide addition rate is more stable and less aggressive. The CIL tank is well fed according to the amount of pulp solid entering it.

Specific cyanide consumption responds well to ppm deviations. Contrary to the control before modification, we observe areas of stability in the adjustment of the specific consumption. These zones correspond to the moment when the ppm is stable around the setpoint. And the mass flow is also stable.

4. Comparative Analysis of Data before and after Modification

The graphs on the left represent the trends before modification. Those on the right are the trends after modification of the program. The difference is striking in the stability we see in the graph to the right, especially at the level of ppm overruns as illustrated in **Figure 18**.

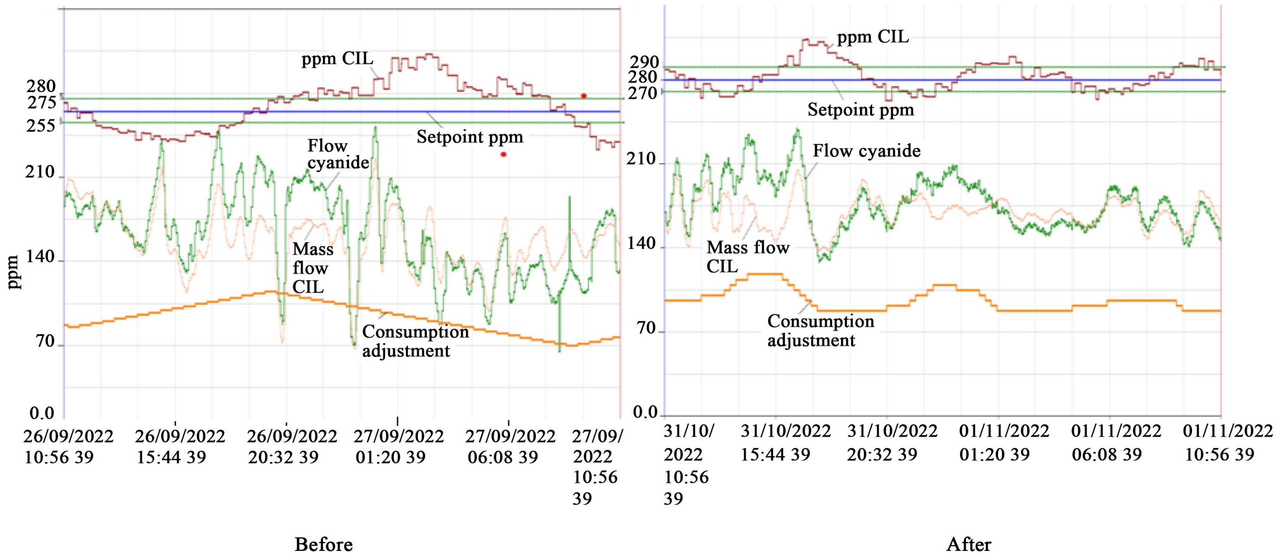

Figure 18. Comparison of trends.

In order to keep the control always stable, we have identified the disturbing causes below. The operations team should monitor these factors.

- Shutdown of a production line;
- Transfer of cyanide to the ILR;
- Manual resumption or change of ratio of the evacuation to eyelash by the operators;
- Opening of the bypass valve;
- Lack of cyanide flow to reach the set point requested by the control loop;
- Dilution of the cyanide concentration.

Based on these factors and our findings, we make the following recommendations:

- Have a constant cyanide concentration. Notify automation in case of change. Ensure that there is no dilution after preparation.
- Keep the bypass valve closed at all times unless the PV (actual cyanide flow) does not reach the SP (setpoint) while the pump is at 100% speed and the control valve is 100% open and the ppm is not reached.
- Ensure the proper functioning of MINTEK by regular calibrations.
- Monitor the transfer of cyanide to the ILR and ensure that the power supply to the CIL A is not cut off.

Avoid large sudden evacuations of the thickener towards the CIL A by changing the ratios or by putting the flow loops in internal auto and proceeding in stages.

5. Conclusions

The conduct of the study allowed us to cover several technical and scientific fields in the industrial environment. We modeled the process related to the control of ppm and according to the action plan which had been defined in the analysis of the causes. Modifications were made to the PLC program. It should be noted that the modeling and simulation of automated production systems responded perfectly to the need for our redesign of the optimization system.

The changes made had a significant effect on ppm control at the CIL. Deviation amplitude reduced around the target by ±10 over a longer duration. The correction time is reduced to a maximum of 1 hour if the target is exceeded by ±10 instead of 4 to 8 hours previously. The control loop reacts well apart from the disturbances caused by the factors mentioned above. Operators no longer need to perform cyanide shortage compensation corrections.

At the end of this study and in light of the results obtained, we can affirm that this study was a success and contributes to improving the variability of the ppm in the CIL. It is therefore certain that savings will be made on the cost of cyanide.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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