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Optimization and Improvement of Gold Purification

Yong Lu[a], Yong Liu

Henan University of Science and Technology, Luoyang 471000, China.

[a]1028620271@qq.com

Abstract

Gold purification is a complex process involving physical chemistry and electrochemistry. At present, the main technology of gold purification in China is the combination of physical chemistry. Such as aqua regia solution, chlorination in aqueous solution, solvent extraction solution, fire smelting solution, electrolytic method, etc. Each gold purification technology has different processing characteristics, therefore, for different quality materials to be processed, the processing method should be chosen to adapt to its material characteristics. From the perspective of industrial control, the gold purification process is a typical complex industrial controlled object, which has the characteristics of nonlinear multi-dimensional precision and high real-time performance. In the traditional gold purification process, a large number of controllable parameters involved in the process do not have precise values, which is a drawback of the traditional manual operation: the accuracy of the controllable parameters is not enough, which leads to unqualified products (product accuracy is not up to the standard), and rework is required (resulting in additional and large processing costs). The object of this study is the gold refining section of some gold smelter in HeNan China, aiming the gold purification process (semi-automatic production process) was optimized and improved into an intelligent production process with high automation degree,which optimize the process of material control, potential control, temperature, PH value and other controllable parameters and product quality.

Keywords

Gold Refining; Intelligent Production Process; Controllable Parameters to Optimize.

1. Introduction: Gold purification production technology of chlorination reduction in aqueous solution

Part of the flow chart of gold purification process by chlorination reduction in aqueous solution in the gold purification section of some Chinese gold smelter is shown in Figure 1.The finished gold produced by this process can fully meet the requirements of national standard finished gold.

This study focuses on process 2 (gold powder dissolution) and process 4(gold ion solution reduction to pure gold powder). Process 2 mainly relies on the oxidation of chlorine gas and chlorate and the newly generated hypochlorous acid to dissolve the gold-containing materials (gold powder and impurities). Process 4 takes advantage of differences in the oxidation properties of metal ions. In the case of all metal ions co-existing in solution, when the reducing agent is added, the gold ion is the most oxidizing, so the gold will be reduced preferently. The specific operation process is as follows:

Procedure 2 (dissolution of gold-containing materials): After the unpurified gold powder is transported, add a certain amount of water and hydrochloric acid to the dissolving kettle (ensure the mass concentration of hydrochloric acid is 180-200g/L). Then open impeller (frequency of 50 hz), to control the steam valve, steam is piped in, start to heat up, ensure the reaction (quality gold dissolved)

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temperature between 65 ~ 75. After that, Add gold powder and chlorination agent (main component is sodium chlorate) to the dissolving kettle, and the mass ratio of chlorination agent and gold is 1:3.5~1:4. After the unpurified gold powder is dissolved and diluted with water, the lead chloride precipitation can be precipitated out. Then the gold ion solution is filtered and transferred into the reduction kettle through a pressure pump.

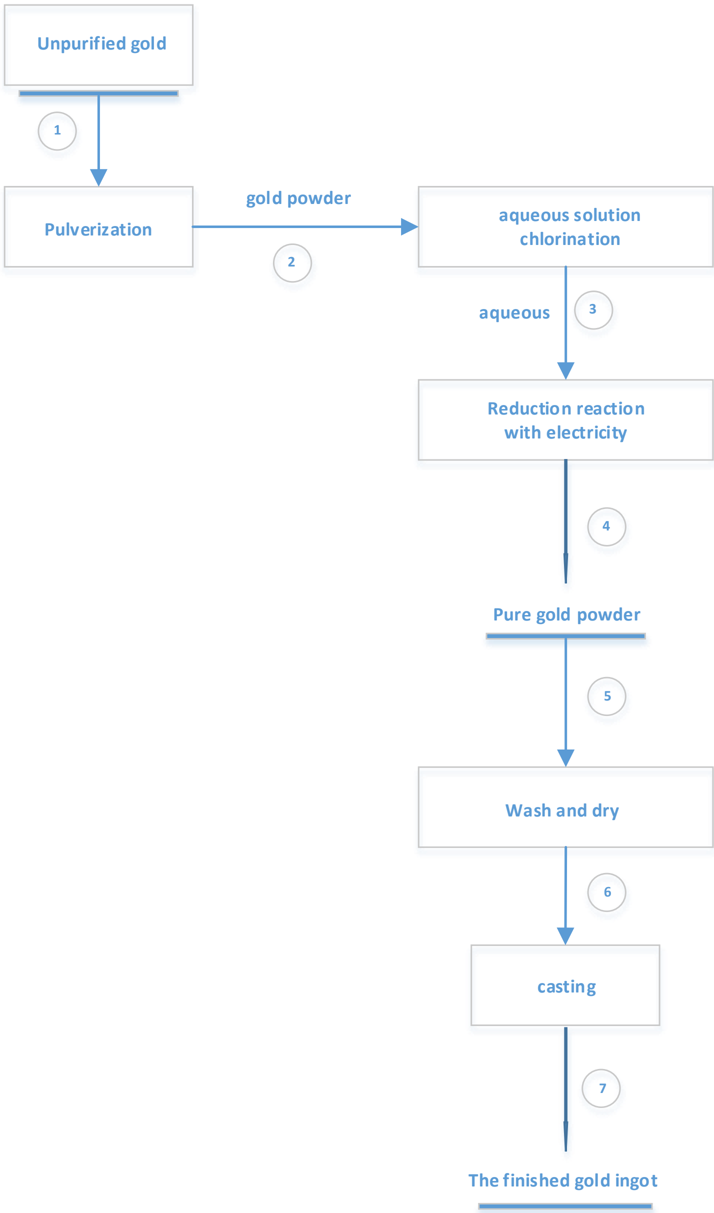

Figure 1. Gold purification process

Process 4 (reduction of gold ion solution to pure gold powder) specific operation steps: Pour filtered gold ion solution into reduction reaction kettle, by adding acid or alkali liquor to ensure the electric potential to achieve more than 720 mv (if the electric potential is too low, adding lye can make electric potential rise), control the temperature between 50 to 60 degree centigrade (the temperature lasted for the whole reduction process), control metering pump to spray reducing agent to gold ion solution continuously for reduction. If electric potential suddenly dropped to below 500 mV, it suggested that unpurified gold converted to pure gold completely. At this time, we need to observe the color of gold ion solution, if more turbid, it suggested that the finished powders of impurity is more, and we need to add sodium chlorate to gold ion solution to dissolve finished gold power again, which could reach the purpose of removal of impurities.

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2. Organization of the Text: Optimization and improvement of gold refining

2.1 Error Analysis

2.1.1 Error One: (error generated by process 2): Dosage of chlorination agent and hydrochloric acid

The main chemical reaction equations for procedures 2 and 4 are shown in the following figure[1]:

$$2Au + 8HCL + 2NaClO_3 = 2NaAuCl_4 + Cl_2 + O_2 + 4H_2O \quad (1)$$

$$6Ag + 6HCL + NaClO_3 = 6AgCl + NaCl + 3H_2O \quad (2)$$

$$10Cu + 20HCL + 4NaClO_3 = 10CuCl_2 + 4NaCl + O_2 + 10H_2O \quad (3)$$

$$10Pb + 20HCL + 4NaClO_3 = 10PbCl_2 + 4NaCl + O_2 + 10H_2O \quad (4)$$

$$PbCl_2 + 2HCL = PbCl_4^{2-} + 2H^+ \quad (5)$$

$$2NaAuCl_4+3Na_2SO_3+3H_2O=2Au+3H_2SO_4+8NaCl \quad (7)$$

$$Pb^{2+}+SO_4^{2-}=PbSO_4 \quad (8)$$

Figure 2. Main chemical reaction equations

Since the dissolution of gold needs to be carried out under acidic conditions, and a certain amount of hydrochloric acid and chlorinating agent is needed to be consumed during dissolution, the specific dosage standard is not given in the specific operation steps given in Process 2 (for materials with different gold content, how much hydrochloric acid and chlorinating agent should be consumed for each batch of materials). In the actual production operation, the default material dosage criteria for production workers is: no matter what grade of material, the mass ratio of gold powder and chlorination agent is 4:1, the addition amount of hydrochloric acid is 500L (mass purity of hydrochloric acid is 32%) and the addition amount of water is 500L. This leads to two situations:Firstly, Insufficient dosage of sodium chlorate and hydrochloric acid results in the incomplete dissolution of unpurified gold, thus reducing the reduction rate of unpurified gold, resulting in waste, and thus leading to economic losses.Secondly, if we add hydrochloric acid and chlorination agent too much, the unpurified gold will be fully dissolved, but the existence of excess hydrogen chloride and sodium chlorate in the solution, will react with the reducing agent in process 4 (gold ion solution reduction to pure gold powder), consuming a large amount of reducing agent, resulting in the waste of reducing agent, and then cause economic losses. In view of the above problems, it is necessary to figure out the accurate material dosage of different quality of unpurified gold to make the economic loss to reach the minimum.The calculation is as follows:

In the theoretical state, it can be obtained according to the chemical equation (1)that:For every 2 gold atoms dissolved, 8 hydrogen chloride molecules and 2 sodium chlorate molecules need to be consumed at the same time, that is, when all gold atoms are dissolved completely: the substance amount ratio of gold, hydrogen chloride and sodium chlorate is 2:8:2, that is :1:4:1. According to the chemical equations (2), (3) and (4), when the impurities (silver, copper and lead) dissolve, the corresponding ratio of hydrogen chloride and sodium chlorate needs to be consumed, that is, when the silver is completely dissolved, for every 6 dissolved silver atoms, the corresponding ratio of 6 hydrogen chloride molecules and 1 sodium chlorate molecule needs to be consumed. the substance amount ratio of silver, hydrogen chloride and sodium chlorate is 6:6:1.According to the relative atomic mass,it can be calculated that when the silver is completely dissolved, the mass ratio of silver,

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hydrogen chloride and sodium chlorate is 647.4:219:106.5. When copper is completely dissolved, each dissolved 10 copper atoms, need to consume 20 molecules of hydrogen chloride and 4 molecules of sodium chlorate, the amount of substance ratio of copper, hydrogen chloride and sodium chlorate is 10:20:4=5:10:2.Thus, according to the relative atomic mass,it could be calculated that: when copper is completely dissolved, the mass ratio of copper, hydrogen chloride, sodium chlorate is 317.5:365:213. When plumbum is completely dissolved, each dissolved 10 plumbum atoms, need to consume 20 hydrogen chloride molecules and 4 sodium chlorate molecules.Thus, the amount of three substance of ratio of plumbum, hydrogen chloride and sodium chlorate is 10:20:4=5:10:2. Then according to the relative atomic mass, it could be calculated that: when plumbum is completely dissolved, the mass ratio of plumbum, hydrogen chloride and sodium chlorate is 1036:365:213.

2.1.2 Error Two (error generated by process 4): Dosage of reducing agent added

In the actual production operation, no matter how the grade of unpurified gold powder is, the mass ratio of reducing agent and unpurified gold powder is 1:1.2. However,every batch of unpurified gold powder containing different grade of material will result in different dosage of reducing agent. Therefore, when we reduce gold ion solution to pure gold powder, it is necessary to accurately calculate the dosage of reducing agent.The calculation is as follows:

In the theoretical state, it can be obtained from chemical equation (7) that: Reducing gold ion solution back into pure gold powder ,essentially, is reducing Au^{3+}contained in $NaAuCl_4$ to Au (gold), and each two Au^{3+} ions contained in $NaAuCl_4$ need to react with three Na2SO3 (effective constituent of reducer) molecules,accordingly, reducing to two gold atoms. As a result, the amount of substance ratio of Au^{3+} and Na_2SO_3 is 2:3. According to the relative atomic mass, we could get that the mass ratio of Au^{3+} and Na_2SO_3 is 394:378.

2.1.3 Error Three (Error generated by process 4): electric potential error

Since process 4 (reducing gold ion solution to pure gold powder) needs to control the electric potential value more than 720 mV during the whole reaction. In practice, a production worker uses sampling methods for measuring electric potential (take out part of the reaction solution and measure its electric potential). For its disadvantages: since sampling methods costs a certain amount of time, this method could neither achieve the goal of real-time measurement for electric potential of gold ion solution, nor feedback control according to the real-time measurement of data.

In theory, as long as there is Au^{3+} in the solution undergoing redox reaction, the electric potential value in solution will be about 720 mV, keeping the positive and negative error during 30mV and 40mV. Once the concentration of Au^{3+} in solution tend to zero, the electric potential in solution would suddenly dropped to below 500 mV. Therefore, the electric potential in solution is an important parameter to judge whether there is remained Au^{3+} in solution.

2.2 Optimization scheme

2.2.1 Scheme1: process optimization

In the actual production operation, before the dissolution of unpurified gold powder, the production workers will generally make a rough estimate that the mass ratio of sodium chlorate and unpurified gold powder is 1:4. Once we get the weight of unpurified gold powder, the dosage of sodium chlorate will be calculated accordingly. However, that is a rough estimate with large error.

Process optimization:

The factory's unpurified gold powder, before being transported to gold purification section, need to be sent to a special department for quality inspection, testing gold content and impurity content. We just need combine the test results (gold content percentage and impurity content percentage) with the weight of unpurified gold powder to figure out the accurate weight of gold and the various impurities. Combining the chemical equation of (1) (2) (3) (4) in figure 2, we could not only figure out how much HCl and $NaClO_3$ the gold need to consume, but also the dosage consumed by impurities (silver, copper, plumbum). Last but not least, we could get the accurate dosage of HCl and $NaClO_3$ by making a summation.

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2.2.2 Scheme2: Build a system architecture to assist gold purification

In order to meet the requirements of automatic feeding, intelligent calculation of dosage of adding material and real-time measuring parameters of gold ion solution, the system architecture diagram was constructed based on the production process and available equipment, as shown in Figure 3.

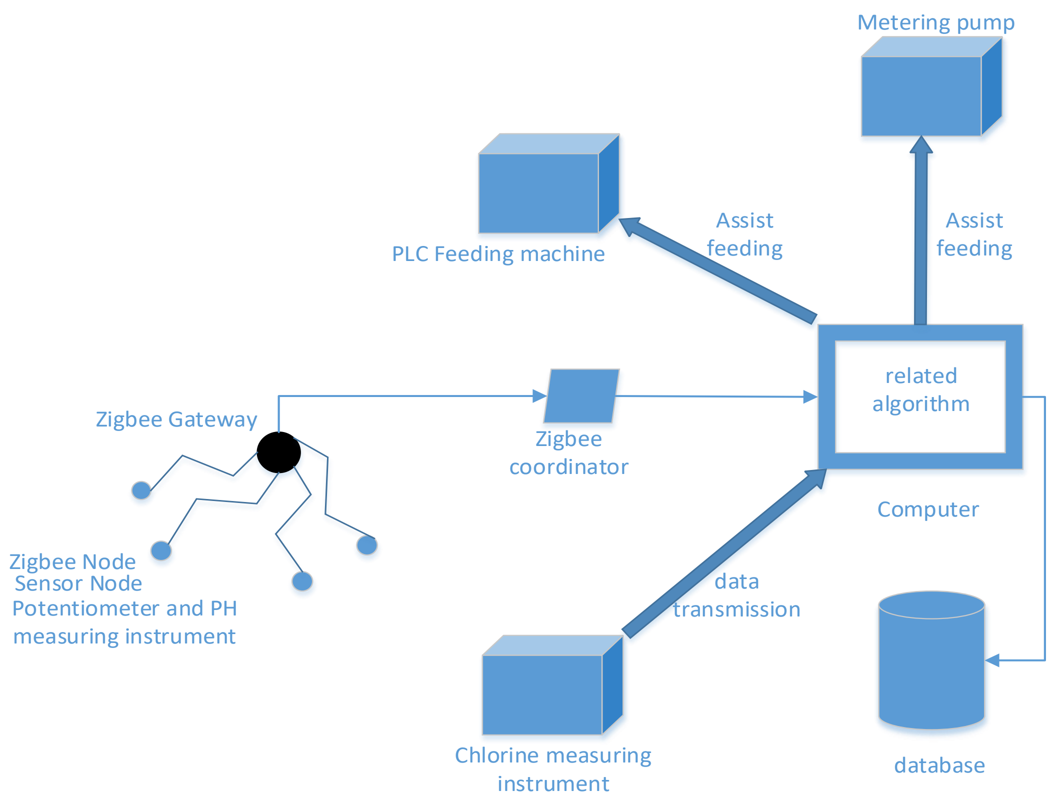

Figure 3. System architecture diagram

2.2.2.1. Data Transmission Module

Zigbee Node: Zigbee Nodes need to contact with sensor nodes. The function of Zigbee nodes is to receive collected data by all kinds of concentration sensor, pH measurement instrument and electric potential meter and send these datum to Zigbee Gateway.

Zigbee Gateway: The function of Zigbee Gateway is to receive and processing datum from many Zigbee nodes and after that, send these datum to Zigbee coordinator.

Zigbee coordinator: As a transfer station of communication between Zigbee module and computer software, the function of zigbee coordinator is to receive datum from zigbee gateway and send these datum to computer for further disposal.

2.2.2.2. Data Acquisition Module

Chlorine measuring instrument: The role of the chlorine measuring instrument is mainly to measure chlorine gas of reaction process. According to the chemical equation (1) in figure 2, every 2 mol dissolved gold elemental, would produce 1 mol chlorine and 1 mol oxygen. According to the relative atomic mass, every 394 g dissolved gold, would produce correspondingly 71 g chlorine gas 32 g oxygen. Since there is no gold ions concentration sensors on the market, we can determine how much the gold dissolved into the solution gold according to the chlorine gas.

Silver ion concentration sensor: The function of silver ion concentration sensor is to acquire real-time datum of silver ion in solution for further processing of accurate calculation.

Copper ion concentration sensor: The function of copper ion concentration sensor is to acquire real-time datum of copper ion in solution for further processing of accurate calculation.

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Plumbum ion concentration sensor: The function of plumbum ion concentration sensor is to acquire real-time datum of plumbum ion in solution for further processing of accurate calculation.

Hydrogen ion concentration sensor: The function of hydrogen ion concentration sensor is to acquire real-time datum of hydrogen ion in solution for further processing of accurate calculation.

Potentiometer: The function of potentiometer is to acquire real-time datum of electric potential value in solution for further processing.

PH measuring instrument: The function of PH *measuring* instrument is to acquire real-time datum of PH value in solution for further processing.

2.2.2.3. Programming language

Among diverse programming language, such as Java, PHP, Python, Go, C++, C#, etc, C# has a lot of advantages. Its characteristics in programming are as follows:

(1) Programming style: Safe, stable, simple and efficient.

(2) Application platform: Windows.

(3) Integrated development environment: Visual Studio.

(4) Application fields: Industrial system application, medical system application, and financial system application.

Because of the safety and efficiency of programming in C# and the compatibility of hardware interface, which needs a lot of hardware interfaces in industrial field, such as Zigbee communication module interface, PLC feeding machine interface, Single Chip Micyoco interface, etc, generally, C# is the main programming language which is often used in industrial system application.

2.2.2.4. Response module (metering pump/PCL feeding machine)

Metering pump: Metering pump is a reciprocating positive displacement pump, used to add liquid raw material, whose dosage of volume of liquid raw material could be remotely controlled by computer.

PLC feeding machine: PLC feeding machine is the frequently-used machine for feeding in industry, which often applies to solid powder. The mass of material and feeding speed could be controlled by computer remotely.

3. Data Processing Module (computer software)

3.1 Logical flow chart

Figure 4: Logical flow chart is as follows in Figure 4. When the software starts running, the first test is whether we can receive the data. If we could receive the data, it suggests that the data acquisition module and the data transmission module run normally. The next step is to determine whether we could receive all types of datum. Among them, the grade of unpurified gold data and quality data need to manually input. Data collected by the data acquisition module: the concentration of Ag^{+}, Cu^{2+}, Pb^{2+}, H^{+}, PH value.

Before adding hydrochloric acid, chloride agent and unpurified gold powder, there is nothing in the solution. Therefore, all these datum is 0. But if we could receive data of 0, the transmission module is running normally. Next, according to the manual input data (the grade and quality of unpurified gold powder), the computer could figure out accurate dosage of hydrochloric acid and chloride agent when the batch of unpurified gold powder completely dissolved. After the making the temperature of dissolving kettle up to 80, firstly, the computer control metering pump to add hydrochloric acid to dissolving kettle. Then computer control PLC to add unpurified gold powder with chlorinating agent to dissolving kettle. During feeding process, the data acquisition module and the data transmission module run continuously, the real-time collected data in solution is shown on the computer to achieve real-time monitoring the various parameters in the solution. Once the datum of parameters in the solution satisfy the three conditions at the same time, the computer would control to stop feeding automatically, and save all datum of parameters in solution to the database.

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Figure 5: The logical flow chart of reducing gold ion solution to pure gold powder is as shown in Figure 5. At the beginning, acquire datum of all kinds of parameters and show these on the computer. Figure out the dosage of reducing agent and threshold of relative parameters according to the collected datum. Then, determine whether the environmental parameters (temperature, PH value, electric potential) achieve working standard. If not, control relative equipment to make corresponding parameters achieve working standard. After that, computer could make an accurate calculation again according to the variation of parameters. Finally, computer control the metering pump to reduce the gold ion solution to pure gold powder. During the whole reducing process, the data acquisition module and the data transmission module run continuously to ensure the real-time monitoring the datum of parameters of the solution. Once one or more datum reach the threshold, computer stops feeding and save the datum to database automatically.

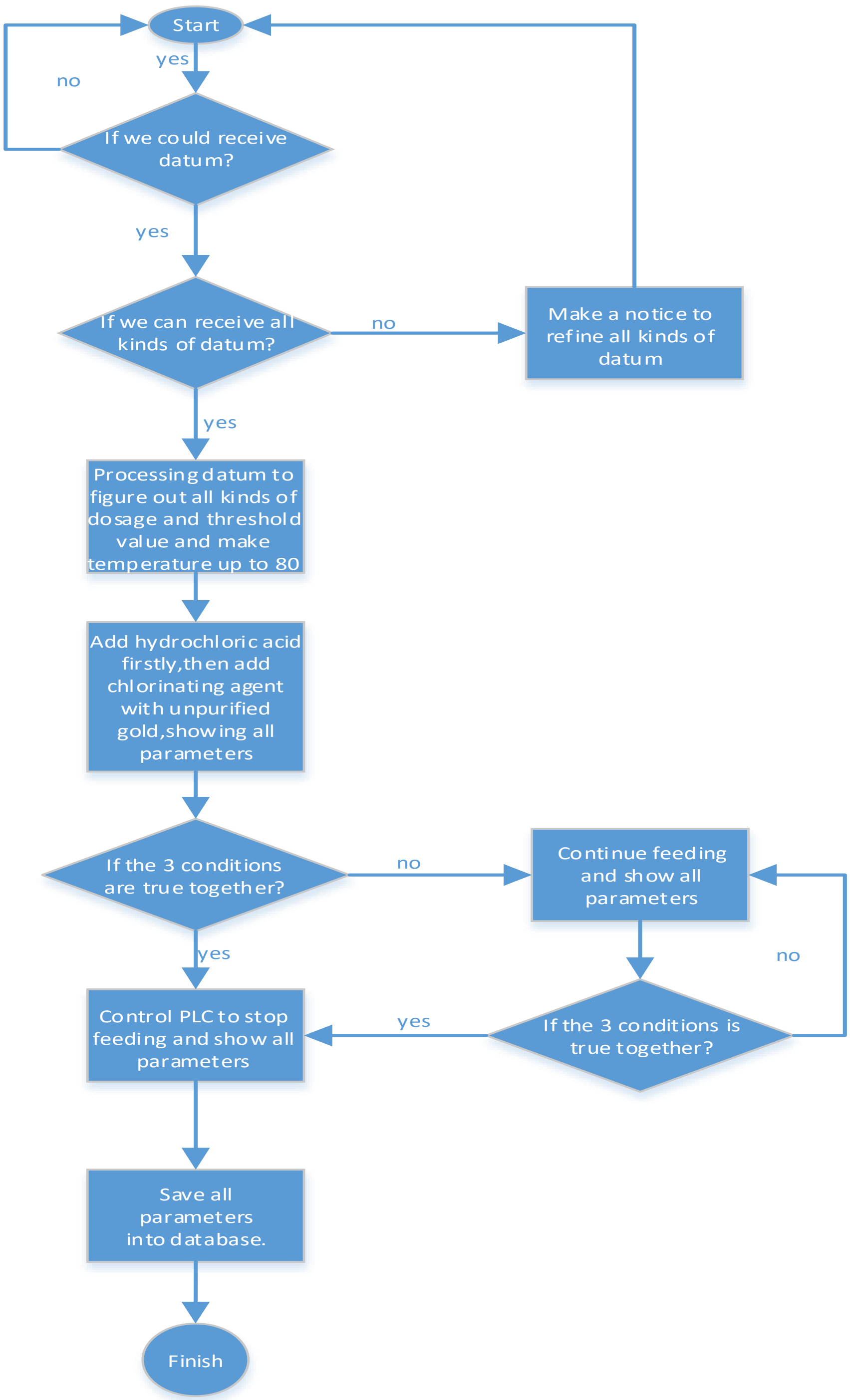

Figure 4. Logical flow chart of dissolution of unpurified gold powder

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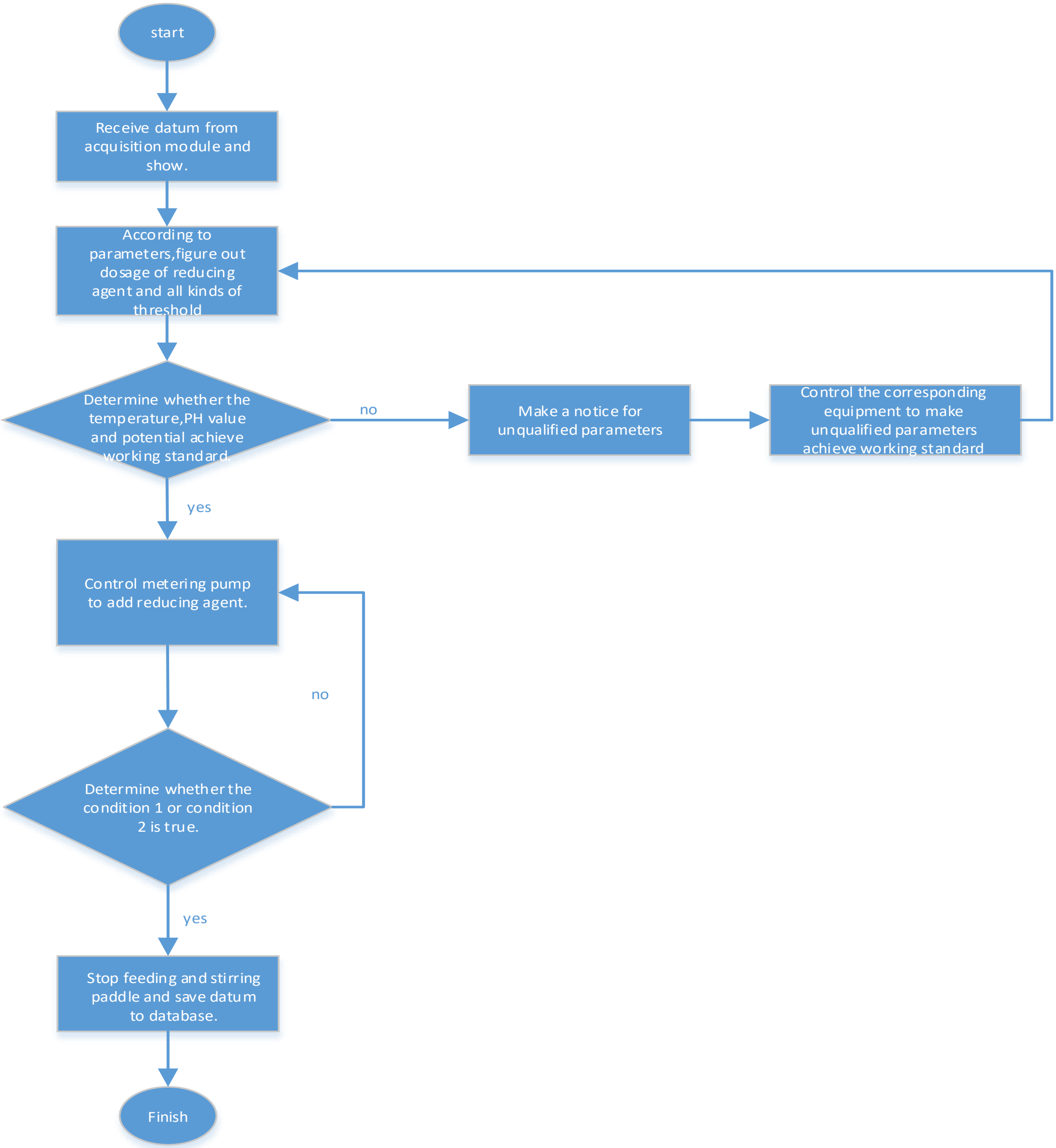

Figure 5. Logical flow chart of reducing gold ion solution to pure gold powder

3.2 The function of computer software

Process 1: The dissolution of unpurified gold powder

Real-time monitoring the variation of parameters: According to the datum from Zigbee module, the real-time parameters value could be shown on the computer. The main parameters value in solution are: The concentration of Ag^+, Cu^{2+}, Pb^{2+}, H^+, ClO_3^- and the electric potential value in solution.

Accurate calculation and automatic feeding: According to the grade and quality of every batch of unpurified gold powder, computer software could figure out the accurate dosage of hydrochloric acid, chlorinating agent and all kinds of threshold.

Process 2: Reducing gold ion solution to pure gold powder

Real-time monitoring the variation of parameters: According to the datum from Zigbee module, the real-time parameters value could be shown on the computer. The main parameters value in solution are: The concentration of Ag^+, Cu^{2+}, Pb^{2+}, H^+ and the electric potential value in solution.

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Accurate calculation and automatic feeding: According to the grade and quality of every batch of unpurified gold powder, computer software could figure out the accurate dosage of hydrochloric acid, reducing agent, lye and all kinds of threshold.

3.3 Algorithm

Process 1: The algorithm of dosage of hydrochloric acid and chlorinating agent

The dosage of material consumed by gold: According to chemical equation (1) in Figure 2, every 2 mol dissolution of Au(gold) need to consume 2 mol $NaClO_3$ and 8 mol HCL. Thus, according to the relative atomic mass, we could get that every 394g dissolution of Au, need to consume 213g $NaClO_3$ (sodium chlorate) and 292g HCL (hydrogen chloride). As a result, if Au need to be dissolved completely, the mass ratio of Au, $NaClO_3$, HCL is 394:213:292.

The dosage of material consumed by silver: According to chemical equation (2) in Figure 2, every 6 mol dissolution of Ag(silver) need to consume 1 mol $NaClO_3$ and 6 mol HCL. Thus, according to the relative atomic mass, we could get that every 647.4g dissolution of Ag, need to consume 106.5g $NaClO_3$ (sodium chlorate) and 219g HCL (hydrogen chloride). As a result, if Ag need to be dissolved completely, the mass ratio of Ag, $NaClO_3$, HCL is 647.4:106.5:219.

The dosage of material consumed by copper: According to chemical equation (3) in Figure 2, every 10 mol dissolution of Cu(copper) need to consume 4 mol $NaClO_3$ and 20 mol HCL. Thus, according to the relative atomic mass, we could get that every 635g dissolution of Cu, need to consume 426g $NaClO_3$(sodium chlorate) and 730g HCL (hydrogen chloride). As a result, if Cu need to be dissolved completely, the mass ratio of Cu, $NaClO_3$, HCL is 635:426:730.

The dosage of material consumed by plumbum: According to chemical equation (4) in Figure 2, every 10 mol dissolution of Pb (plumbum) need to consume 4 mol $NaClO_3$ and 20 mol HCL. Thus, according to the relative atomic mass, we could get that every 2072g dissolution of Cu, need to consume 426g $NaClO_3$(sodium chlorate) and 730g HCL (hydrogen chloride). As a result, if Pb need to be dissolved completely, the mass ratio of Pb, $NaClO_3$, HCL is 2072:426:730.

Every batch of unpurified gold powder has its own mass and quality (Au, Ag, Cu, Pb percentage composition). Suppose the mass of some batch of unpurified gold powder is m, the percentage composition of Au is x%, the percentage composition of Ag is a%, the percentage composition of Cu is b%, and the percentage composition of Pb is c%. Accordingly, the mass of Au, Ag, Cu, Pb of that batch of unpurified gold powder is mx%, ma%, mb%, mc%. According to the dosage of material consumed by Au, Ag, Cu, Pb, we could get that if a batch of unpurified gold powder of which Au, Ag, Cu, Pb percentage composition is x%, a%, b%, c%, weighing m, needs to be dissolved completely, the dosage of $NaClO_3$ consumed by Au, Ag, Cu, Pb is $\frac{213}{394}mx\%$, $\frac{106.5}{647.4}ma\%$, $\frac{426}{635}mb\%$, $\frac{426}{2072}mc\%$ and the dosage of HCL consumed by Au, Ag, Cu, Pb is $\frac{292}{394}mx\%$, $\frac{219}{647.4}ma\%$, $\frac{730}{635}mb\%$, $\frac{730}{2072}mc\%$.

As a result, as long as we import the data of mass and quality of unpurified gold powder into computer software, the computer could figure out the accurate dosage of hydrochloric acid and chlorinating agent.

The extra dosage of hydrochloric acid: According to the working standard, we need to keep the PH value in reaction kettle below 2. Therefore, we need extra dosage of hydrochloric acid. The detail calculation is as follows:

If PH value is 2, that is, $PH=-lg[c(H^+)]=2$,

Accordingly, $c(H^+)=0.01mol/L$.

If PH value is below 2, that is, $PH=-lg[c(H^+)]<2$,

Accordingly, $c(H^+)>0.01mol/L$.

As a result, as long as we keep the concentration of H^+ above 0.01mol/L, the PH value could be controlled below 2.

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Suppose the volume of the solution is 1000L, that is, V=1000L, c=0.01mol/L.

Accordingly, $m_{(HCL)}=N_{(HCL)}M_{(HCL)}=c_{(HCL)}V_{(HCL)}M_{(HCL)}$=0.01mol/L*1000L*36.5g/mol=365g.

Therefore, the mass of extra dosage of HCL is 365g. Since the mass percentage of hydrochloric acid used in this production process is 32%, of which density is close to 1.

Accordingly, ρ(32% hydrochloric acid) =1kg/L=1000g/L.

Therefore, in one liter of 32% hydrochloric acid, $m_{(HCL)}$=1000g*32%=320g.

Thus, to keep the PH value below 2, we need to add the extra volume of hydrochloric acid:

V=365÷320=1.14L (32% hydrochloric acid).

As a result, to get the real dosage of hydrochloric acid, we only need to figure out the sum of the dosage of hydrochloric acid consumed by Au, Ag, Cu, Pb and the extra dosage of hydrochloric acid.

Process 1: The time of feeding and stopping feeding (hydrochloric acid and chlorinating agent)

The time of feeding: According to the logical flow chart, after importing the data of mass and quality into the computer software, with the data acquisition module and the data transmission module running normally, the computer software could figure out the accurate dosage of hydrochloric acid and chlorinating agent automatically. Then, computer controls the mtering pump to add hydrochloric acid into reaction kettle. Last but not least, computer controls the PLC feeding machine to add unpurified gold powder with chlorinating agent.

Condition 1: The time of stopping feeding: According to the chemical equation (1),(2),(3),(4), the unpurified gold powder would react with HCL and $NaClO_3$, consuming H^+ and CLO_3^-. during which period, the amount of substance of CLO_3^- would not increase obviously with adding chlorinating agent ($NaClO_3$) continuously. At the same time, in the strong acid solution, the concentration of H^+ would decline gradually with the dissolution of unpurified gold powder. Therefore, as long as we find that the concentration of H^+ stop going down and the concentration of CLO_3^- begin to go up, it suggests that the unpurified gold powder has been dissolved absolutely. This situation could be considered as the condition one whether the unpurified gold powder has been dissolved absolutely.

Condition 2: The time of stopping feeding:

According to the paper *Optimization and improvement of gold refining process in a Gold Smelter* written by Zhuyi Du, during the period of dissolution of impurities, the electric potential value is below 1000mV [1]. Once the electric potential value climbs up to about 1050mV, Au begins to dissolve. If the electric potential value climbs up to 1100mV, it suggests that Au has been dissolved absolutely. Therefore, whether the electric potential value climbs up to 1100mV could be considered as the condition two.

Condition 3: The time of stopping feeding: Once the dosage of $NaClO_3$ reach the accurate value calculated by computer, it suggests that all the unpurified gold powder has been dissolved almost.

Therefore, this situation could be considered as the condition three.

Process 2: The algorithm of dosage of hydrochloric acid, lye and reducing agent

Before adding reducing agent, we should check whether the working condition could satisfy the working standard, keeping the temperature between 50 and 60, electric potential value above 720mV, PH value between 2 and 3. Generally, the electric potential value and PH value would change together. Therefore, as long as we keep the PH value between 2 and 3, correspondingly, the electric potential value would keep above 720mV.

The dosage of hydrochloric acid and lye:

As we know: PH = $-\lg[c(H^+)]$,

If PH = $-\lg[c(H^+)] = 2$,

$c(H^+)$=0.01mol/L.

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If PH = -lg[c(H^+)] = 3,

c(H^+)=0.001mol/L.

Therefore, we only need to keep the concentration of H^+ between 0.001mol/L and 0.01mol/L to keep PH value between 2 and 3.

Suppose c(H^+)=x. If PH<2,

that is, when x>0.01mol/L, the required amount of substance of OH^- is $N_{(OH^-)}$.

Suppose volume of the solution is 1000L. Then, after adding lye,

the remaining concentration of H^+ is: c(H^+) = x - c(OH^-) = x - $\frac{N(OH-)}{V}$=x - $\frac{N(OH-)}{1000}$,

To keep the c(H^+) between 0.001mol/L and 0.01mol/L,

we take the median: c(medial) =$\frac{0.001+0.01}{2}$ = 0.0055mol/L.

Accordingly, x - $\frac{N(OH-)}{1000}$ = 0.0055.

Then, $N_{(OH^-)}$ =(1000x - 5.5)mol.

According to the relative automatic mass,

we could get the mass of NaOH is: (1000x - 5.5)40g.

Since the mass concentration of industrial lye is 32%,

the required mass of lye is $\frac{(1000x-5.5)40}{32\%}$g.

Therefore, when the concentration of H^+ is above 0.01mol/L,

the required mass of 32% lye is : $\frac{(1000x-5.5)40}{32\%}$g.

When PH>3,

that is, when x<0.001mol/L, suppose the required amount of substance of H^+ is N(H^+).

To keep c(H^+) during 0.001mol/L~0.01mol/L,

we take the median: c(median)=$\frac{0.001+0.01}{2}$=0.0055mol/L.

Then, $\frac{N(H+)}{1000}$ + x = 0.0055mol/L.

We could get: $N_{(H^+)}$ = (5.5 - 1000x)mol.

According to the relative automatic mass,

the required mass of HCL is (5.5 - 1000x)36.5g.

As a result, when PH>3, the required mass of 32% hydrochloric acid is $\frac{(5.5-1000x)36.5}{32\%}$g and accordingly, x is the concentration of H^+ from the data acquisition module.

When PH<2, the required mass of 32% industrial lye is $\frac{(1000x-5.5)40}{32\%}$g, and accordingly, x is the concentration of H^+ from the data acquisition module.

The dosage of reducing agent:

According to the chemical equation (1) in Figure 2, if the reaction produce 1 mol Cl_2, at the same time, it would produce 2 mol $NaAuCl_4$. Therefore, the amount of substance ratio of Cl_2 and $NaAuCl_4$ is 1:2. According to the chemical equation (7) in Figure 2, every 2 mol $NaAuCl_4$ will react with 3 mol Na_2SO_3. Thus, the amount of substance ratio of $NaAuCl_4$ and Na_2SO_3 is 2:3.

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As a result, the amount of substance ratio of Cl_2, $NaAuCl_4$, Na_2SO_3 is 1:2:3. That is, the amount of substance ratio of Cl_2 and Na_2SO_3 is 1:3. Suppose the mass of Cl_2 collected by chlorine measuring instrument is x g. Accordingly, the mass of of Na_2SO_3 is 3x g. Since the mass concentration of Na_2SO_3 is 450g/L, the volume of Na_2SO_3 we needed is $\frac{3x}{450}$L.

As a result, if the mass of Cl_2 collected by chlorine measuring instrument is x g, accordingly, the volume of Na_2SO_3 solution of which mass concentration is 450g/L, which we need to add into gold ion solution, is $\frac{3x}{450}$L.

Process 2: The time of adding and stopping adding reducing agent (Na_2SO_3)

The time of adding reducing agent (Na_2SO_3): According to the logical flow chart in Figure 5, if computer could receive the datum from gold ion solution which could be shown normally, it suggests that the data acquisition module, the data transmission module and computer software run normally. After that, computer begins to check that whether the temperature, PH value and electric potential value could achieve the working standard. If not, accordingly, control correspond equipment to adjust the parameters to working standard. At last, computer figure out the dosage of Na_2SO_3 solution according to the adjusted parameters.

The time of stopping adding reducing agent (Na_2SO_3):

Condition 1: Once the volume of Na_2SO_3 solution added by metering pump achieves the accurate value calculated by computer software, this situation could be considered as condition 1 of stopping adding reducing agent.

Condition 2: To some extent, there is a special connection between the amount of Au^{3+} and electric potential value in gold ion solution. Proved by a lot of production practice, once the electric potential value in gold ion solution achieved to 695mV [1], the Au^{3+} in gold ion solution had been reduced to Au almost. And at this time, this finished gold powder could satisfy the national standard absolutely. Therefore, once the electric potential value collected by the data acquisition module achieved to 695mV, this situation could be considered as condition 2 of stopping adding reducing agent.

Since the demand of purity is very strict in gold refining process, the more time it costs, the more impurities it produces. Therefore, once either the condition 1 or condition 2 is satisfied, it's the time for metering pump controlled by computer to stop adding reducing agent.

4. Conclusion

Compared with the previous gold refining process, the improved process reduces labor costs, reduces security risks and improves economic benefits for the following reasons:

Reason 1: In the manual operation of gold refining process, the calculating dosage of material manually was upgraded to calculate the dosage of material automatically by computer. There is a qualitative improvement in the accuracy of materials, which not only saves a lot of raw material costs, but also avoids manual operation in the feeding process (the feeding process will produce toxic gas chlorine), avoiding safety risks greatly.

Reason 2: In the previous gold refining process, due to the manual feeding, the problem of dosage error of reducing agent is serious, which results to rework frequently. What's worse, the reworking would result to economic losses. However, the improved process could measure the real-time datum of various parameters in gold ion solution, which is used to figure out the accurate dosage of reducing agent, chlorinating agent and the threshold of various parameters. What's more, in the previous process, because of the manual measurement for electric potential value, we couldn't get the real-time data, which led to the dosage error of raw material. However, in the improved process of gold refining, we could get the real-time datum of various parameters in solution by the data acquisition module and the data transmission module, avoiding the time error of measuring electric potential and further losses.

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