STUDY ON DESIGNING A COMPLETE PILOT PLANT FOR PROCESSING SANDSTONE ORES IN PALUA-PARONG AREA

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1. Le Quang Thai, Tran Van Son, Vu Khac Tuan, Tran The Dinh, Trinh Nguyen Quynh, Đoan Thi Mo, Nguyen Hong Ha, Bui Thị Bay, Pham Minh Tuan, Than Van Lien, "Studying on Design of a complete Pilot Plant for Processing Sandstone Ores in Palua-Parong Area", to be published in Journal of Nuclear Science and Technology;
2. Le Quang Thai, Pham Minh Tuan, Trinh Nguyen Quynh, Vu Khac Tuan, Nguyen Hong Ha, Bui Thi Bay, " Ion Exchnge Resin Selection for Concentration and Purification of Uranium Leached by Sulfuric acid Solution", to be published in Journal of Nuclear Science and Technology.

ABSTRACT: Design work is the first step of the construction and operation of pilot plant. Thus, the project "Study on designing a complete pilot plant for processing sandstone ores in Palua - Parong area" was conducted to design a pilot plant for testing entire technological process to obtain yellowcake.

Based on a literature review of uranium ore processing technology in the world, information of ore and previous research results of uranium ore in Pa Lua - Pa Rong area at the ITRRE, a suitable technological flowsheet for processing this ore has been selected. The size, location of the pilot plant and planed experiments has been selected during the implementation of this project, in which basic parameters, designed system of equipment, buildings, ect. were also calculated.

Keywords: *Pilot plant, uranium, uranium ore processing.*

1. INTRODUCTION

Pilot plant is a small scale simulation of the future industrial operations. This is an intermediate stage of testing. The main objectives of the pilot plant is to determine the technical and economic indicators and the environment of the entire uranium ore processing and personel training for operation types of equipment and for control of the process.

According to the results of the Uranium Exploration Project in Pa Lua - Pa Rong area, uranium reserve was calculated with a high reliability (C122 level). The size, complexion, uniformity of ore body and composition of the ore were also determined. Meanwhile research works on technologies for processing the ores in this area to get uranium concentrate have come up with an appropriate technology with a high recovery yield. However, in order to produce uranium from ores in Pa Lua - Pa Rong area, it is necessary to carry out feasibility study, especially in the case of Vietnam that does not have adequate experience in processing uranium ores and other similar ores. Therefore, operation of an ore processing pilot in which design of the pilot is very important and essential at present.

As considered a simulation of a plant in the future, the objective of this pilot is to verify the technology which was developed in the laboratory and optimize operational parameters of components in the process. In addition, other objectives were also paid attention, including study on circulation of solution in components and the accumulation of impurities in the whole operation of the pilot, necessary and adequate information for design, cost estimate of investment and operation, etc.

For these reasons, the topic "Study on designing a complete pilot plant for processing sandstone ores in Pa Lua - Pa Rong area" was conducted to design a pilot plant for testing entire technological process to obtain yellowcake.

2. RESULTS AND DISCUSSION

2.1. General information of ore

According to the results of exploration in the phase 1 of the project for uranium ore exploration in Pa Lua - Pa Rong area, uranium reserve in this area is 5,500 tons of U_3O_8 (in compliance with reserve level of C122, approximately equal to RAR level which is the highest reliability). However, the data at the end of 2007 showed that uranium reserve in the long-term vision might reach over 16,000 tone of U_3O_8.

Sandstone ores in Pa Lua - Pa Rong have geological structure ranging from complex to very complex in which ore body can be a single vein or system of veins that have distribution without law; veins are in the forms of matrix, lens, cluster, tube with discontinuous distribution and destructed fault. This characteristic will affect the selection of methods for ore exploitation during implementation of production.

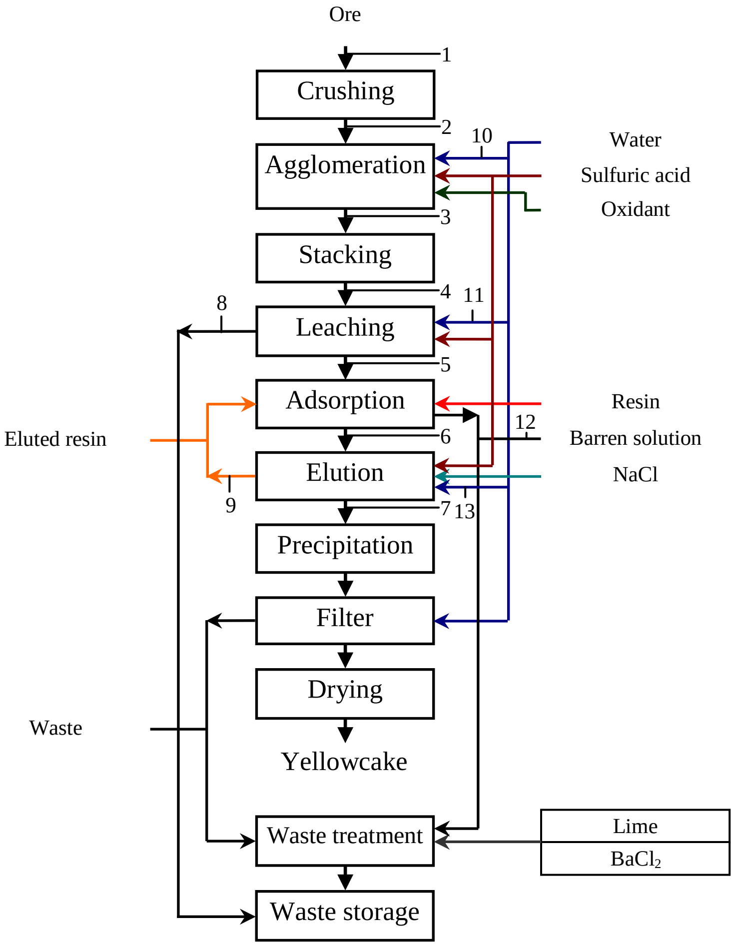
In terms of uniformity, in the area of Pa Lua, the thickness of rock layer containing ores changes from 1.0 to 3.5 m, changing unstably while the average contents of U_3O_8 in the ore bodies change from 0.031% to 0.095%, varying very unevenly. In Pa Rong area, the content of U_3O_8 in the ore body is in the range of 0.006 - 1.43%, accounting for average 0.075%. The content of U_3O_8 in the rock layers containing ores distributes from unevenly to very unevenly. Average thickness of rock layers containing ores is relatively stable. In the 3 layers containing ores, the layer containing No 1 ore lying at the lowest level has large varying co-efficiency in thickness and contents, but the highest content of U_3O_8 and the largest thickness.

In terms of mineral composition, it is possible to divide into groups including minerals creating the host rock, uranium minerals (primary minerals: nasturan and hydrated nasturan, coffinite and secondary minerals: uranophan, uranioxiacid - metaurnaioxiacid, autunite, metaautunite and hydrated metaautunite, uranoxiacid, soddyite, bassetite, etc.) and companying mineral group (sulfur mineral, oxide mineral, ferro and manganese hydroxides and mineral of carbonate group). Sandstone ore in this area consists of no weathered (primary ores) and weathered forms.

In terms of chemical composition, the average uranium content of the area is 0.04 - 0.06% U_3O_8. The ore does not contain a considerable amount of rare and precious elements that are valuable to consider recovery during ore processing. Vanadium and Molybdenum are not in the range of concentrations that are usually paid attention to. Other impurities such as Cu, Ni, Cr, Mn, Ti etc. are not considerable and cause little affects to the quality of the products.The content of carbonate in the ore which ranges from 2% to 6% may lead to high acid consumption in the leaching process; however, it is still in the permissible limit for applying the method of leaching by acid sulphuric. Uranium contents in different ore objects are not the same. Due to the different levels of weathering, compactness of different ores, the ratio between reduction and oxidation forms of uranium are different, leading to the different ability of uranium leaching. This requires piloting to be flexible in terms of technology.

2.2. Selection of complete flowsheet

Based on mineralogical, chemical compositions and results of laboratory research as well as some pilots after laboratory research, the group of authors proposed a flow sheet for processing sandstone ores in the area of Pa Lua - Pa Rong, similar to the flow sheet for processing low grade ores that have been used in the world. According to the flow sheet in the below figure, the ore processing process consists of main components, including ore handling (crushing and grinding), agglomeration, stacking, leaching, ion exchange, precipitation, filtration, drying, effluent treatment and solid waste management. As chemical composition of the ore varies unevenly in the ore body, technological condi -tion would be pointed out in the scope to apply for the ore with the average uranium content of 0.05% U based on the previous research results.



Uranium ore processing flowsheet

- The ore handling stage is to reduce size of ore particles to the appropriate size for leaching: crushing at two levels, in which at the first level, crushing from the size of ore particles after exploitation to the size of -10 cm (80%). A system of sieves with respective sizes was used after each level of crushing to avoid the ore to be over-crushed.

- Agglomeration stage is to ensure even distribution of particle sizes and acid in the ore mass: concentrated sulfuric acid and water are added together with ore into a rotary drum mixer. Acid consumption in this component accounted for around 30% - 40% of the total acid consumption for the whole leaching process. The moisture content reached 5%.

- Stacking is to put the whole mixed ore mass into a heap with solution containing uranium. In order to carry out this, the ore mixed from the previous component was transferred to the leaching area by rubber conveyor system. The height of the ore heap was around 3 - 3.5 m. After that, a system of pipes to provide solution (with dropper) on the surface of the ore layer with distance between holes on the pipe of around 30 - 35 cm. The size of the ore heap will be calculated based on determination of pilot scale as mentioned below.

- Leaching: this is the main stage of the process for removing uranium from the ore and obtaining uranium containing solution. Solution of leaching agent (acid or circulated solution) is pumped into the heap via distribution system with a flow rate of around 10 - 20 l/m^2.hour by batch. After leaching stage, water usually was pumped into the heap to recover the whole dissolved uranium and residual acid from ore residues. Water consumption based on the ratio of water/ore reached around 0.7. Leaching duration was around 2 months. Recovery yield reached around 80 - 85%.

- Ion exchange: this stage was to remove majority of impurities from uranium and increase the content of uranium in the solution and was carried out in a continuous ion exchange system. Ion exchange resin used was strong base anion resin such as purolite. In the initial stage, uranium was removed from leaching solution to the resin, but most of impurities went with the effluent. Before conducting uranium adsorption, the leaching solution was adjusted to pH 1.6 by NaOH solution. In this stage, retention time of the solution in the resin bed was around 8-10 minutes (longer than that for Amberlite IRA 420 resin). The next step was to elution in order to remove uranium from saturated resin into solution and increase uranium concentration. Eluant was solution containing NaCl 1M and H_2SO_4 0.1M. Retention time of the solution in the resin bed was around 15 minutes. Total volume of the eluant for this stage was 18 bed volumes. Uranium concentration in product solution reached around 10 g/l. The yield of uranium recovery reached 98 - 99%. Between these two main stages there were stages of rinsing resins with sulfuric acid 1/1000 (volumetric ratio).

- Precipitation: this is the stage for recovery of uranium in the form of yellowcake as product. To ensure that the product has high purity and stability, H_2O_2 was used as precipitating agent. pH of precipitation process was maintained at 3.3 during the whole precipitation by adding dilute NH_4OH solution. Consumption for H_2O_2 was 0.182 g H_2O_2/g $U_3O_{8.}$ Mixing duration was 2 hours. The solution was kept for 2 more hours to let crystals stable. The yield of uranium recovery reached over 99%, the content of U_3O_8 reached over 80%; content of impurities met the ASTM standards for commercial products.

- Filtration, drying and packaging product: these are the last stages of the flow sheet to complete products, packaging and releasing. A vacumm coveyor filter is used in the filtration.

- Treatment of the effluents was to dispose wastewater to the environment or recycle them in the process. The treatment was carried out in a mixturer by neutralization method through 2 stages.

Neutralizing agent was lime. Initially, the solution was neutralized to pH 8 and mixed for 20 minutes. Lime was continued to be added to reach pH 10 and mixed for additional 20 minutes to allow Ra to be co-precipitated completely with $BaSO_{4.}$ The solution was kept for several days and then was sedimented. Solid waste and tailings were collected and transferred to the landfill for disposal and management.

2.3. Size and location of the pilot plant

Yield of stages from ore crushing to leaching was determined by the amount of ore to be processed, but the later stages such as ion exchange, precipitation, drying, etc... depended on the uranium content in the ore. Therefore, the yields of those stages in the technological flow sheet for processing sandstone ores in Pa Lua - Pa Rong area were very different from each other. In principle, the larger scale of the pilot, the higher the reliability of the obtained information; however, the larger scope, the more difficult the provision of ore samples, especially the provision of budget. In order to reduce the necessary amount of ores for the pilot later on, stages including precipitation, filtration and drying would be operated in batch pattern (this kind of equipment is popular) to have sizes large enough.

The other stages are divided into groups working in continuous mode. The first group include ore preparation, agglomeration and stacking with capacity of 10 tons of ore/hour. The second one include leaching, ion exchange and liquid waste treatment. Leaching system consists of 5 boxes (85 tons of ore/box). Ion exchange system with yield of 185 litters of solution/hour works continuously 24 hours/day and 30 days/month.

Through the survey, a suitable place for pilot plant Pa Lua village, Pa Toi commune, Nam Giang district, Quang Nam province, because it is near the ore body.

2.4. Mass balances

Based on the selected flow sheet, some of the main streams were calculated and given in below table. The calculation is based on the following parameters:

Average moisture content of the ore (%): 2

Leaching efficiency (%U): 82

Saturated uranium loading of resin (g U/l): 45

Efficiency of uranium recovery (%): 98

Characteristics of the main streams of the block diagram

Stream	Working mode	Solid			Liquid			
		Kg/h	g U/t	g U/ h	L/ h	g U/L	Density	g U/h
1	Continuously, 8 hours/day and 2 days/month	10,000	500	5,000	204.1		1.0	
2		10,000	500	5,000	204.1		1.0	
3		10,000	500	5,000	526.3			
4	Continuously, 24 hours/day and 30 days/month	231	500	116	12.2			
5					185.0	0.514		95.1
6		2.2	42750	93.2				
7					13.1	7.125		93.2
8		228	90	21				
9		2.2						
10					322.2	0	1.0	0
11					172.8	0	1.0	0
12					185.0	0.010		2
13					13.1	0	1.0	0

2.5. Calculation, design and selection of equipments

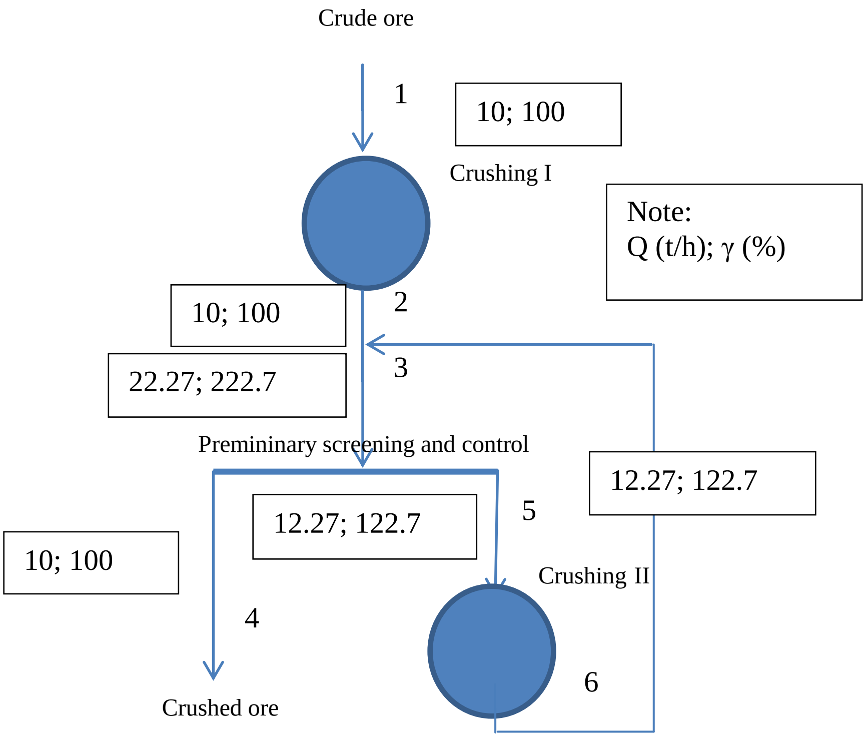
2.5.1. The equipments in the ore handling stage

With processing capacity of 10 tons/hour and the characteristics of the ore, on the basis of the required size of ground ore, a two stage grinding system has been selected. Due to the average hardness, low moisture and the largest size (maximum diameter of 250 mm) of the ore, a jaw crusher should be selected for phase 1, and a roll mill should be selected for phase 2 of grinding. A quantitative requirement is shown in the figure below.

According to a calculation, a jaw crusher PE400(A) X600 is selected for phase 1 and a single roll crusher 900A КСД for phase 2. This selected grinding system of two crushers has met the requirements of productivity and ore particle size. Additionally, a mechanical screening ZKS0615 has been selected.

2.5.2. Agglomerator

The designed ore agglomerator system consists of a mixer as a main part and an auxiliary system such as transportation equipment to weighing and carrying ore to a temporary storage, equipment for measurement of concentrated sulfuric acid volume and a tank for water supply.



- The calculated parameters of the ore agglomerator are as follows: the rotation of the barrel is 25 cycles/min.; mixing drum is 1.2 m diameter and 7.7 m length; electric motor power is of 30 kW.

- Conveyor for ore transportation from warehouse to the mixer: minimum band width 300 mm; tilted angle 20^o; transmission speed 150 m/min. and the drive motor 4.5 kW.

- A shaking chute feeder with shaking frequency of 43 times/min. is selected. The technical data are as follows: Feeder hopper dimensions 800 x 800 mm; shaking amplitude 300 - 360 mm; maximum feed size 200 mm and engine power 3kW.

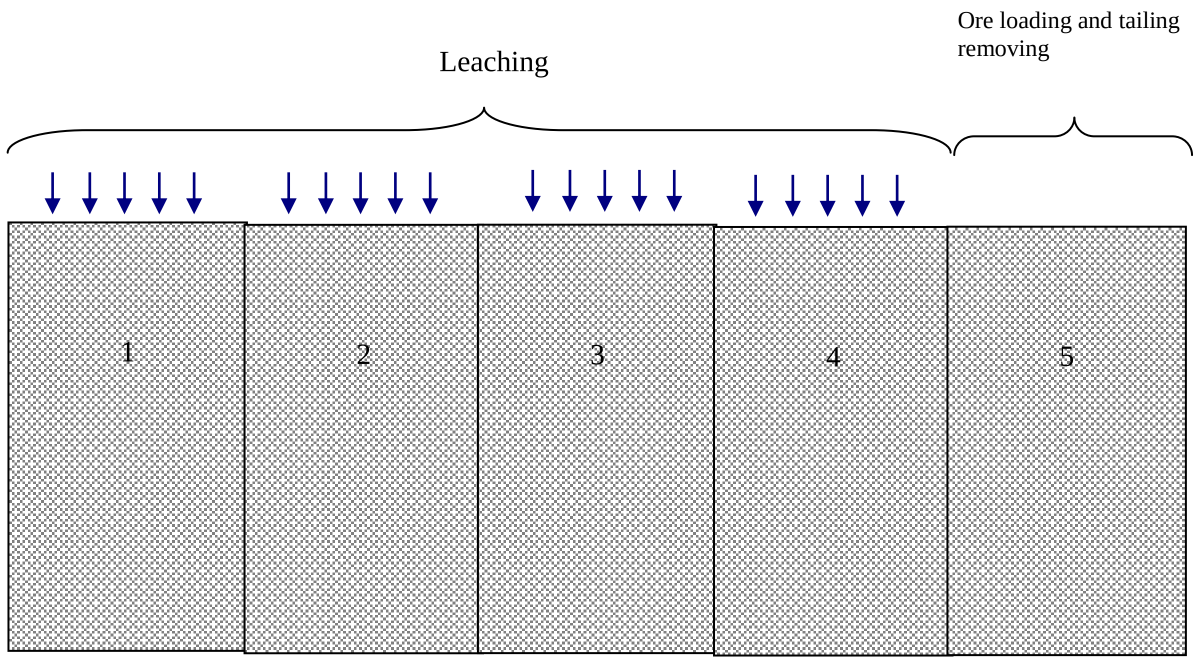
2.5.3. Leaching system

a. An ON/OFF leaching system is selected. According to this technology schema, 4 leaching boxes are in operation and 1 box is for preparation phase (discharge of leached ore and recharge fresh ore) simultaneously. Sulfuric acid solution is supplied to an individual box by dripping system. Uranium dissolution process occurs while the acid solution leaked through the ore. Leaching solution is collected into a pregnant tank by a corrugated perforated drainage pipe system placed at the bottom of leaching pad. Leaching solution obtained from a leaching pad will be supplied as a leach solution to the next one.

b. Leach pad size

The bottom of each box is 3 m x 3 m square and a the height of 6 m. Number of boxes is 5. The selected input data for calculation and design of leach pad system are as follows:

- Volume of ore (ton/batch): 85
- Ore particle size (mm): <10
- Moisture of ore (%): 5
- Ore bulk density: 1.65
- Flow rate of acid solution (l/m^2.h): 15 - 20
- Concentration of acid (g/l): 75



c. Acid dripping system

The Ore-Max dripping system is selected. The system consists of emitter line in which the emitters are installed internally and welded to the inside of the tubing and fixed inside the pipe with certain distances, emitter pressure regulator, emitter line connectors, pumps and other accessories.

- Emitter line with emitters of 2 liters/min. is selected; the distance between the emitter is 0.35 m. Thus, each pipeline includes 9 emitters, and distance from the top of pipelines to the box sides is 0.1 m. According to the calculation as a design described above, the selected emitter line for acid dripping system is Max-Emitter line 16MM 2 LPH: Part No. OL21614MX; Wall Thickness 0,89 mm; Max-Emitter Spacing 35 cm). Total length of emitter line required for 5 box leach system is 405 m.

- The pressure regulators are installed at the top of each pipeline to ensure the dripping rate of each emitter. The pressure regulator Ore-Max OLPRH1016, pressure 10 psi, diameter 16 mm with emitter line connector is selected.

d. Leaching solution collection

Due to a small area the leaching box bottom as designed so one main drainage pipe will be put on the center of a box bottom. It is a Corrugated Perforated plastic Pipe of 50 mm diameter. The tube axis direction is down gradient along to the axis of the box.

- The branches:

• Corrugated perforated plastic pipe of 42 mm diameter.

• Placed 45 degrees angling compared to the main pipe. When coming from the main pipe is 250 mm a segment of 500 mm is bended parallel to the main pipe;

• The distance between axis of two adjacent pipes is 200 mm.

• A branch pipes is placed alternately to the pipe in the other side of the main pipe.

The slope of the leaching box bottom: 3%; there are 4 layers for a leaching box

- The bottom layer: the compacted soil;

- The second layer: concrete as a base for box

- The third layer: 2 HDPE fabric liners with thickness 1.5 mm. On the surface of this layer the solution collection system is located.

- The top layer (in contact with the ore): ore with bigger size (used ore, generally) to avoid the pipes blocking and obstructing of solution flow due to the sludge formation of fine ore particles.

2.5.4. Ion exchange system

The ion exchange system includes a sorption column, an elution column and two wash columns, in which the sorption column performs selective sorption of uranium from the feed solution; The size of elution column is as the same as the sorption column.

a. The input data

- Capacity: 185 liters/hour
- Sorption retention time: 10 min.
- Elution retention time: 15 min.

b. The main parameters

The sorption and elution column size:

+ Resin volume: 77 liters;
+ Diameter: 0.22 m;
+ Height: 2.23 m.

Wash Column (2 identical columns):

+ Resin volume: 15 liters
+ Diameter: 0.14 m
+ Height of resin volume: 0.97 m
+ Height of column: 1.27 m

Pumps:

+ Pumps for sorption: 500 liters/hour (higher than required flow rate 185 liters/hour);
+ Pump for elution: 200 liters/hour (a little bit higher than required flow rate 123 liters/hour);
+ Pumps for washing: the pump for washing is utilized to wash and to transfer the resin. Pump for elution can be chosen for wash columns.

2.5.5. Precipitation, filtration, washing and drying

- Precipitation: Two identical vertical cylindrical reactors with cone angle 120° bottom, working volume V_w = 3.25 m^3 (total volume V = 4 m^3) of which the first reactor will be used for impurity removal and the second one for product precipitation. The working capacity of the precipitation reactor is 4 batches/day. A uranium solution container with a suitable capacity for this stage has been selected.

- Solution - precipitate container after precipitation is a upright, flat bottom and no cover box with total volume V = 4 m^3 and working volume V_w = 3.25 m^3.

- Filtration equipment: using automatic filter press: Plate size 470 x 470 mm and number of plates 15.

- Discontinuously electric drying cabinet is used to dry yellowcake with a capacity of 10 kg/batch.

2.5.6. Liquid waste treatment system

The chosen system consists of several processes: precipitation - decantation, filtration, adsorption and ion exchange with processing capacity of 1 - 1.5 m^3/h to ensure the quality of waste after treatment reach QCVN 40: 2011/BTNMT standards.

2.5.7. Solid waste disposal area

Solid wastes primarily include ore and residues obtained from the liquid waste treatment process. The volume of residues should be buried 1773.55 m^3/year. Burial zones are designed in Point 5.2.2.1, Clause 5.2.2, Section 5.2, Article 5 of TCXDVN 320: 2004 - Residue of hazardous waste landfills - Design Standards).

2.5.8. Dust collection system

Method of dry collection is selected, in which the cyclone is used to recover coarse dust particles and bag filters for the fine dust particles. Collected dust is then transported in sealed round screw conveyors to agglomerator.

2.5.9. Design and installation of equipment system of ore processing, waste treatment and warehouse and support buildings

Based on the size and the type of used equipments, the warehouse area is calculated as follows: crushing area: 40 m^2; ore agglomeration area: 126 m^2; ore processing area: 216 m^2 and support: area 108 m^2. The workshops are designed in standards of industrial buildings.

The equipments are arranged in arrays of work group work and workshop area. Installation diagram of equipments is described in figure.

2.6. Water, electricity demand and preliminary estimation of pilot plant investment and operation costs

The parameters of water, electrical power demand, investment and operation costs of pilot plant are calculated on the basis of the scale, the number of devices used, the number of used equipments and the pilot plant is expected to operate for 6 months.

Total electrical power is 67,936 kWh, including 50,258 kWh for operation of equipments and 17,678 kWh for lighting purpose).

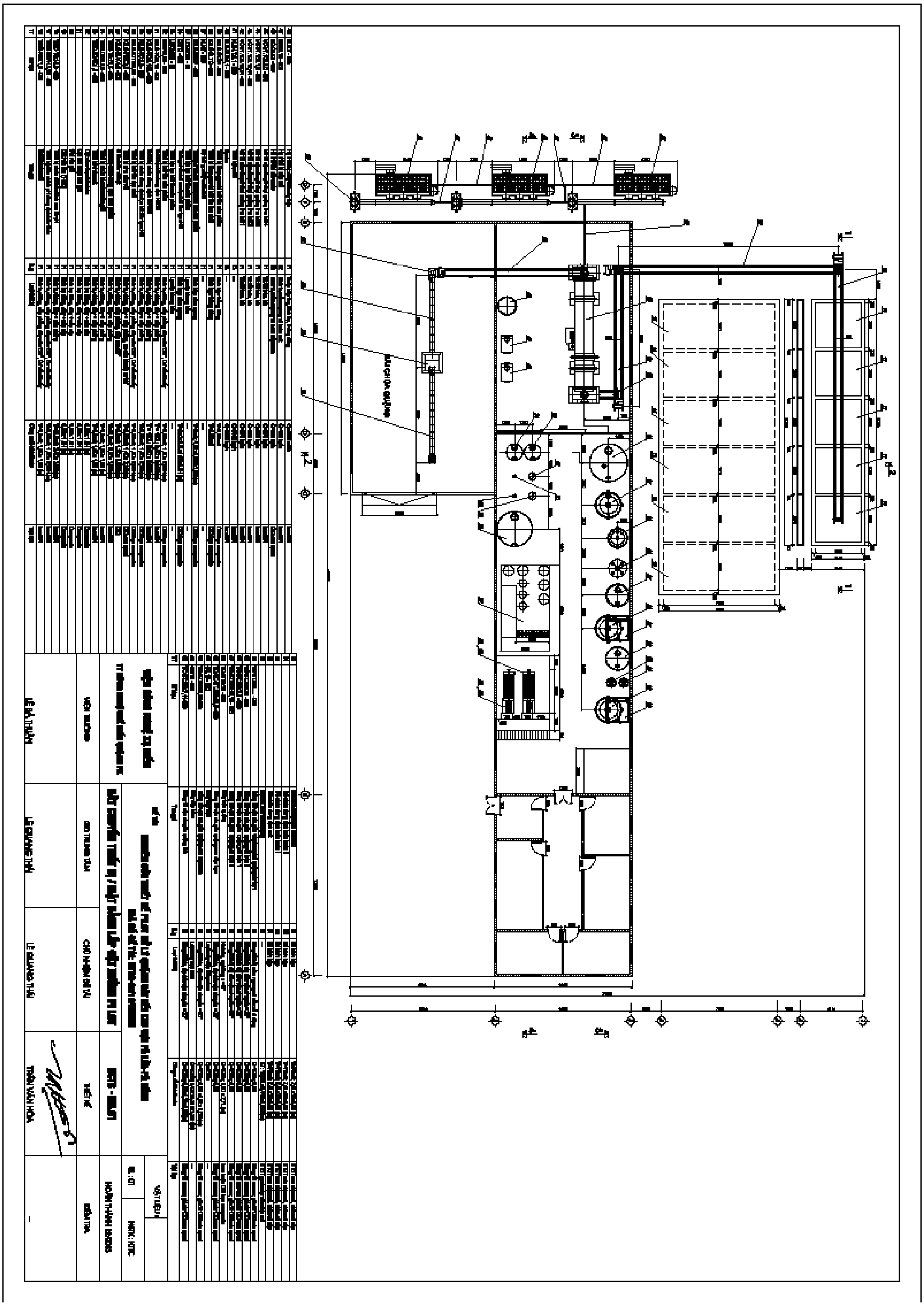
Total water demand is 3,880 m^3, including 3,718 m^3 for testing and 162 m^3 for living demand.

Cost of pilot plant construction includes many items, in which expenses for the construction of plant, purchase and installation of equipments and ore sampling occupy a large proportion. The total investment cost is estimated at about VND 23.8 billion.

Operating costs include the purchase cost of raw materials, electricity, labor, management and other expenses. Preliminary cost estimates for the total operating costs of 9 billion.

2.7. Additional study of oxidant and ion exchange resin selection

With the existing conditions in Vietnam and by references published in the world, the use of agent MnO_2 as an oxidation for uranium ore processing in Pa Lua - Pa Rong by heap leaching (which uses ore agglomeration) or mixing and curing is appropriate in comparison with other agents, at a cost of 4 kg MnO_2/ton of ore.



Strong base anion resins of GS300 (India) and Purolite A400 (UK) can be used for solution processing in industrial scale. For leached solution of similar components, suitable conditions for the absorption stage is pH of about 1.6 and retention time of 8 minutes.

3. CONCLUSIONS

1) Pa Lua - Pa Rong sandstone is a low grade uranium ores. For the treatment of this ore to obtain uranium, a following technological process is proposed: the ore is undergone a two stages crushing to the size of -10 mm. The crashed ore is mixed with about 1/3 of the total acid desired for leaching, oxidizer and water so that the moisture of the mixture is about 5%. The mixture is placed on a leaching pad then a 75g/l solution of sulfuric acid is introduced on the top of the pile. Leaching solution obtained is concentrated and purified by means of a strong base ion exchange resin, elution solution is a mixture of 1M NaCl and 0.05M H_2SO_4. Uranium is precipitated by H_2O_2 (0.182 kg of H_2O_2 per 1kg of U_3O_8) at adjusted pH 3.3 by using NH_4OH solution. After decantration, filtration and drying a solid concentrated uranium is obtained and packed. The uranium recovery efficiency is about 76 - 83%.

2) The designed Pilot plant consists of 3 sections:

\+ First section includes the continously running equipments for ore crashing, size sorting, mixing and ore stacking with capacity of 10 tons of ore/h (8 hrs/day, 2 days/month);

\+ The second section includes leaching, ion exchange and waste water treatment (running 24 hrs/day, 30 days/month). The heap leaching consists of 5 leaching box (4 for leaching and 1 for ore discharge/recharge);

\+ The third section includes precipitation, filtration, drying and packing. Batch running. Capacity of precipitation reactor and dryer is 4 m^3 and 10 kg/batch respectively, press filter is 470 x 470 mm.

3) The site selected for the pilot plant is as the same as the site of workshop for uranium ore testing at Pa Lua, Pa Toi village, Nam giang district, Quang nam province (6^o North latitude and 105^o South longitude).

4) A plan for testing at the site has been determined to implement the targets of this project. It consists of 4 categories: collecting technical data of ore, technology testing, testing the materials for buiding and for making equipment, testing of analytical procedures.

5) On the basis of technological parameters and productivities, a material balance caculation for solid, liquid streams, especially for uranium in the continous running equipments has been made.

6) On the calculation and pilot design: The basic parameters of devices are calculated, it is can be utilized as a basic for design and selection of equipment (especialy regular equipment). The preliminary design drawings of main machines and equipment such as leach pad, ion exchange system, etc. have been made.

7) The installation diagram of equipment in the pilot plant, drawings of the factory and the auxiliary area have been made.

8) For six months in operation, it is expected the electricity consumption (including electricity to operate equipment and lighting) to be 67,936 kWh, total water demand is 3,880 m^3. The investment and operation costs are expected to be VND33 billion.

9) The additional research in this project shown that we can use the oxidation agent MnO_2 - a commonly used chemical- for uranium leaching in the processing of Pa Lua- Pa rong ore by permeability leaching method (ore is aggregated using acid and water to enhance permeability). For ion exchange resins, instead of using amberlite resin IRA-420 we can use the resins Purolite A400 (UK) and GS300 (India) because of its fairly inexpensive (80- 85% compare to IRA-420) and available in Vietnam.

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