



Studying on design of a complet pilot plant for processing sandstone ores in Pa Lua – Pa Rong area

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Abstract: Design, construction and operation of a pilot for processing uranium containing ores are important stages in the process of project development of uranium production from ores because uranium contained minerals and the composition of minerals are unstable factors. In this case, pilot needs to be a simulation of a plant in the future, but with upgrade equipment compared that at laboratory scale. Results of lab research were used to select the most appropriate process for ore processing and selection of equipment for each stages.

In the circumstance when there has been a lack of experience in processing uranium ores in Vietnam, the design and construction of such a pilot with completed technological procedures are essential. The main purpose of this work is to verify results of lab researches and optimize operational parameters of the process. In addition, several purposes were also considered such as study on the effects of solution circulation/recycling and accumulation of impurities in a long run; obtain necessary and sufficient information for design, cost estimate for investment and operation... The pilot only can achieve the expected objectives when ore sources (including reserves and characteristics) are determined; a complete technological process for obtaining technical uranium (yellowcake) is designed; investment and operational capitals are estimated and these estimates show the costs and benefits of the process.

In this article, the authors will focus on the presentation of research results, including data on ore, process technology, material balance, pilot scale, the basic parameters of equipments, installation diagram of equipments, construction, power and water needs identification, preliminary calculation of investment and operational costs.

Keywords: *pilot plant, uranium, uranium ore processing*

I. INTRODUCTION

According to the results of the Uranium Exploration Project in Pa Lua - Pa Rong area, the size, complexion, uniformity of the ore body and composition of the ore were also determined. Beside information on ore body, research works on technologies for processing the ores in this area to obtain technical uranium concentrate have come up with an appropriate technology with 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 Vietnam does not have adequate experience in processing uranium ores and other similar ores. Therefore, operation of an ore processing pilot, including design of the pilot is very important and essential at present.

As considered a simulation of a plant in the future, the main objective of this pilot is to verify the technology which was developed in the laboratory and optimize operational

parameters of stages in the process. In addition, other objectives were also considered, including study on circulation/recycling of solution in stages 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.

To meet the objectives of the pilot plant, the authors have compiled informations of the ore, process technology, determined the size and location of pilot, calculated material balance, calculated basic parameters of the devices, designed some special equipments and installation of equipment system,...

II. ORE CHARACTERISTICS

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 . However, according to the data at the end of 2007, uranium reserve in the long-term vision can 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 [1]. This characteristic will affect the selection of methods for ore exploitation for 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 ranges 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 the average of 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 three layers containing ores, the layer No 1 is lying at the lowest level and has large varying co-efficiency in thickness and contents, but is the highest in content of U_3O_8 and the largest thickness [2].

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 accompanying mineral group (sulfur mineral, oxite mineral, ferro and manganese hydroxides and mineral of carbonate group). Sandstone ore in this area consists of unweathered (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 considerable amounts 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 significant 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 sulphuric acid. Uranium contents in different ore bodies 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 the pilot to be flexible in terms of technology.

In the technology for processing ores to obtain technical uranium (yellowcake), leaching ore is the most complicated stage and plays the determining role to the yield of uranium recovery and product prices. However, on the one hand, due to the lack of experience in processing ores at the large scale and on the other hand, it is necessary to assess the impacts of impurity accumulation to the whole process when using circulated solutions as well as to achieve other objectives of the pilot; therefore, it is necessary to design and construct a complete pilot, including the whole process like a miniature plant.

III. SEVERAL CONCERNS IN DESIGNING THE PILOT

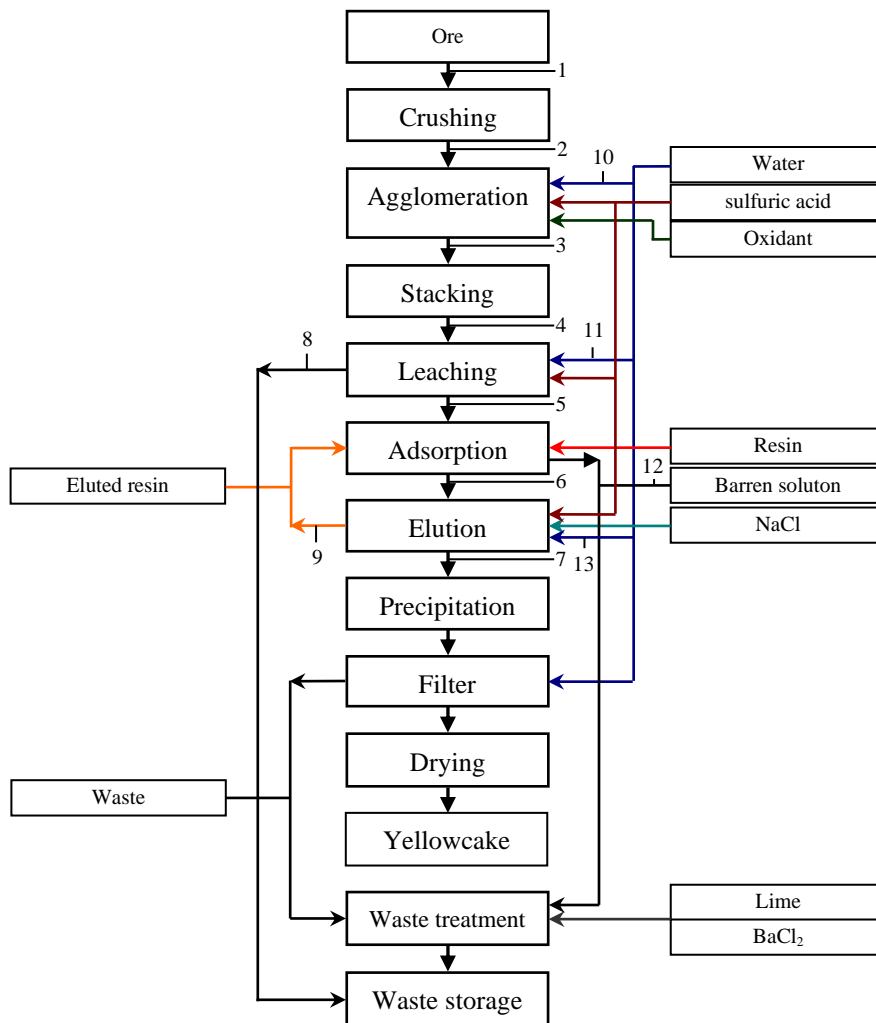


Fig. 1. Uranium ore processing flowsheet

As sandstone in the area of Pa Lua - Pa Rong is of low grade ore, trial options are all focusing on techniques, including heap leaching (percolation and mixing-curing with strong acid). To ensure stability of leaching step, in the technological assembly line, it is needed to have agglomeration, even when applying percolation, because during the agglomeration, fine particles will agglomerate to form larger particles to ensure even distribution of particles of all sizes in the ore mass to increase permeability. In addition, to be able to adjust technological parameters, when designing and selecting equipment, it is necessary to pay attention to sizes to make sure the quality of the trials.

IV. DESCRIPTION OF TECHNOLOGY FOR ORE PROCESSING

Based on mineralogical, chemical compositions and results of laboratory research as well as some large-scale laboratory research, the group of authors proposed a flowsheet for processing sandstone ores in the area of Pa Lua - Pa Rong, similar to the flowsheet for processing low grade ores that have been used elsewhere in the world. According to the flowsheet in figure 1, the ore processing process consists of main stages, 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 condition would be able to apply for the ore

with the average uranium content of 0.05% U up based on the previous research results.

- The ore crushing stage is to reduce size of ore particles to the appropriate size for leaching: crushing at two stages, in which at the first stage is to crush ore from the run-off-mine size to the size of -10 cm (80%). A system of sievers with respective sizes was used after each stages 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 bed: concentrated sulfuric acid and water are sprayed together into ore in a rotary drum mixer. Acid consumption in this stage accounted for around 30% - 40% of the total acid consumption for the whole leaching process [25]. The moisture content reached 5% [12].

- Stacking is to put the whole mixed ore mass into a heap. In order to carry out this, the ore mixed from the previous stage was transferred to the leaching area by rubber conveyor system. The height of the ore heap was 6 m [25]. After that, a system of pipes to provide solution (with dropper) is placed on the surface of the ore layer with distance between holes on the pipe of around 30 - 35 cm [28]. 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 extracting uranium from the ore to solution. Solution of leaching agent (acid or circulated solution) is pumped into the heap via

distribution system with a flowrate of around 10 - 20 l/m².hour by batch [6, 7, 12]. After leaching stage, water is pumped into the top of the heap to wash out dissolved uranium and recover residual acid from ore residues. Water consumption by the ratio of water/ore reached around 0.7 [12]. Leaching duration is around 2 months. Recovery yield reached around 80 - 85% [6, 12, 13].

- Ion exchange [13]: this stage is used 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 adsorbed from leaching solution onto the resin, but most of impurities remained in the effluent. Before conducting uranium adsorption, the leaching solution was adjusted to pH 1.6 [13] 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 H₂SO₄ 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, H₂O₂ was used as precipitating agent. pH of precipitation process was maintained at 3.3 during the whole precipitation by adding dilute NH₄OH solution. Consumption for H₂O₂ was 0,182 g H₂O₂/g U₃O₈. 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 U₃O₈ reached over 80%; content of impurities met the ASTM standards for commercial products [13].

- Filtration, drying and packaging product: these are the last stages of the flowsheet to complete products, packaging and releasing. A vacuum conveyor 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 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 BaSO₄ [13]. 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.

Table I. Characteristics of the main streams of the block diagram

Stream	Description	Working mode	Solid			Liquid			
			Kg/h	g U/t	g U/ h	L/ h	g U/L	Density	g U/h
1	Raw ore (including moisture) to crusher	Continuously, 8 hours/day and 2 days/month	10000	500	5000	204.1		1000	
2	Crushed ore to agglomerator	Continuously, 8 hours/day and 2 days/month	10000	500	5000	204.1		1000	
3	Mixed ore to stacking	Continuously, 8 hours/day and 2 days/month	10000	500	5000	526.3			
4	Ore during leaching	Continuously, 24 hours/day and 30 days/month	231	500	116	12.2			
5	Leached solution to ion exchange system					185.0	0.514		95.1
6	Saturated resin to elution step in IX system		2.2	42750	93.2				
7	Eluate to yellowcake precipitation					13.1	7.125		93.2
8	Tailling		228	90	21				
9	IX resin return to adsorption step		2.2						
10	Water to agglomerator					322.2	0	1000	0
11	Water to leaching					172.8	0	1000	0
12	Effluent					185.0	0,010		2
13	Water to preparation of eluant solution					13.1	0	1000	0

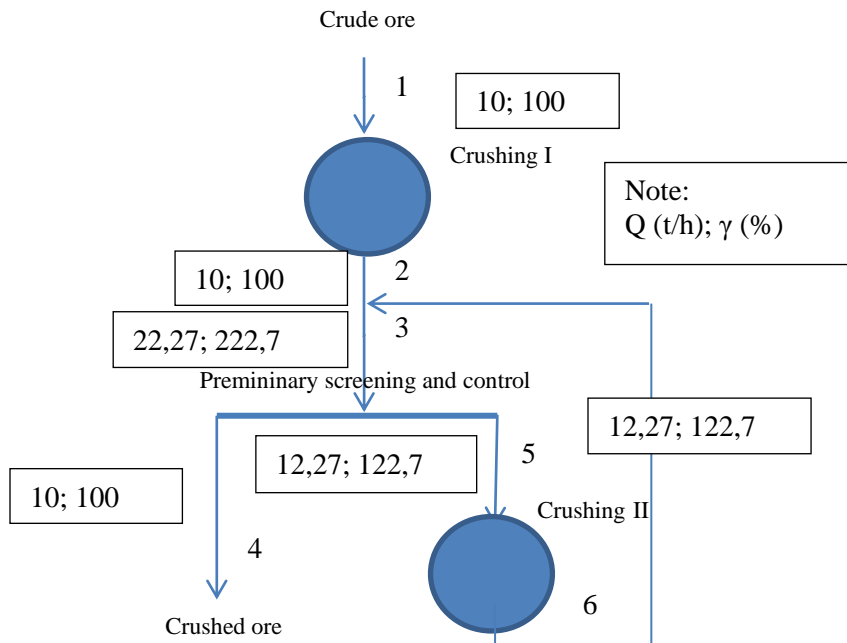


Fig. 2. Quantitative diagram of ore crushing

V. 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, to work in the larger scope, it is much more difficult in 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) with large enough sizes.

The other stages of the pilot are divided into groups working in continuous mode. The first group includes ore preparation, agglomeration and stacking with capacity of 10 tons of ore/hour. The second one includes 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 liters of solution per hour works continuously 24 hours per day and 30 days per 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.

VI. MASS BALANCES

Based on the selected flowsheet, the mass balances of some of the main streams were calculated and given in table I. 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 of IX stage (%): 98

VII. CALCULATION, DESIGN, SELECTION OF EQUIPMENTS

A. The equipments in the ore crushing stage

With processing capacity of 10 tons/hour, 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 step 1, and a roll mill should be selected for step 2 of grinding. A quantitative diagram is shown in the figure 2.

According to a calculation, a jaw crusher PE400(A) X600 is selected for step 1 and a single roll crusher 900A KCD for step 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.

B. 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 rpm; the mixing drum is of 1.2 m in diameter and 7.7 m in 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°; transmission speed 150 m/min. and the drive motor 4.5 kW.

- A shaking trough feeder with 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 3 kW.

C. Leaching system

1. Leaching system selection

An ON/OFF leaching system is selected. According to this technology schema (figure 3), four leaching boxes are in operation and one 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 permeates through the ore. Rich uranium solution is collected into a pregnant tank by a corrugated perforated drainage pipe system placed at the bottom of leaching box. More barren leaching solution going out from a previous leaching box in series will be used as leach solution for the next one.

2. Leaching box size

The bottom of each box is 3m x 3m square and the height is 6 m. There are five boxes connected in series. The selected input data for calculation and design of leach box system are as follows:

Table II. Input data for calculation and design of leach box system [6, 7, 12, 13]

Parameters	Value
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

3. 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 two liters/min. is selected; the distance between the emitter is 0.35 m. Thus, each pipeline includes nine emitters, and distance from the top of pipelines to the box sides is 0.1 m. According to the calculation per 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 all five 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.

4. 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 are the perforated plastic tubing of 42 mm diameter, placed angling 45 degrees compared to the main pipe. Distance between branch pipes is of 200 mm.

The slope of the leaching box bottom is 3%; there are four layers in each leaching boxes:

- The bottom layer: the compacted soil;
- The second layer: concrete as a base for box;
- The third layer: two 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.

D. Ion exchange system

The ion exchange system includes a sorption column, an elution column and two

1. The basic data

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

2. 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

- Precipitation: Two identical vertical cylindrical reactors with cone angle 120° bottom, working volume $V_{\text{working}} = 3.25 \text{ m}^3$ (total volume $V = 4 \text{ m}^3$) 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 four batches per 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 $V = 4 \text{ m}^3$ and operation volume $V = 3.25 \text{ m}^3$.

G. Solid waste disposal area

Solid wastes primarily include ore and residues obtained from the liquid waste

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.

+ 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.

E. Precipitation, filtration, washing and drying.

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

- Electric batch drying cabinet is used to dry yellowcake with a capacity of 10 kg per batch.

F. Liquid waste treatment system

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

treatment process. The volume of residues to be buried is 1773.55 m^3/year . Burial zones are designed to meet requirements 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).

H. Dust collection system

Method of dry collection is selected, in which the cyclones are used to recover coarse dust particles and bag filters for the fine dust particles. Collected dust is then transported into closed-circuit screw conveyors to agglomerator.

VIII. 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 m³, including 3,718 m³ for testing and 162 m³ for living demands.

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 VND23.8 billions.

Operating costs include the purchase cost of raw materials, electricity, labor, management and other expenses. Preliminary cost estimates for the total operating costs of VND9 billions

I. 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 m²; ore agglomeration area: 126 m²; ore processing area: 216 m² and support: area 108 m². 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 3.

IX. CONCLUSIONS

1. Pa Lua - Pa Rong sandstone is low grade uranium ore. 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 NaCl 1M and H₂SO₄ 0.05M. Uranium is precipitated by H₂O₂ (0.182 kg of H₂O₂ per 1kg of U₃O₈) at adjusted pH 3.3 by using NH₄OH solution. After decantation, filtration and drying a solid uranium concentrate is obtained and packed. The uranium recovery yield is about 76 - 83%.

2. The designed pilot plant

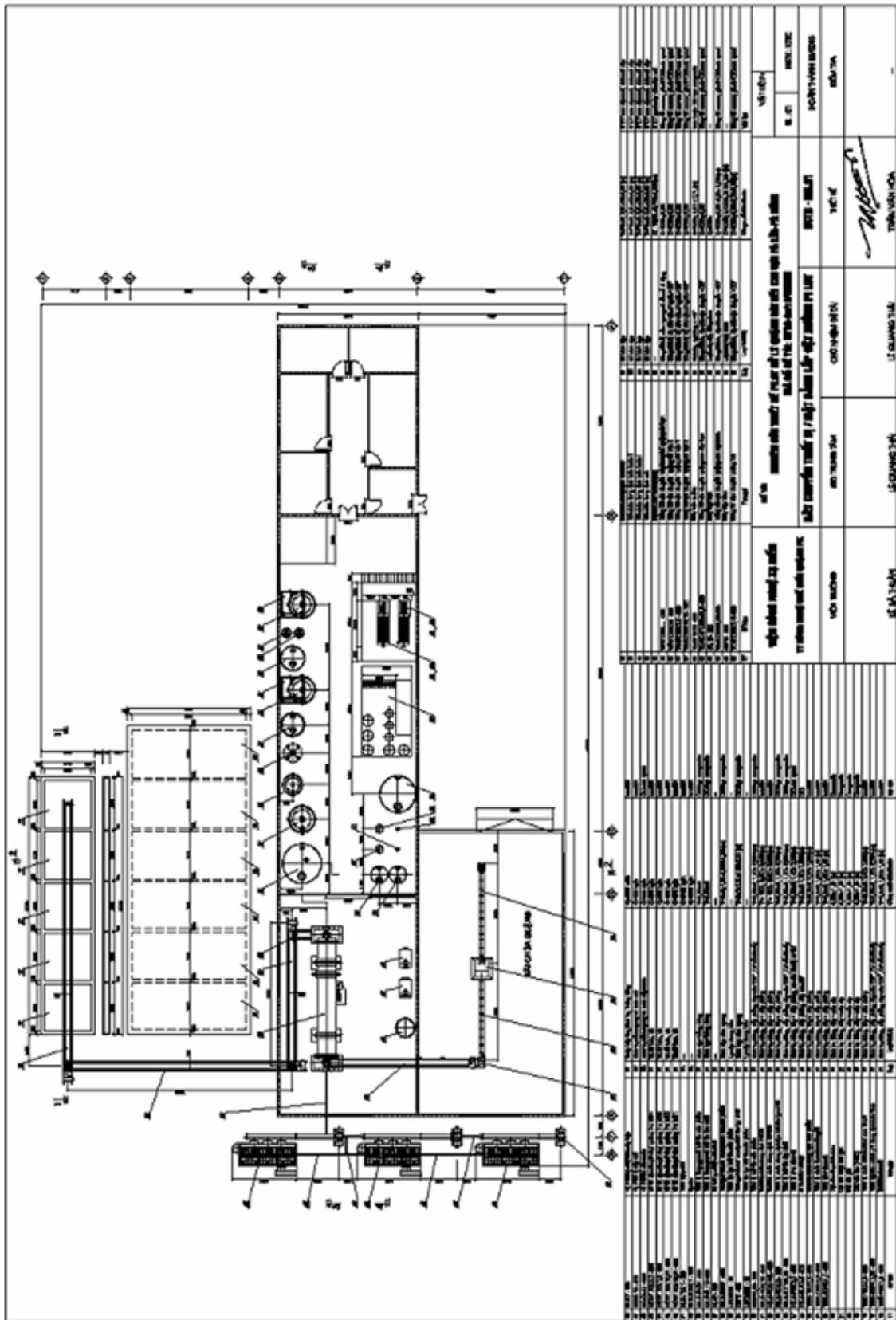


Fig. 3. Layout of pilot plant

3. consists of three phases:

- First phase includes equipment for ore crushing, size sorting, mixing and ore stacking with capacity of 10 tons of ore/h (8 hrs/day, 2 days/month);

- The second phase includes leaching, ion exchange and waste water treatment (running 24 hrs/day, 30 days/month). The heap leaching consists of five leaching boxes (four for leaching and one for ore discharge/recharge);

- The third phase includes precipitation, filtration, drying and packing. Capacity of precipitation reactor and dryer is 3.25 m³ and 10 kg/batch respectively, press filter is 470x470 mm.

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

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

6. On the calculation and pilot design: The basic parameters of devices have been calculated, it can be used as basis for design and selection of equipment (especially standardized equipment). The preliminary design drawings of main machines and equipment such as leach box, 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 m³. The investment and operation costs are expected to be VND33 billions.

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