Red Mud Issues in Vietnam

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Abstract

Vietnam has planned to develop a bauxite, alumina and aluminum industry based on its abundant resources. The red mud is currently the subject of concern in Vietnam. Some small plants are currently producing aluminium hydroxide for few decades. A commercial scale alumina refinery was put into operation in 2012 and another one will be commissioned soon. Construction of the disposal sites, treatment and re-use, chemical composition and trace elements of the red mud of these projects are described.

Keywords: Red mud, disposal, alumina.

1. Introduction

According to the United States Geological Survey in 2010, Vietnam is estimated to hold the world's third-largest bauxite ore resources, after Guinea and Australia. The majority of resources of Vietnam is located in Central Highlands and has only been mined to a minimum extent. Bauxite is typically strip mined and is used to produce aluminum.

According to the estimation of Ministry of Industry and Trade of Vietnam, potential resources in the Central Highlands could amount to 11.0 billion tons but the proven reserves are only 3 billion tons (Figure 1). It is worthwhile to develop a large-scale bauxite mining, processing, refining and smelting industry in Vietnam, which is outlined in the ambitious Master Plan on Exploration, Mining, Processing and Use of bauxite ore for the period 2020 with an outlook to 2025 [2]. But alumina refining generates a huge amount of caustic waste, so-called red mud, and this becomes a major concern in this country.

Figure 1. Bauxite Reserves Map of Vietnam [1].

2. Current Projects Generating Red Mud in Vietnam

Vietnam has indicated in the Master Plan that it needs about US$15.6 billion to invest in major bauxite and alumina refining projects by 2025 to make use of its vast, largely untapped bauxite ore reserves, most of them in Central Highlands. At present, Vietnam has three projects generating red mud: Tan Binh Chemical Plant in Ho Chi Minh City, Tan Rai Refinery project in Lam Dong province and Nhan Co Alumina refinery project in Dak Nong province. The latter two alumina refinery projects are being built by China Aluminum International Engineering Co., (Chalieco), the engineering arm of the Aluminum Corporation of China Ltd (Chalco), in the frame of an EPC (Engineering, Procurement and Construction) contract.

2.1. Tan Binh Chemical Plant of Vinachem's Southern Basic Chemicals Company in Ho Chi Minh City

This plant has a history of nearly four decades. It produces nowadays 20 000 tons of aluminum hydroxide per year which is used as feedstock for chemicals for water treatment. The bauxite source is mined and beneficiated in the Bao Loc Mine, Lam Dong province. Tan Binh discharged around 40 000 tons of adherent liquor annually with the red mud in the past, this red mud was used mainly to leveling and landfill, causing negative effects to the environment. However, for the past 2 years, Tan Binh has discharged approximately 34 000 tons per annum of filtered red mud subsequent to the installation of a filter press from Japan with 4 tons/hour capacity. The filtered, almost dry red mud is used by other companies and individuals to make bricks, tiles, pigments and settling additives.

Chemical composition of the red mud of Tan Binh: Al_2O_3: 22.5 %, Fe_2O_3: 47.6 %, Na_2Osoluble: 0.05 %, SiO_2: 4.8 %; moisture: 23 – 25 %, pH: 11.4 [3].

Trace elements: The Environmental Technology Laboratory of National University in Ho Chi Minh City has measured some trace elements of the Tan Binh dry red mud, including Sb: not measurable (< 0.001 mg/L), As: 0.060 mg/L, Ba: 0.012 mg/L, Ag: n.m. (< 0.001 mg/L), Be: 0.01 mg/L, Cd: 0.012 mg/L, Pb: 0.050 mg/L, Co: n.m. (< 0.001 mg/L), Zn: 0.064 mg/L, Mo: n.m. (< 0.001 mg/L), Ni: 0.026 mg/L, Se: 0.111, Ta: n.m. (<0.001 mg/L), Va: n.m. (< .001 mg/L), Cr: n.d (0.001 mg/L), Hg: n.m. (<0.001 mg/L), F: 0.201 mg/L. The values of all the above elements are much lower than the allowed threshold levels [3, 4].

2.2. Alumin Lam Dong Refinery (former Tan Rai Alumina Refinery) of National Coal and Minerals Industries Group (Vinacomin) in Lam Dong Province

This project is expected to be commissioned by the end of 2011 and to produce 650 000 tons of alumina per year from beneficiated bauxite mined in Tan Rai Mine, Lam Dong province. Table 1 shows the composition of the red mud from the Tan Rai project.

Table 1. Composition of red mud and adherent liquor of Alumin Lam Dong Refinery.

Red mud composition	%	Adherent liquor composition	g/l
Fe_2O_3	46.41	Na_2Ocaustic	4.6
Al_2O_3	16.91	Al_2O_3	4.8
SiO_2	6.60	Solid content in underflow from the last washer	550-650
TiO_2	5.48		
Na_2O combined	3.06		
CaO	4.48		
Others	17.06		
L.O.I	11.70		

For comparison, the national study project with Project Code KC.02.01 showed the following composition of the red mud from Tan Rai bauxite: Al_2O_3: 14.68 %, SiO_2 : 7.51 %, Fe_2O_3 : 52.82 %, TiO_2 : 6.15 %, Na_2O : 3.12 %, CaO : 3.55 %, L.O.I : 11.71 [7, 3].

2.2.1. Red mud disposal of the Alumin Lam Dong Refinery:

The site of the two disposal ponds has been designed stage by stage use for more than 30 years. The lakes should be capable to store 685 000 t/a of adherent liquor and 595,380 t/a of dry red mud from the 650 000 t/a Alumina Refinery. The red mud ponds are located in a valley outside the alumina plant. To fit in the site shape, the dams are constructed to divide the first lake into 8 blocks. Red mud slurry is delivered to the pond by pipes and the sand is transported by truck. The red mud conveying pipeline system includes two pipes for the red mud slurry, one pipe for the neutralized acid and one pipe for caustic slag. At first, the red mud slurry is discharged into the first block. When the first one is full to the design height, the red mud will be discharged into the second block and the process goes on.

Along the dam crest and ditch edge, a ring-shape distribution pipe is laid down following the shape of the natural land, and a branch pipe is located on the ring-shape distribution pipe with valves at every 30 m. Those branch pipes are used to discharge the red mud slurry based on practical considerations. For each discharge period, one branch pipe will be used. After a certain number of months of discharge, the red mud deposit will rise in a uniform shape.

In order to prevent the adherent liquor (having alkaline property) of the red mud from penetrating into and contaminating the underground water, it is necessary to use an anti-seepage design for the surface which is in contact with the adherent liquor. Anti-seepage design has three parts: an anti-seepage layer, a drainage layer and a transition layer.

The flood diverting ditch is located outside the site to channel off the rain water to the downstream ditch.

The red mud lake management station is built nearby to facilitate the monitoring and the management.

If the red mud block reaches the designed final height, it will be shut off to recover the vegetation and the ecological environment [4].

2.3. Nhan Co Alumina Refinery Project of Vinacomin in Dak Nong Province

This project is now under construction, and is expected to be commissioned in 2016 and to produce 650 000 tons of alumina per year from beneficiated bauxite mined at the Nhan Co deposit, which belongs to Gia Nghia Mine Complex in Dak Nong province. Table 2 shows the composition of red mud from the Nhan Co Project.

Table 2. Composition of dry red mud and adherent liquor of Nha Co Alumina project.

Red mud compostion	%	Adherent liquor composition	g/l
Fe_2O_3	46.32	Na_2O_{total}	< 3.5
Al_2O_3	17.56	$Na_2O_{caustic}$	
SiO_2	6.70	Al_2O_3	< 3.0
TiO_2	7.20	Solid content in underflow from the last washer	550 - 650
$Na_2O_{combined}$	3.43		
CaO	5.29		
Others	13.50		
L.O.I	11.71		

2.3.1. Trace elements in Gia Nghia bauxite samples

A research done by a foreign partner for Vinacomin in 2006 shows some trace elements in Gia Nghia bauxite as follows [4, 5]:
a/ Trace elements affecting product quality with "threshold levels", see Table 3:

Table 3. Trace elements in Gia Nghia bauxite.

	Element (ppm)							
	Be	Cr	Cu	Mn	Ni	P	Zn	Zr
Untreated	0.7	584	61	600	75	1059	74	314
Treated (+ 1 mm)	0.5	661	50	476	51	912	54	227
Average	0.6	623	55	538	63	986	64	270

b/ Trace elements of possible environmental concerns in Gia Nghia bauxite, see Table 4:

Table 4. Trace elements of environmental relevance in Gia Nghia bauxite.

	Element (ppm)									
	Ag	Cd	Se	As	Be	Hg*	Pb	Sn	V	CrVI*, Ra*
Crude ore	Nd	Nd	Nd	2	0.7	0.09	8	3	297	
Beneficiated (+ 1 mm)	Nd	Nd	Nd	Nd	0.5	0.07	7	2	229	

Legend: Nd: Not detected (below the detectation limit); *: Not analyzed for

Conclusions from studies of above Gia Nghia bauxite samples:
1) The crude bauxite ore is generally low in available alumina and high in reactive silica, with the reactive silica is present at high levels throughout the bauxite horizon, although the reactive silica levels are lower close to the surface.
2) Washing with water to remove fine bauxite significantly improves the available alumina/reactive silica ratio.
3) Available alumina is present almost entirely as gibbsite (about 90 %). Almost all the silica is in kaolinite (about 85 %).
4) Several trace elements in bauxite are higher than usual levels and in some cases are sufficiently high to warrant further investigation on potential product quality issues. No impurities were identified that are likely to cause significant environmental issues.

Further, the studies of the samples showed that the bauxite is high in extractable organic carbon (EOC), which appears to be reduced by washing. Carbonate and oxalate formation rates are low. According to CSIRO's Report "Characterisation of Vietnamese bauxite-Further Studies, January 2009", total inorganic carbon and total organic carbon was 0.08 and 0.11 grams of carbon per 100 g bauxite.

2.3.2. Tra Red mud disposal of Nhan Co Alumina project

This is similar to the Tan Rai Alumina Refinery project.

3. Some Researches on Red Mud Usages in Vietnam

3.1. Removal of Fluoride, Lead, Arsenic and Phosphate from Aqueous Solution by Using Activated Red Mud

Since red mud is a highly alkaline waste material formed by the Bayer process of alumina production in bauxite exploitation and alumina industry, it has high metal oxides contents which are active components for the adsorption of heavy metal cations. In the study conducted by a group of researchers at Institute of Chemistry, Vietnam Academy of Science and Technology (VAST), the red mud from Alumin Lam Dong refinery (formerly known as Tan Rai Alumina Refinery) was characterized and investigated for removal of fluoride, lead (Pb), arsenic (As) and phosphate from aqueous solution. The characterization of red mud performed by XRD and SEM shows a significant powder structure with very high increase of surface area of almost 1.5 times after activation by heat treatment at 800 °C in 4 hours and acid treatment in HCl 1M in 2 hours. The factors influencing the adsorption including acid concentration, equilibrium pH and contact time were also investigated. The results show that the adsorption properties of activated red mud depend on pH values and acid concentration. The removal of fluoride can be reached 100 % after 120 minutes with the maximum adsorption capacity attaining 8.6 mg/g. The adsorption of As(III) and As(V) reach the maximum when pH are 7.5 and 4; the contact time are 45 minutes and 90 minutes corresponding to the maximum adsorption capacity of 0.48 mg/g and 0.50 mg/g, respectively. The percentage of lead removal was found increasing gradually with the increase of pH and reached the maximum when pH was 4, then decreased significantly. After the contact time of 75 minutes, the maximum adsorption capacity of Pb(II) ions was 2.99 mg/g while the lead removal percentage reached about 96 %. Similarly the percentage of phosphate removal was found increasing gradually with the increase of pH and reached the maximum when pH was 3, then decreased significantly. After the contact time of 1.5 hours, the maximum adsorption capacity of PO_4^{3-} ions was 270.27 mg/g corresponding to qmax (P) of 88.2 mg/g while the phosphate removal percentage reached about 95 %. The Langmuir isotherm model fits well with all adsorption of fluoride, arsenic, lead and phosphate showing one layer adsorption property. This study has shown that red mud can be potentially treated to produce a new adsorbent material which is cheap, environmental friendly and having a high adsorption capacity for wastewater pollutants removal, suitable to Vietnamese conditions [10, 11].

3.2. Iron Recovery and Magnetite powder, Sponge Iron, Steel Production from Red Mud

Based upon the studies of chemical composition and characteristics of red mud generated from alumina production in the Central Highlands and laboratory-scale fundamental studies, the same group of researchers at the Institute of Chemistry, Vietnam Academy of Science and Technology (VAST) continued to conduct the project "Research on the technology to produce steel and non-fired building materials from red mud generated from alumina production in the Central Highlands" which resulted in a production of a batch at industrial scale of 200 tonnes of red mud. The obtained results include steel billet equivalent to steel type CT5 with iron recovery of 70 % from the red mud.

Red mud slurry was separated by high pressure filter in order to separate the liquid from the solid red mud. The filtered liquid portion containing residual caustic soda and aluminate was returned to the Bayer process. The red mud slurry which was obtained from Alumin Lam Dong refinery (formerly known as Tan Rai Alumina refinery) has the solid/liquid ratio of 40.7/59.3. Table 5 shows the composition of dry red mud samples and the adherent liquor [7].

Table 5. The composition of dry red mud and adherent liquor from Alumin Lam Dong refinery (formerly known as Tan Rai Alumina refinery).

Dry red mud compostion	%	Adherent liquor composition	g/l
Fe_2O_3	51.10	Na_2O_{total}	5.11 – 5.34
Al_2O_3	16.71	Al_2O_3	1.77 – 2.38
SiO_2	5.98		
TiO_2	5.83		
Na_2O	3.32		
CaO	2.79		
L.O.I	17.01		

The dry red mud then was grinded and mixed thoroughly with coal, dolomite, lime according to the optimum weight ratio of (Red mud: Coal: Lime: Dolomite = 100:7:12:6). Subsequently, the mixture was pelletized and fed to the sintering lines using residual coal gas (CO 21 %) from pig iron blast furnace. The sintering duration lasted 20 minutes under 900 °C. The Fe_2O_3/FeO ratio was actively controlled within the range from 0.85 to 1.15 so that the Fe_2O_3 was only reduced to magnetite (Fe_3O_4).

After that the sintered red mud was grinded and magnetically separated to recover magnetite powder which was supplied to the production of pig iron or sponge iron. Each 2.4 tons of dry red mud gives 1.0 tonnes of magnetite powder. The magnetite powder recovered from the red mud has 61.1 % total iron (T-Fe), was utilized to produce sponge iron. The resulted sponge iron has 90 % total iron (T-Fe) in which metallic iron amount was 83.4 %. Consequently, the steel billet produced from the sponge iron met the Vietnamese and Japanese standards. The steel billet was analyzed by Vietnam Directorate for Standards, Metrology and Quality (STAMEQ) equivalent to steel type CT5. The above technology was accepted by granting a patent in June 2015 [11].

Furthermore, non-fired building bricks are produced from the dry red mud, slag and fly ash from the steel and sponge iron production through geopolymerization process with the optimal weight ratio of 10/30/60, respectively. The resulted brick specimens meet the Vietnam Standards (TCVN 6476:1999) with compressive strengths higher than the standards, conformable to environmental regulations.

4. Public Concern

Bauxite mining and processing issues were the most prominent environmental issues that emerged during 2009 in Vietnam. The region, considered strategically important in Indochina, produces 80 percent of Vietnam's coffee output and is also a key area for commodities such as pepper, rubber, cocoa and cotton.

Some scientists and environmentalists raised concerns on the social and environmental impact of the mining activities in the Central Highlands. Forests and agricultural land used by coffee and tea farmers are threatened by the plans and opponents have raised concerns about the toxic waste red mud generated through the refining of bauxite.

Critics say the impact of any potential contamination of regional waterways on both highland crops like coffee and downstream crops of rice would be devastating, and that land clearance for future storage facilities could wipe out many ethnic minority communities in the region.

Furthermore, Dong Nai province in the south - an important economic hub - could be negatively affected by the runoffs from the mines flowing downstream via waterways from the Central Highlands. It must be noted that people's concerns are very realistic, and key elements of the infrastructure important to bauxite extraction, such as water and power supplies, are not up to expectations.

In terms of national interests, sustainable and long-term development, bauxite exploitation will generate critical environmental, social and security effects. Others argued the mining would destroy vast forests and crop areas and create mountains of caustic sludge, i.e. red mud.

Some people argue that they don't know what kind of benefit they will get from the project, but it's so miserable to look at these hills cleared from tea plantations.

Bauxite beneficiation and alumina production would require extensive use of water, and thus these may contaminate the water resources of the region that already lacks water for its industrial crops (coffee, rubber...).

Experts believe that underground sources of water in the Central Highlands are limited and have already diminished significantly over the last decade due to intense irrigation.

The large quantity of red mud sludge could break down any reservoir and cause an environment disaster. Red mud accumulated over the years and caused a serious environmental problem. With such unsafe storage, red mud slurry could overflow reservoirs or infiltrate the soil and be washed by rainwater into waterways throughout the Central Highlands and down to the southern region of Vietnam.

Worries over threats of red mud sludge spills have been sparked by the tragedy in Hungary several months ago if a reservoir breaks.

On Oct. 4, 2010 in Hungary, the torrent of toxic (caustic) material was burst out when a reservoir wall collapsed, and the red mud flood eventually flowed toward the Danube River. Critics of the new bauxite mining industry in Vietnam raised their voice after being silenced in 2009. The European disaster gave Vietnamese dissenters an opportunity to bring attention to the two bauxite mines and Chinese technology-based alumina refineries under construction in the Central Highlands of Vietnam, the potential impact of which worried scientists, environmentalists, religious groups, bloggers and even national heroes.

Some people have been requesting the government to postpone or entirely cancel the mines, and demanded that even the bauxite tailings after washing must be filter pressed before discharging into the pond! The petition called the Hungary disaster a serious warning and said that calling off the multimillion dollar project would be a bitter decision but one that has to be undertaken by the interests of the "national destiny".

The government then required the project investor Vietnam Coal and Mineral Industries Group (Vinacomin) and the relevant ministries to conduct an overall investigation of the projects. The government has agreed to oversee the environmental impact study of the mines, and a working group visited Hungary after the disaster, but some have their doubts. The prime minister would reconsider the continuation of the projects after further assessments of the environmental safety issues.

Bauxite has been defined as an important resource for socio-economic development of the region. But, many scientists, environmentalists and cultural experts disagree and have expressed their strong concerns on the negative impacts of the mining. They also point out that the government exaggerates the economic benefits [8].

5. Conclusion

The huge bauxite potential of Vietnam is worth to develop to an industry of suitable size for the public and economic benefits. Using an up-to-date technology level environmental impacts caused by mining and refining could be overcome if the government imposes a sustainable, transparent and consistent policy that balances the interests of the areas of mining and beneficiation and locations of refining and smelting, and also the interests of the state, the companies and the public.

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