

Fly Ash Processing of Thermal Power Plants and Orientation of Rational Utilization By-products in the Context of Circular Economy

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Abstract: Thermal power fly ash is a source of waste that is harmful to the environment and human health. There have been many studies on the treatment of fly ash and the recovery of fly ash for unburnt bricks, porous concrete, etc. However, the amount of coal in these products significantly leads to wasting coal resources in ash (30%). In order to make products cleaner, and meet civil requirements, thermal power fly ash needs to be processed more thoroughly. In this study, fly ash was processed by flotation and acid-leaching methods. Clean coal after flotation in optimal conditions has an ash content of 8.78% and a recovery of 74%; tailing has an ash content of 96.56%. Clean coal after HNO₃ and HF leaching with an ash content of 0.36% is recommended to be used as a fuel coal slurry (COM/CWM) or coal electrodes, etc. By-products of the leaching process are recommended to be recovered solvents while the tailings products of the flotation are used to make green concrete, and middling products are used to make unburnt bricks. This research is the first demonstration of UCC production from fly ash. It opens up a direction for efficient production, processing, and use of fly ash in the context of the circular economy trend in Vietnam.

Keywords: Fly ash; flotation; acid leaching; fuel coal slurry (COM/CWM); construction material

1. Introduction

Coal fly ash is a by-product of coal combustion in thermal power plants. Fly ash is characterized by fine and heterogeneous powder particles. This product flies with the flue gas and is retained by electrostatic precipitators (Alterary & Marei, 2021). Fly ash consists of three main components: organic materials, inorganic materials composed of amorphous and crystalline phases, and fluid materials contained in both organic and inorganic materials (ASTM, 2011). Fly ash is often stored in waste product tailing pond or used as unburnt bricks, cement and additives for the construction industry. The problem with fly ash when applied in the civil sector is the amount of impurities containing coal (fly ash contains about 30% unburned coal), and the lack of technology for further processing of this by-product. There is a need to recover this amount of coal to save resources and prevent water/air pollution. However, because the recovered fly ash is often extremely fine in size and has been burned (low volatile matter), it is difficult to re-burn in thermal power plants and in other industrial applications (Hower & Mastalerz, 2001). The application direction for recovered fly ash coal is to use it for purposes such as fuel coal slurry (COM/CWM), materials requiring high carbon content, carbon electrodes... The requirements of coal for these applications are that the coal must have low ash content and high carbon content. The technologies to achieve that coal quality can be listed as: ultra-clean coal (UCC), hypercoal, etc.

Ultra-clean coal production technology is a technology that combines physical and chemical methods to produce coal with an ash content of < 1%, in some cases, < 0.25%. The waste products of these processing processes with high ash content and approximately 0% coal content are suitable for the production of green concrete, unburnt bricks, etc. It can be said that recycling this amount of fly ash will bring dual benefits in terms of economy and environment and comprehensive use of resources in the trend of a circular economy. Currently, there is no research or technology that proposes the production of ultra-clean coal from thermal power fly ash. This article presents a new technology for the production of ultra-clean coal from fly ash and recommends solutions for using this type of product and its accompanying by-products. The research results are the basis for further research to optimize production costs towards commercializing this new type of product.

2. Literature review

Ultra-clean coal (UCC) is defined as coal that has been processed by conventional methods, ground to fine particle size, and then chemically treated to remove ash, resulting in a final ash content of less than 1%. UCC has numerous potential applications, including serving as a carbon source for the silicon smelting industry (Steel et al., 2001); oil substitute for the production of chemicals and aromatic materials (Steel et

al., 2001); Coal slurry fuel production can be used to replace oil combustion in diesel engines (Flynn et al., 1990; Jorjani et al., 2011; Nydick et al., 1987; Kakwani et al., 1992; Urban et al., 1988), production of activated carbon used in filters for water and air purification; production of carbon fiber, an extremely strong reinforcing material used in construction (Caton & Hsu, 1994); carbon anode fabrication to replace petroleum coke (Steel et al., 2001); and as a fuel for advanced power generation technologies, such as direct combustion in gas turbines (The Coal Resource: A Comprehensive Overview of Coal, 2009). Ultra-clean coal production technology uses physical methods, chemical methods and a combination of the two methods above.

In terms of physical and chemical methods, gravity separation technology with equipment such as Mosley, Falcon, and Knelson multi-gravity separation equipment is used to process fine coal of 0.25 mm in size (Honaker et al., 1995, 1996, 2000; Özgen et al., 2009; Rath et al., 2011). Gravity separation technology can basically process fine coal but can not reduce the ash content of coal further. Flotation technology with microcell (Yoon et al., 1990), Jameson (Mohanty & Honakeri, 1999), column flotation (Firth B., n.d.), Denver D-12 (Jena et al., 2008) systems has also been studied. In general, column flotation has advantages over conventional flotation because of higher carbon content and recovery rate of the product, lower maintenance cost, and improved process control. Research directions on flotation reagents and flotation regimes are also presented by the authors (Ayhan et al., 2005; Reza & Farahnaz, 2007; Tsai, 1982; Xiu-Xiang et al., 2009). The ash content of the coals studied is about 7%. Attempts to reduce the ash content further result in a rapid decline in recovery. In addition, ash is often mixed into the coal structure, and thus physical improvement of coal quality is difficult, although the technology may be straightforward. Some limitations of physical coal cleaning are given here: (1) Very fine grinding is required to release fine pyrite impurities. Fine grinding is the most energy-intensive operation and the ultrafine particles are difficult to handle and dewater; (2) Desulfurization increases with finer grinding but reduces the separation density and also leads to dewatering problems; (3) Physical removal of pyrite sulfur may also cause loss of volatile matter; (4) Physical separation is not suitable for chemically bound minerals in coal.

Regarding chemical methods, acid leaching, alkaline leaching, and combined alkaline and acid processes have been studied. In the papers, HF and HNO₃ were used in combination to effectively treat quartz, kaolinite, FeS₂, and other inorganic impurities (Alvarez et al., 2003; Blanchard et al., 1995; Jorjani et al., 2011; Karaca & Önal, 2003; Rodríguez et al., 1996; Rodríguez et al., 1997; Rubiera et al., 2003; Steel & Patrick, 2001, 2003; Wu & Steel, 2007). The results showed that the ash content of coal could be reduced to below 0.2%. In addition, HCl, EDTA, H₂SO₄ were also used in some studies (Ahnonkitpanit & Prasassarakich, 1989; Alam et al., 2009; Karaca & Ceylan, 1997; Manoj B. & Elcey, 2010; Mukherjee et al., 2001; Mukherjee & Srivastava, 2004; Ohki et al., 2004; Steel et al., 2001; Vasilakos & Clinton, 1984; Xing, Deng, et al., 2025; Xing, Liu, et al., 2025) with low ash content, removing almost all inorganic sulfur in coal.

For alkaline leaching, NaOH is the optimal chemical choice for removing inorganic minerals, quartz and sulfur (Friedman & Warzinski, 1977; Kara & Ceylan, 1988; Saydut et al., 2011). The process takes place at high temperature, high pressure or molten alkaline leaching (Lolja, 1999). In addition, KOH or Ca(OH)₂ is used instead or combined in the leaching process to reduce production costs, less corrosion of furnaces and equipment (Stambaugh, 1977; Wang et al., 1996; Wang & Tomita, 1997).

In addition, the combination of acid and alkali in the dissolution of inorganic substances in coal such as the combination of NaOH/H₂SO₄/HNO₃ (YANG et al., 1985), NaOH/HCl (Mukherjee & Borthakur, 2001), KOH/HCl (Mukherjee & Borthakur, 2003), NaOH/HCl (Karaca & Yıldız, 2005) was studied. The ash content of coal was 3-10% with 37% organic sulfur and 100% inorganic sulfur removed.

Chemical enrichment of coal is considered essential to effectively remove finely distributed and tightly bound minerals from coal. Ultra-clean coal (UCC) can be produced by reducing ash-forming minerals, pyrite sulfur, and organic sulfur. Chemical cleaning of coal is simple when operated under "comfortable" conditions. Although chemical treatment can often remove impurities better than physical treatment, the higher cost limits its commercial application.

UCC studies have been conducted on Bituminous or Anthracite coal. Research on the production of ultra-clean coal from fly ash and its orientation for fuel (COM/CWM) or non-fuel (carbon electrode) purposes has not been studied or presented.

3. Result and discussion

2.1. Study sample and experimental procedure

2.1.1. Sample

Fly ash (FA) samples were provided by the thermal power plant of Dak Nong Aluminum Company - Vinacomin (Vietnam). The samples were mixed, to take samples for ash analysis, particle size analysis, SEM image analysis, and chemical analysis; the remaining part was used as samples for experimental work.

Tab. 1. Particle size distribution of fly ash (FA)

Fraction size, mm	Yield, %	Ash content, %
0.5 - 1	0.25	71.76
0.2 - 0.5	0.42	71.97
0.1 - 0.2	7.74	65.25
0.074 - 0.1	7.21	61.37
0.04 - 0.074	18.38	50.11
0.02 - 0.04	14.13	49.12
- 0.02	51.87	78.70
Sum	100	66.93

Tab. 1 shows the particle size distribution of fly ash. The sample has a fine material with over 85% of the -0.074 mm fraction (of which, 50% is below 0.02 mm). The ash content of the samples at different fraction sizes is similar at around 60 - 80%. Due to the fine size of the material, the processing method is oriented to be a combination of flotation and separation.

Fig. 1 and 2 describe the particle size, particle shape, and surface characteristics of particles which is performed by Scanning Electron Microscope – SEM combined with X-ray energy dispersive spectroscopy (EDS). The sample has a relatively uniform particle size, and regular shape with a high content of iron, aluminum, sulfur, and silicon. These are also the main inorganic components that need to be removed during ultra-clean coal processing.

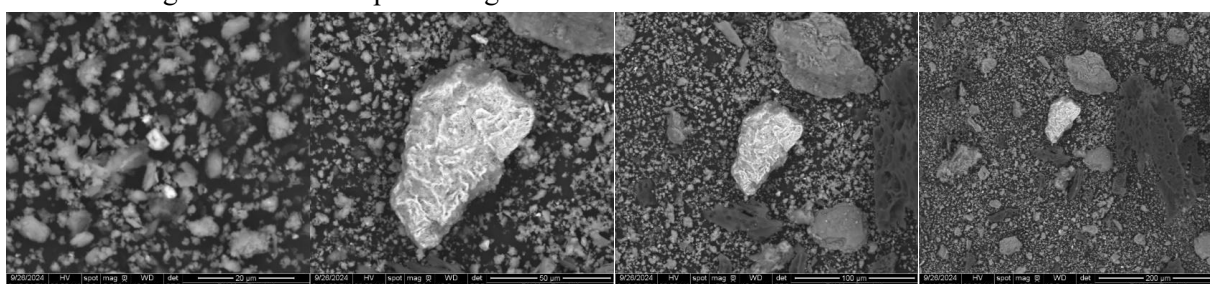


Fig. 1. SEM images of fly ash

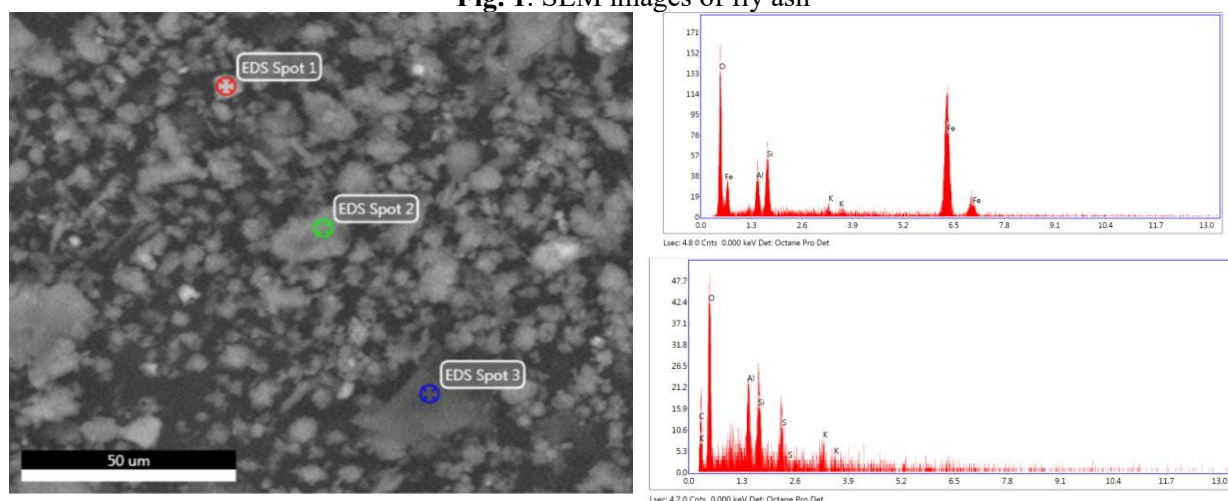


Fig. 2. The surface elemental composition of the samples was determined using the SEM-EDS method

Tab. 2 presents the results of the chemical analysis of the substances in fly ash. Accordingly, SiO_2 , Al_2O_3 , TFe_2O_3 , and K_2O are the dominant substances with a total content of up to 81%. The approach to

treating impurities in fly ash is to use a combination of flotation and acid leaching to remove a large amount of impurities, thereby significantly increasing the C content in coal.

Tab. 2. Chemical composition of fly ash samples determined by chemical method

Criteria	SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	K ₂ O	Na ₂ O	SO ₃	Cl ⁻	LOI	C
Grade content (%)	44.88	25.55	6.34	4.45	0.34	0.37	0.14	12.31	12.59

2.1.2. Chemicals and laboratory equipment

The experimental chemicals used are flotation reagents and HNO₃ and HF acids. The collector is a mixture of fuel oil + kerosene + oleic acid. This is a combined hydrocarbon collector, used to flotation coal and naturally hydrophobic substances. The frother MIBC (methyl isobutyl carbinol) is an organic chemical compound, used in flotation, making the air bubbles more durable, tougher, smaller, and float slower during the process. Nitric acid (65%, density of 1.41 g/cm³) is used to remove inorganic minerals for the ultra-clean coal research process. Hydrofluoric acid (48%, density of 1.15 g/cm³) is used to treat metal oxides and quartz sand in the coal composition.

The experimental equipment used in the laboratory includes: a flotation machine, agate and pestle mortar, magnetic stirrer, thermostat, lab scale, drying oven, filter, lab glassware, etc. Images of the equipment are shown in Fig. 3.



Fig. 3. Laboratory equipment

2.1.3. Experimental procedure

The coal sample was tested to remove invaluable minerals by two main methods, namely physical-chemical and chemical methods.

Regarding the flotation method, the first sample with a mass of 1000 grams was stirred in a 3-liters flotation machine. The collector was put into the cell and stirred for 5 minutes before adding the frother and stirring for 1 minute. After the stirring time, air was supplied to the flotation machine through the air suction valve. The froth recovery process took place until the foam was gone, aiming to maximize the recovery of clean coal and make the reject ash as high as possible. Due to the purpose of pretreatment for leaching, the optimal flotation parameters were chosen so that the ash content of the reject ash was the highest, the ash content of clean coal was less than 10% to make it easy to leach and save acid costs. The flotation clean coal sample is then fed into a 1-liter flotation machine for the cleaner stage, while the reject is fed to the scavenger stage in a 3-liters machine cell with the dosage of the collector and frother equivalent to half the dosage of the rougher stage. The samples are then filtered, dried, and weighed and the technological indicators are determined.

Regarding the leaching procedure, the flotation clean coal sample is fed into HNO₃ leaching before

being leached with HF with the technological indicators investigated being acid concentration, L/S ratio, separation time, and mud temperature. After leaching, the residue of the process is dried, weighed, and analyzed to determine the technological indicators.

2.2. Coal pretreatment experiment by flotation method

The fly ash sample was first treated to improve its quality by flotation. The purpose of this stage is to recover the maximum clean coal in the fly ash and thoroughly separate the coal in the reject. The experimental regime was selected in the direction of achieving the highest value of waste rock ash. The experimental diagram is shown in Fig. 4. The results of the flotation are given in Tab. 3.

Clean coal after one rougher stage and one cleaner have the ash content of 39.6% and 8.78% respectively with the recovery rate of the combustible part reaching nearly 60%. Correspondingly, the carbon content increased from 12.59% to 61.46%. The ash content and carbon content achieved after two rounds of coal flotation were relatively suitable for subsequent separation experiments because most of the soil, rocks, and invaluable minerals were separated. According to the results of the clean coal chemical analysis in Tab. 4, the SiO_2 content was only 3.88%, Al_2O_3 2.5%, and the remaining compositions were all below 1%.

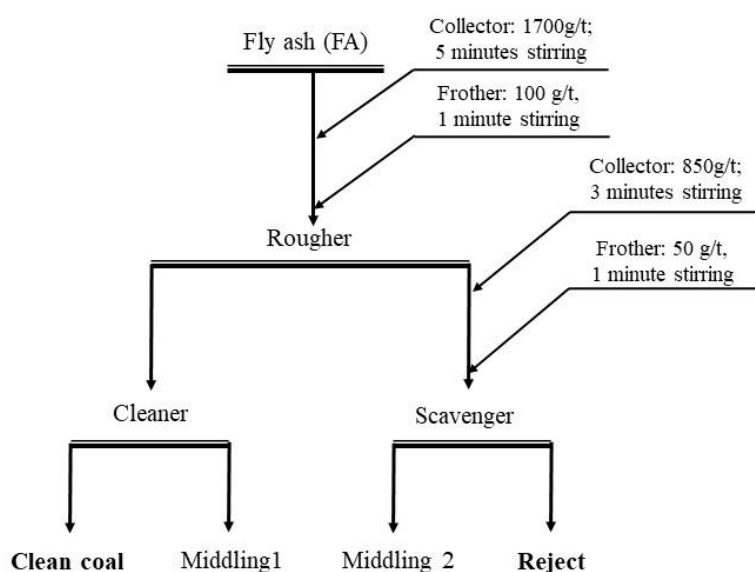


Fig. 4. Fly ash flotation flowsheet

Tab. 3. Fly ash flotation results

Products	Ash content, %	Yield, %	Recovery, %
Clean coal	8.78	20.57	56.74
Middling 1	53	20.83	29.6
Middling 2	40.59	4.47	8.03
Reject	96.56	54.13	5.63
Fly ash (FA)	66.93	100	100

Tab. 4. Chemical composition of clean coal after flotation

Elements	SiO_2	Al_2O_3	Fe_2O_3	K_2O	Na_2O	SO_3	Cl^-	LOI	C
Grade content (%)	3.88	2.50	0.56	0.45	0.10	1.49	0.01	91.48	61.46

It can be seen in Tab. 4 that the main challenge in the production of ultra-clean coal is the high content of impurities SiO_2 , Al_2O_3 , and Fe_2O_3 . These impurities have fine to ultra-fine particle sizes, that have not been completely liberated (Fig. 5 and 6). They have similar physical properties, so it is difficult to separate them from coal by mechanical methods. The clean coal sample has a very low ash content but still does not meet the requirement. The next option to treat this type of coal is to use methods with HNO_3 , which is expected to dissolve inorganic minerals (except Si), the remaining SiO_2 is dissolved with HF.

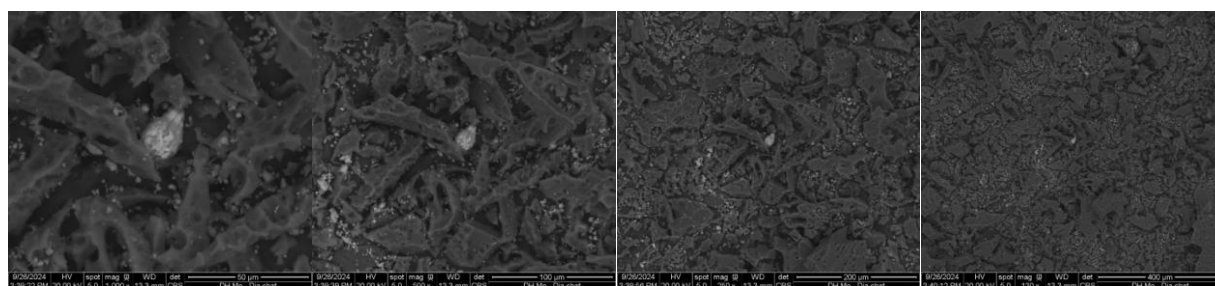


Fig. 5. SEM image of clean coal after flotation

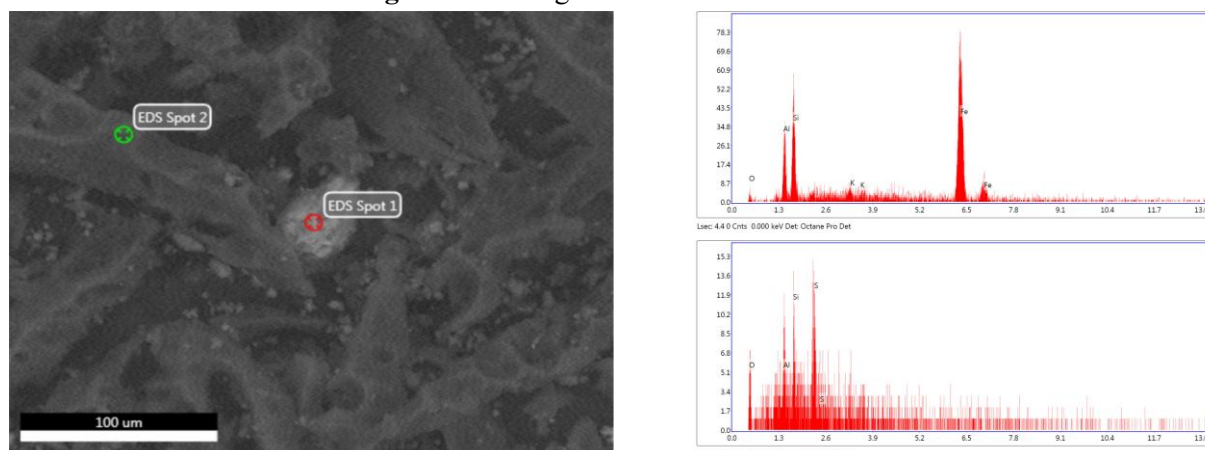


Fig. 6. The surface elemental composition of the clean coal was determined using the SEM-EDS method

The ash content of reject after scavenger is 96.56% at a very low loss of combustible part of only 5.63%. The reject is mainly composed of SiO_2 , Al_2O_3 , and Fe_2O_3 (Tab. 5). Other chemical components such as rare earth elements or useful metals (Ag, Cu, Pb, Zn, Sn, etc.) account for an extremely small proportion, which is very difficult to recover with the current technology level.

Tab. 5. Chemical composition of reject after scavenger stage

Elements	Al_2O_3	CaO	TFe_2O_3	K_2O	MgO	MnO	P_2O_5	TiO_2
Grade content (%)	28.22	1.22	6.59	4.43	1.45	0.07	0.13	1.01

2.3. HNO_3 acid leaching

The clean coal after flotation was sent to HNO_3 leaching before HF treatment. The purpose of this step is to remove most of the minerals (except SiO_2) from the coal composition. The experimental sample was conducted according to the conventional experimental method, investigating one technological parameter while keeping the other technological parameters stable. The technological parameters investigated were: HNO_3 acid concentration, liquid-solid ratio (L/S ratio), leaching time, and leaching temperature.

Based on the results of the HNO_3 leaching (Fig. 7), the optimal parameter chosen was acid concentration 0.8 M, L/S ratio 6/1, leaching time 6 hours, and leaching temperature 50°C . The clean coal after flotation with ash content of 8.78% was reduced to 6.78% at the actual recovery of the combustible part of this stage 97.9%, and the carbon content 79.97%. The clean coal after HNO_3 leaching showed relatively uniform particle size, from 10 to 100 μm (particle size is completely suitable for the subsequent Si separation process with HF). The EDS image showed that there was still a small amount of Al, K, and Mg but it was not significant. The amount of Si remaining was relatively large because it could not be dissolved in HNO_3 .

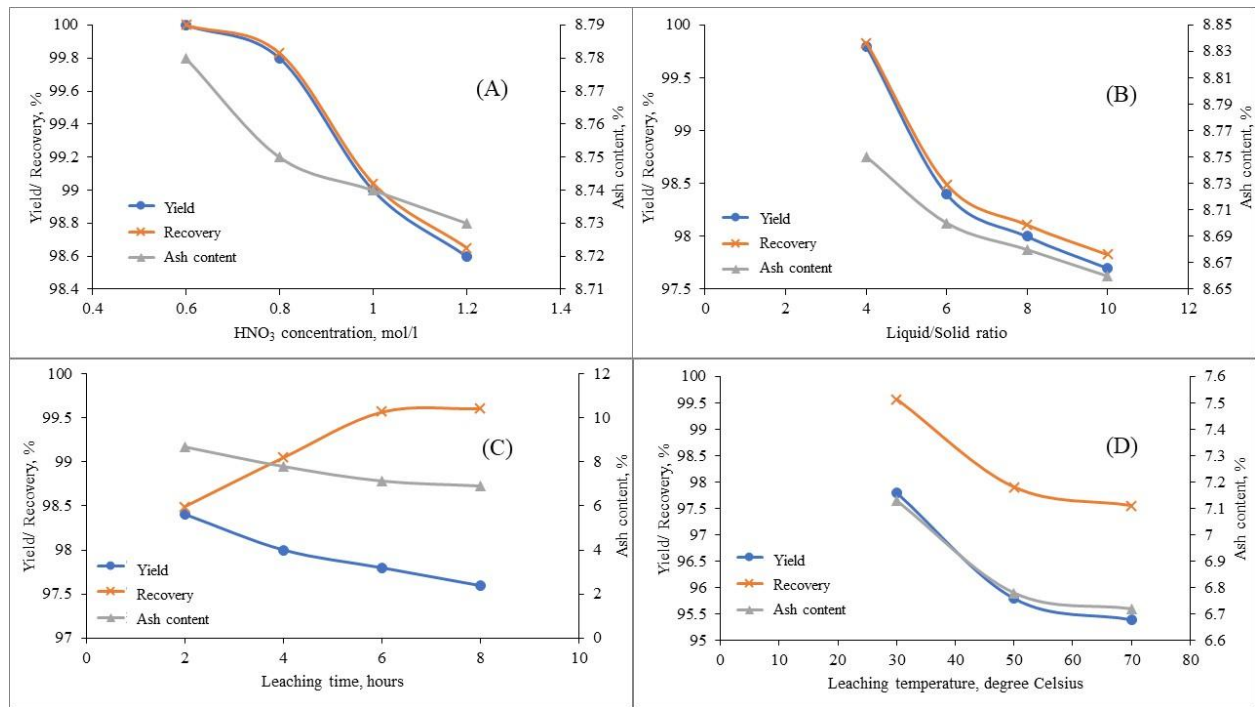


Fig. 7. The diagram shows the relationship between HNO₃ acid concentration (A), liquid/solid ratio (B), dissolution time (C) and dissolution temperature (D) to clean coal yield, recovery and ash content

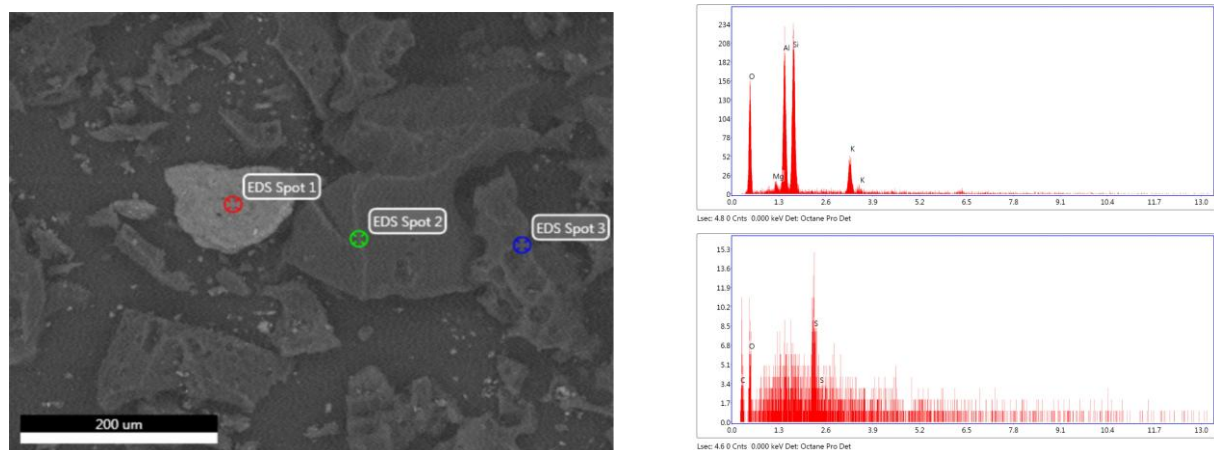


Fig. 8. The surface elemental composition of the clean coal after HNO₃ leaching (SEM – EDS)

2.4. HF acid leaching

The clean coal after HNO₃ leaching is dissolved with HF. The purpose of this step is to remove SiO₂ from the coal composition. The experimental sample is conducted according to the conventional experimental method, investigating one technological parameter while keeping the other technological parameters stable. The technological parameters investigated are: HF acid concentration, liquid-solid ratio, leaching time, and leaching temperature. The experimental results are shown in Fig. 9.

Experimental results show that the optimal parameter for producing ultra-clean coal is HF concentration 2.5M, L/S ratio 6/1; leaching time 18 hours, leaching temperature 30°C. Ultra-clean coal has an ash content of 0.73%, at recovery (in stage) 97.32%, and a carbon content of 85.07%.

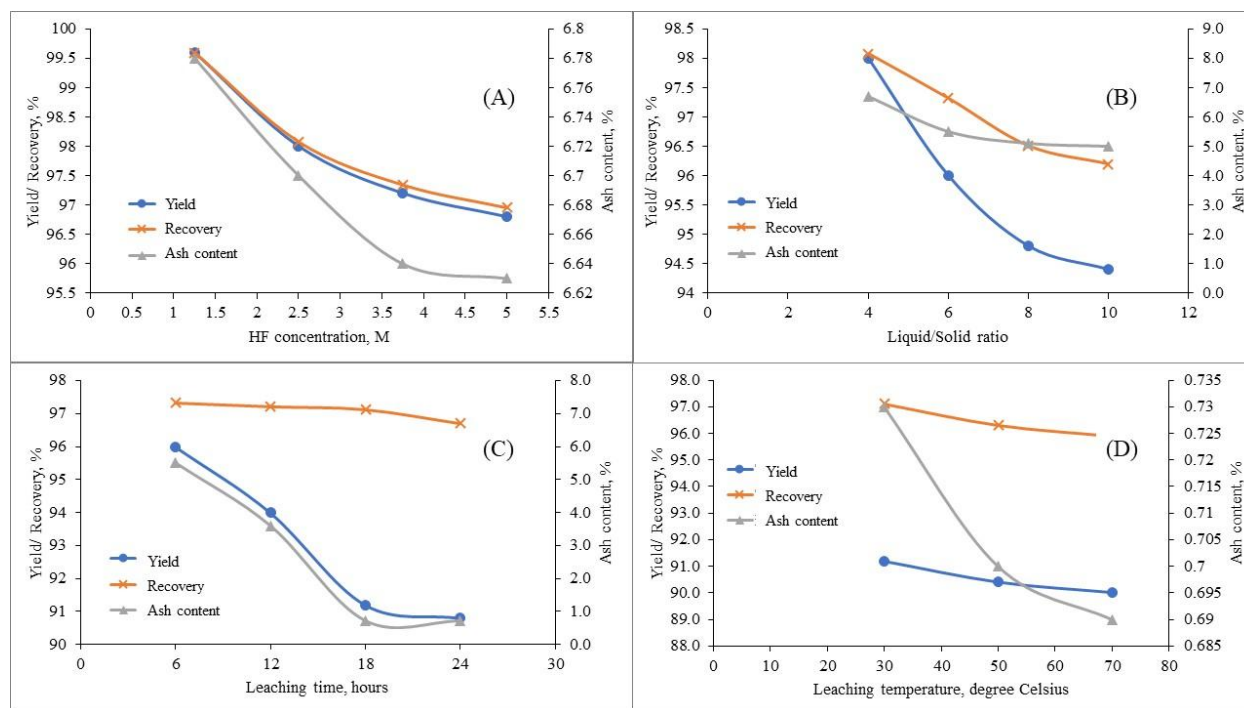


Fig. 9. The diagram shows the relationship between HF acid concentration (A), liquid/solid ratio (B), dissolution time (C) and dissolution temperature (D) to clean coal yield, recovery and ash content

Overall, in the most optimal mode possible, the coal ash content was reduced to 0.36%. The experimental results were comparable to those of studies worldwide with raw bituminous coal using acid methods. The microwave coal pretreatment process creates cracks in the fine fly ash particles, increasing the leaching efficiency. However, the experiment was based on previous studies without actual observation of the fly ash particle surface using advanced equipment. In literature, the ash content could be further reduced to 0.1% or even to 0% by combining acid and alkaline methods. Therefore, further studies are needed to increase ash removal efficiency and optimize the process as well as the production costs in the future.

2.5. Proposed flowsheet for processing ultra-clean coal from fly ash and bi-products

The experimental results achieved the goal of producing ultra-clean coal with ash content <1% from fly ash, the reject almost completely removed coal matter (ash content 96.56%). However, SiO₂ and other organic matter in the clean coal were not completely removed because of the uncompletely liberation degree. To break the coal structure and increase the leaching efficiency, the clean coal sample after flotation and the clean coal sample after HNO₃ leaching were pretreated with microwaves at an energy level of 800W for 1 minute (Jorjani et al., 2011). The experimental results are shown in Tab. 6.

Tab. 6. Results of coal leaching using HNO₃ and HF with microwave pretreatment

HNO ₃ leaching (in chosen optima parameters)	Ash content: 6,1%
HF leaching (in chosen optima parameters)	Ash content: 0,36%; Carbon grade content: 91,16%

The results of preliminary pretreatment experiments show the prospect of applying this direction to improve the efficiency of separating inorganic minerals and producing ultra-clean coal. Images of the products are shown in Fig. 10. From there, the proposed flowsheet is presented in Fig. 11.

The products arising during processing are proposed as follows:

- Ultra-clean coal with ash content below 1% is proposed to produce a Coal Water Mixture (CWM) or Coal Oil Mixture (COM). This is a suspension mixture including coal, additives, and water or oil. Coal particles with a certain particle size composition (80-90% -0.074 mm level) are evenly and stably distributed in water with a content of 65-70%. Coal fuel slurry has the properties of a liquid (similar to heavy fuel oil) so it has advantages that conventional coal does not have. CWM fuel slurry is dust-free, non-flammable, and non-explosive. CWM requires smaller storage although tanks or containers with a

certain capacity must be built. CWM is easily transported by pipeline or ship. However, CWM must have low viscosity to be pumped more easily and sprayed more effectively into the furnace. When switching from oil to fuel coal slurry, there is no need to change the configuration of the thermal power plant and the combustion is simple, only need to change the burner. CWM is safe to use and environmentally because water coal slurry is not classified as an explosive commodity and it is easy to add desulfurizer during production or immediately before combustion. The production process of fuel coal slurry is introduced in the study of Sunggyu Lee et al. (2007). In addition, with a sufficiently high carbon content, ultra-clean coal can be used in combination with graphite in the production of carbon electrodes, and other metallurgical applications..

- Reject: Reject has been almost completely removed of coal (ash content reaches over 96%) with the main chemical components being CaO , SiO_2 , Al_2O_3 , K_2O , which is safe and meets the requirements for the production of unburnt bricks (J. Jena et al., 2020; Luu Dinh Thi & Le Thi Thanh Tam, 2021; Murugesan et al., 2017; Ngo et al., 2020), green concrete (Anish et al., 2023; Chandio et al., 2020; Golewski, 2018; Onyelowe et al., 2022), cement (Golewski, 2020; Mahavir Balmukund Varma & Pravin Gadling, 2016; Pangdaeng et al., 2014; Tlegenov et al., 2024; Wei-Ting Lin, 2020), lightweight concrete (Daniela González Betancur et al., 2019; Wibowo et al., 2024; Wibowo & Saidani, 2023).

- Middling products: Due to the relatively high ash content of the middling (50.81%), the best solution to use this material source reasonably is to blend it with the initial coal source feeding to the thermal power furnace to continue burning.

- Leaching liquor after HNO_3 and HF leaching: need a solution to precipitate impurities and treat them by landfill. The acid solution is recovered and reused in the separation process.

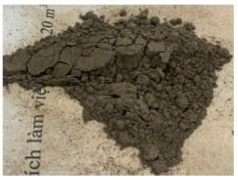
				
Fly ash (A = 66.93%; 12.59%C)	Clean coal after flotation rougher stage (A=31.06%)	Reject after flotation rougher stage (A=92.19%)	Clean coal after flotation cleaner stage (A = 8.78%; 61.46%C)	Middling 1 after cleaner stage (A = 53%)
				
Middling 2 after flotation scavenger stage (A = 40.59%)	Reject after flotation scavenger stage (A = 96.56%)	Clean coal after HNO_3 leaching (A = 6.78%; 79.97%C)	Clean coal after HF leaching (A = 0.73%; 85.07%C)	Clean coal after HF leaching, with microwave pretreatment (A = 0.36%; 91.16%C)

Fig. 10. Images of products of the ultra-clean coal production process in optimal parameters

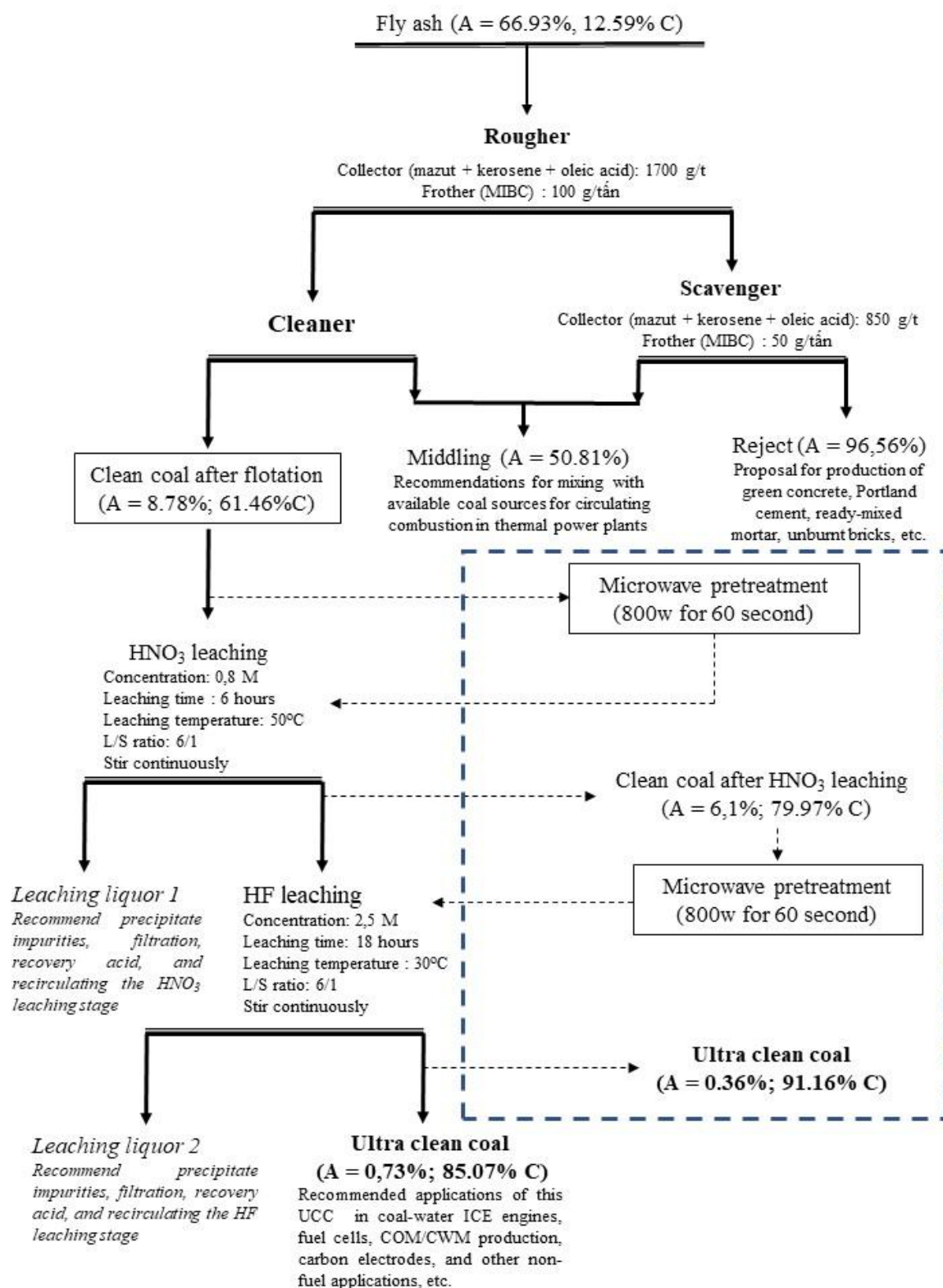


Fig. 11. Proposed diagram for producing ultra-clean coal from fly ash of the thermal power plant, Dak Nong Aluminum Company - Vinacomin

3. Conclusion and outlook

3.1. Conclusion

Thermal power fly ash is a source of waste that is harmful to the environment and human health. There have been many studies on fly ash treatment and recovery for construction. However, to avoid wasting coal resources in fly ash (30%) and making waste products cleaner, meeting civil requirements, fly ash needs to be processed and treated more thoroughly;

A solution for fly ash treatment to recover ultra-clean coal with ash content $<1\%$, providing a new source of materials has been studied. The ash after treatment has an ash content of nearly 100% , which can be completely disposed of or provided to households that produce clean building materials, friendly to humans and the environment;

The technological solution includes three steps: Flotation of fly ash, separation with HNO_3 , and separation with HF;

The flotation technology parameters to improve the quality of fly ash include a rougher (1700 g/t of collector dosage, 100 g/t of frother dosage), cleaner, and scavenger (850 g/t of collector dosage, 50 g/t of frother dosage). The clean coal obtained after the cleaner has an ash content of 8.78% at a recovery of 56.74% . The reject has an ash content of 96.56% at a loss of 5.63% ;

At the step of HNO_3 leaching, the optimal technology parameters are HNO_3 concentration of 0.8 M , L/S ratio of $6/1$, leaching time of 6 hours, and leaching temperature of 50°C . Clean coal has the ash content of 6.78% at a recovery of 97.9% (in stage), a total recovery of 55.55% ;

At the step of HF leaching, the optimal technological parameter is HF concentration of 2.5 M , L/S ratio of $6/1$, leaching time of 18 hours, and leaching temperature of 30°C . Clean coal has an ash content of 0.73% at the recovery of the burnt part (in this stage) of 97.12% , and the total recovery reaches 53.95% ;

In the case of microwave pretreatment energy level 800 W for 60 seconds, clean coal has an ash content and carbon content of 0.36% and 91.16% , respectively.

Processed fly ash with low ash and high carbon content is suitable as raw material for coal-oil mixed fuel (COM), coal-water mixed fuel (CWM), carbon electrode, etc., while the reject is suitable for green concrete, non-fired bricks, etc.

3.2. Outlook

It is necessary to study in more detail the dosage of flotation reagents, sludge concentration and flotation flowsheet to optimize the cost of flotation production;

There is a plan to thoroughly treat middling products to increase the actual recovery of the combustible part in coal products recovered from fly ash;

There is a need for solutions to treat the solution after leaching process and reuse acid;

Propose and test production of green concrete, porous concrete, unburnt bricks or other construction products from reject that have completely separated coal matter.

It is necessary to further improve the technology of producing UCC from fly ash, aiming at pilot production on a semi-industrial scale and commercial operation.

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