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Coal Fly Ash in Vietnam and its Application as a Lightweight Material

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Each year in Vietnam, to operate the country's thermal power plants, it is necessary to utilize a large quantity of coal. The power plants then generate a large amount of coal fly ash (FA), which is a hazardous solid waste that can seriously affect the environment. There is an urgent need to develop appropriate solutions for treating or reusing the generated FA. In this study, the layout of coal-fired thermal power plants in Vietnam, as well as the country's coal use and FA emissions, are discussed. Research is reviewed on the potential applications of FA in Vietnam, along with related research from the past 20 y worldwide, and is found to demonstrate that the main application of FA is that of a geopolymer in construction, acting as a low-cost adsorbent that removes compounds, organic matter, emissions, metals, light aggregates, backfills, and auxiliary baselines, and synthesizes zeolites. On that basis, FA samples collected in the northern and southern regions of Vietnam were analyzed for their chemical compositions. The results determined that FA throughout Vietnam has the chemical composition, SiO_2 + Al_2O_3 + Fe_2O_3 over 70 wt%. This is FA of classification F, according to TCVN 10302: 2014 (2014) and ASTM C618. This study concludes that the fly ash originating in Vietnam is suited to the production of porous, super-light materials with a high technical value, such as aerogels or aerogel composites. Such materials as these possess special properties such as a low density, high specific surface area or porosity, low thermal conductivity, sound insulation, low dielectric constant, low optical refractive index, or a high optical transmission capacity, elasticity, durability, or flexibility. The application of Vietnamese FA in the production of materials such as these is recommended by this paper, as a means of countering the environmental pollution problem of coal-fired thermal power plants and promoting the development of advanced materials in Vietnam.

1. Distribution of coal-fired thermal power plants and the use of coal in Vietnam

In Vietnam, by 2030, 46 new coal-fired thermal power plants will enter operation with a total design capacity of 41,500 MW; 25 plants will employ domestic coal, with a combined capacity of 18,470 MW, and 21 plants will employ imported coal, with a combined capacity of 22,780 MW.
Currently, at least 23 coal-fired power plants are commercially operating in Vietnam, with a total capacity of 16,260 MW. The investors in these plants are a mix of state-owned corporations, private companies, and Build–Operate–Transfer investors. There are two main sources for the materials utilized by the plants: domestic coal (anthracite coal) and imported coal (a mixture of bituminous and sub-bituminous coal). For the coal-fired thermal power plants that utilize domestic coal, the main types of dust that are produced are 5a, 5b and 6a, 6b, with an average FA content that ranges from 29 wt% to 37.5 wt%. Imported coal, on the other hand, generates dust with a lower FA content, ranging from 6 wt% to 7 wt%, and a higher calorific value. The estimated amount of FA that is currently produced is around 25 x 10^6 t/y. The quantity of ash and slag that originates from plants utilizing domestic coal is estimated to be around 19 x 10^6 t/y, while the quantity from plants utilizing imported coal makes up the remaining 6 x 10^6 t/y (Hoang, 2019).
Coal-fired thermal power plants in Vietnam are mainly small- and medium-sized, with capacities below 2,000 MW. In the past, plants were often concentrated around coal mines such as Quang Ninh, Lang Son, and Hai Phong. Due to economic development and the increasing demand for electricity, many thermal power plants have since been built across the country, near to industrial zones. Figure 1 illustrates the distribution of coal-fired thermal power plants in Vietnam, from the North to the South; the power plants can be seen to be

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concentrated in the North East and North Central regions. Of the total emissions produced by the country's coal-fired thermal power plants, the concentrations that are produced in northern, central, and southern Vietnam are 60 wt%, 21 wt%, and 19 wt%.

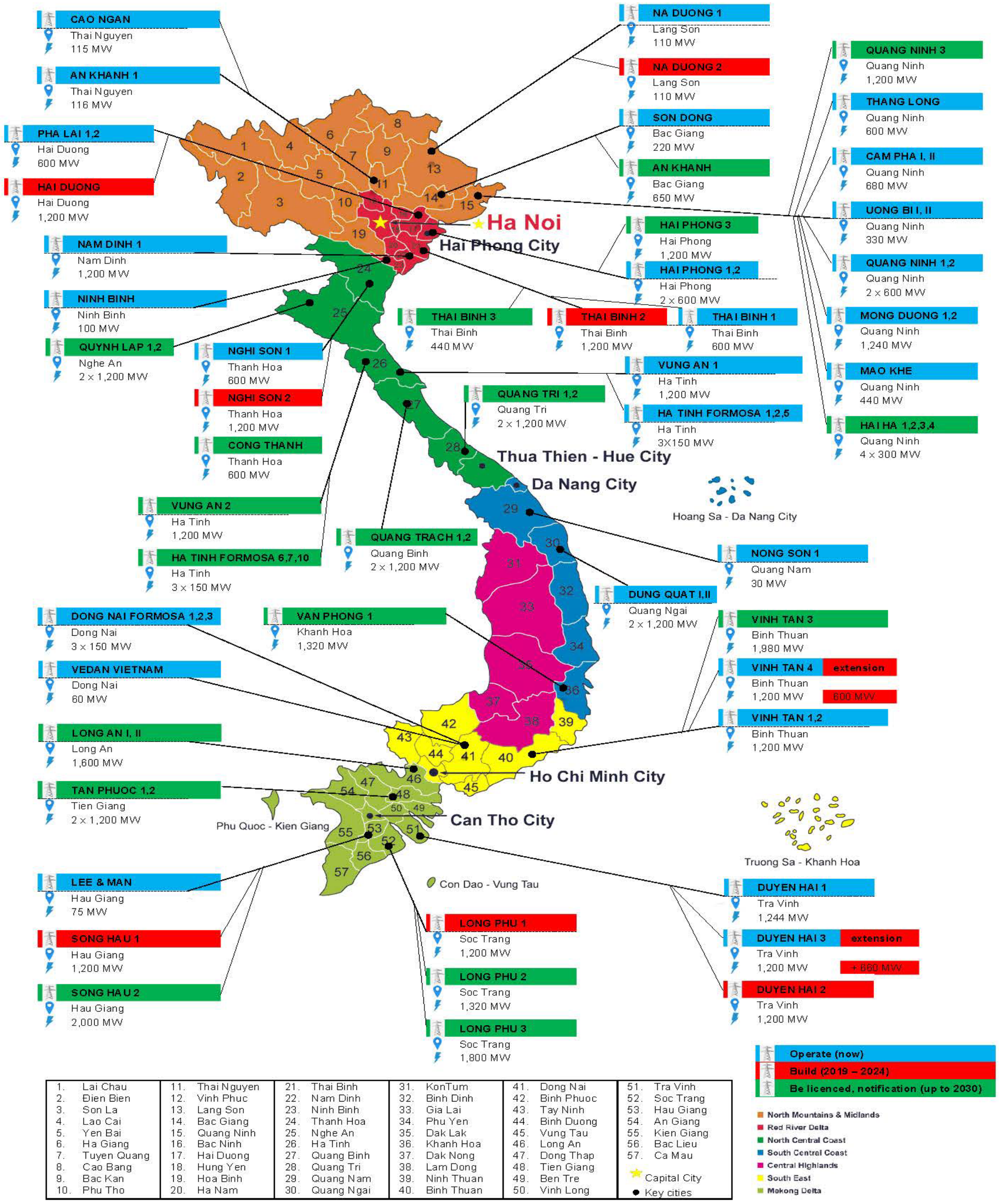

Figure 1: Distribution of coal-fired thermal power plants in Vietnam

According to data published by 23 investors in the Vietnamese power industry, the power plants' combined coal consumption is around 41 x 10^6 t/y, the actual amount of FA produced is around 12.2 x 10^6 t/y, and the amount of FA that is stored in a dump is around 25.2 x 10^6 t. In 2017, the amount of FA that was utilized in Vietnam amounted to nearly 4 x 10^6 t, accounting for around 30 wt% of the total amount generated, of which the North utilized the majority, at around 3.25 x 10^6 t. As of 2018, the volume of FA that is stored on-site at coal-fired thermal power plants in Vietnam amounts to nearly 15 x 10^6 t. To minimize the release of FA into the environment, the FA is collected in reservoirs and then processed by sedimentation, flotation, or electrostatic filtration. Only 30 wt% of the total FA can be recycled in this manner into useful products. The remaining FA that is not recycled is piled up, seriously affecting the balance of the ecosystem and increasing the risk of a natural disaster. Groundwater sources are affected if they come in contact with the FA storage tanks; this has the result of altering the pH and permeability of sediments, clogging the groundwater circuits, and spoiling the water flow, which becomes cloudy and unusable. At the same time, while it is piled up, the toxins that exist in the FA are released into the air, polluting the air that surrounds the dumping sites.

2. Applications of fly ash within the present context

Currently, FA emissions from coal-fired power plants are increasing. It is essential that Vietnam, as with other countries in the world, soon develops appropriate solutions for the treatment and recycling of FA as a practicable material.

Over the past 20 y, many studies have been carried out into the applications of FA. In Turkey, Demibra et al. (2003) studied the effects of mineral additives on the thermal conductivity and compressive strength of mortar. Van de Lindt et al. (2008) reviewed the application and feasibility of FA, along with scrap tire fiber, as materials utilized in a wood wall insulation supplement for residential buildings. Figen et al. (2010) studied the effects of FA, clay, pelit rock, and epoxidized flaxseed oil on the thermal and mechanical properties of insulation. The raw heat treatment process was tested on FA at three temperatures: 1,100; 1,150 and 1,200 °C by Zoric et al. (2012) in Serbia. Binici et al. (2014) synthesized a form of insulation from cotton and FA. The obtained material had a compressive strength up to 9.35–14.4 MPa, a water absorption capacity of 29–34 %, and a thermal conductivity coefficient of 0.226–0.302 W/m^2.K. Feng et al. (2015) developed a geopolymer material supported by porous FA; the material was produced by combining FA and sodium glass with H_2O_2 as a foaming agent. In China, Zhu et al. (2016) prepared insulation materials through the process of direct foaming, utilizing coal FA and waste glass as the main staples, along with borax and calcium carbonate as the foaming agents. In 2016, cenosphere and silica aerogel FA particles were mixed into a light-weight mass, adding polyvinyl alcohol fibers to extend the mechanical properties of the composite. The compressive strength and elasticity of the composite aerogel materials were determined to be 18.63–23.54 MPa and 3.66–4.94 MPa, while the thermal conductivity was reduced to 0.319 W/mK (Hanif et al., 2016). In 2017, FA was pretreated with sodium hydroxide to increase the fire resistance of a polyvinyl alcohol laponite aerogel by freeze-drying. The thermal conductivity of composite material was recorded to score in the range of 0.045–0.058 W/mK (Kang et al., 2017). In 2018, FA was combined with trona ore, an abundant and cheap natural resource; the two were synthesized to form hydrophobic silica aerogel materials through the solid-solid method (Wu et al., 2018). Telesca et al. (2019) researched calcium sulfoaluminate cement and FA-based geopolymers as sustainable binders for mortars.

The results from previous studies can be applied when attempting to convert thermal power industry byproducts, such as FA, into materials of high technical value, such as aerogels and aerogel composites. Some limitations remain in the research. For instance, FA has only recently been employed as an additive in the synthesis of the insulation materials produced for construction. In this way, FA supplements to the composition of the material, reinforcing its texture of the material. FA, has not yet been utilized as the starting source of the material. In previous reports the synthesis process has been found to be complex, involving many environmentally unfriendly chemicals, as well as high chemical and energy costs. The studies into FA recycling, while they have succeeded in building an integrated process on a laboratory scale, have stopped short of developing a pilot-scale fabrication process and calculating the energy and material production costs in practice. A further limitation is that the specifications of materials made from FA are not yet in line with those that are required in practice as a result, for example, of its higher thermal conductivity when compared with traditional insulators (Ahmaruzzaman, 2010).

In Vietnam, FA is mainly employed for the following purposes: as a direct raw material for use in cement factories, as a raw material for the production of unburnt or baked bricks, and as an additive in concrete. In the cement factory, FA is directly ground with the clinker to form the cement. FA is combined as a raw material with the clinker production materials, replacing clay and gypsum, while unburnt coal is employed as the fuel. Among the total raw materials, FA can replace clay at rates of up to 7–12 wt% in cement production. In the production of unburnt bricks, the percentage of FA utilized in each ordinary brick generally ranges from 20 wt% to 25 wt%, though some technologies can employ up to 70 wt% FA in the production of unburnt bricks. In the production of baked bricks, the calorific value of the unburnt coal in the coal-fired thermal power plants can be utilized as a raw material. A concrete admixture is employed in concrete mixing plants. As an additive in this, depending on the quality and stability of the FA, the proportion that can be utilized use as a raw material reaches 35 wt%.

In addition to these uses, FA can be utilized as a binder to reinforce sand and stone materials for the laying of pavements. Results have demonstrated that a mixture of 80 wt% FA and 20 wt% lime, as a binder, achieves

high mechanical strength. FA can also be employed to strengthen soil; soil that is strengthened with FA has a high intensity. This material is comparable with reinforced lime and other, similar chemicals. The soil can be applied as a road foundation or an edge reinforcement, the slope of the slope will be highly effective.
Son et al. (2005) have converted FA into zeolite, which can be utilized to improve soil quality. Don (2005) study the conversion of FA into zeolite and its use as a treatment solution for environmental pollution. Due to the low absorption capacity of heavy metals, many studies have focused on denaturing FA, mainly transforming it into zeolite by mixing the FA with solid caustic soda and heating at a high temperature of around 500–600 °C. Domestic studies in Vietnam have investigated the applications of FA as a raw material and additive in building materials, such as cement and concrete. The employment of FA as the main raw material in the synthesis of materials of high technical value, which is the focus of research abroad, has not yet been taken up and developed by Vietnamese scientists.

3. Chemical properties of the fly ash in Vietnam

In this study, FA samples were collected from coal-fired power plants in Vietnam (i.e., the Pha Lai and Mong Duong thermal power plants in the North and the Duyen Hai 1 and Duyen Hai 3 thermal power plants in the South). The results of a compositional analysis of the FA, using inductively coupled plasma, are presented in Table 1. According to TCVN 10302 : 2014 (2014) and ASTM C618, FA at most coal-fired power plants in Vietnam is classified as F class, with a total oxide content of SiO_2 + Al_2O_3 + Fe_2O_3 over 70 wt%.

Table 1: Chemical composition of the FA in Vietnam

Chemical composition	Duyen Hai 1 (wt%)	Duyen Hai 3 (wt%)	Pha Lai (wt%)	Mong Duong (wt%)
SiO_2	55.7	46.4	57	54.27
Al_2O_3	23.1	22	23.8	25.02
Fe_2O_3	6.1	15.6	4.7	4.71
K_2O	3.76	1.63	6.56	6.76
MgO	1.7	2.9	1.2	1.22
CaO	0.7	7.1	0.81	0.91
Na_2O	0.54	0.61	0.09	0.16
TiO_2	0.52	0.65	0.78	0.78
SO_3	0.15	0.9	0.53	0.73
P_2O_5	0.12	0.64	0.13	0.16
Mn_3O_4	0.04	0.16	0.04	0.04
C	7.57	1.41	4.36	5.24

The main components in the FA generated from Vietnam's thermal power plants include SiO_2 and Al_2O_3. FA with a large proportion of SiO_2 and Al_2O_3 is favorable for the synthesis of porous, advanced, and super-light materials. Such FA is suitable for application to produce thermal and sound insulation with high porosities of over 90 %. The compositions of the SiO_2 found in the FA samples from the Duyen Hai 1, Duyen Hai 3, Pha Lai, and Mong Duong thermal power plants were 55.7, 46.4, 57, and 54.27 wt%, of which the highest result originated from Pha Lai. The composition of Al_2O_3 was found to be 23.1, 22, 23.8, and 25.02 wt%, of which the highest result originated from Mong Duong. The FA generated from Vietnam's thermal power plants also contains small amounts of oxides, such as Fe_2O_3, Na_2O, and MgO, and other elements, accounting for around 10–15 %. The size distribution of the FA particles follows a Gaussian standard distribution with a factor of around 10–30 µm.
Based on its physical and chemical properties, Vietnamese FA has been found to bear the potential to be utilized as an auxiliary material in the production of concrete for social construction projects. Recently, Vietnamese FA in varying concentrations has been employed to alter the composition of conventional Portland cement. Research results have demonstrated that FA has the ability to enhance the anti-corrosion properties of the sulfuric acid in concrete.
In addition, concrete beams with FA contents of 10 and 20 wt% have been found to possess a greater bending resistance than beams without added FA, after 300 d of exposure to a 5 wt% NaCl solution. The thermal characteristics of concrete with a high FA content were studied by Mien et al. (2013), with FA contents that varied from 20 to 50 wt%. The results illustrated that as the FA content increased, the temperature in the center of the concrete block decreased, along with the difference between the temperature at the center of the concrete block and the surrounding ambient temperature. The more the time spent developing the temperature in the concrete was stretched, the more the resulting thermal stress was limited and the cracking in large concrete blocks was reduced.

4. The future of advanced applications of fly ash in Vietnam

Both the previous research results and the composition of FA in Vietnam support the notion that FA is well-suited for use in high-tech advanced materials. One avenue that could be pursued is that of the construction industry. The improved geopolymer properties that FA possesses contribute to its enhanced potential for applications in the construction industry that include cement replacement, binding, aggregating, and coating, as well as forming composites, fibers and textiles, liquid storage materials, insulation, marine structures, refractory materials. Soil stabilization and waste packaging, too, present additional applications of FA.

A second avenue that could be developed for the application of FA relates to its metallic properties. FA can potentially be mined as a raw material to recover metals such as Ge, Ga, Ti, Ag, Cu, Zn, Sn, Mo, and Pb. Metal oxides can also be recovered in this way, such as Fe_2O_3 and TiO_2, which can then be utilized in the synthesis of high-tech advanced materials. In-depth research is required to appropriately assess the potential for such mining of FA in Vietnam.

A third and friendly avenue of the potential applications for Vietnamese FA is improvements to the environment; FA can, for instance, be utilized in soil reclamation or as a water purification material.

The main development trend, which is suited to the conditions in Vietnam is the production of aerogels and aerogel composites. An aerogel is an ultralight porous material with characteristic properties such as a low density, high specific surface area or porosity, low thermal conductivity, sound insulation, low dielectric constant, low optical refractive index, and high optical transmission capacity, elasticity, durability, and flexibility. FA with main ingredients that are rich in Si and Al is suitable as a precursor material in aerogel preparation. At the same time, FA can also be combined with other metal oxides or polymers to improve the mechanical properties of the aerogel material. An aerogel is synthesized using a sol-gel transition in a dedicated solvent and then cured under suitable drying conditions. When the controlled freeze-drying method is employed, the resulting aerogel composite material can be produced at a low cost due to the short drying time involved, thereby minimizing the operating costs and improving the impacts on the environment, as the production process does not involve a toxic solvent and so no complicated solvent removal steps are required. The suitable applications of aerogel composite materials made from FA are diverse, including adsorption, catalysis, electronics, lasers, sensors, insulation, sound insulation, and optics and imaging equipment. In particular, there is a great opportunity for the application of such materials in insulation and soundproofing, as the materials are porous and lightweight, which is favorable for construction and installation. The simple synthesis process for aerogel composite materials made from FA is suitable for large-scale production conversion.

Aerogels made from FA are both electrically conductive and good insulators when mixed with several other materials. Aerogel can be synthesized from various raw materials, including industrial by-products such as rags, waste plastic, and used paper, along with agricultural residues such as straw, rice straw, and rice husk ash. Aerogels are considered to be eco-friendly material and possess a high degree of functionality. The practical uses for aerogels are still limited due to a number of disadvantages with the materials. Aerogels can be, for instance, brittle, fragile, and hygroscopic. In order to improve these shortcomings, aerogel composite materials—i.e., those that are synthesized from two or more different materials to create new materials with superior properties compared to the originals—must continue to be researched and developed by scientists. Through the combination of aerogel with other materials, forming aerogel composites, their limitations can be overcome. The development of aerogel composites made from FA holds the potential for bringing the application of Vietnamese FA in high-tech advanced materials closer to reality.

5. Conclusion

The FA arising from the operation of coal-fired thermal power plants in Vietnam is both a serious environmental problem and an abundant source of raw material that can be exploited for use in many fields. FA can be recycled in construction, backfilling, soil environmental reclamation, and water purification. At the same time, research is also studying the potential of FA for use in advanced materials such as aerogels and aerogel composites. The FA composition in Vietnam is rich in Si and Al, which is favorable for the development of super-light, porous materials with such characteristics as a low density, a high specific surface area or porosity, a low thermal conductivity, and sound insulation. This paper recommends that advanced applications for FA in Vietnam, such as adsorption, catalysis, electronics, lasers, sensors, insulation, sound insulation, and optics and imaging equipment, are developed.

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