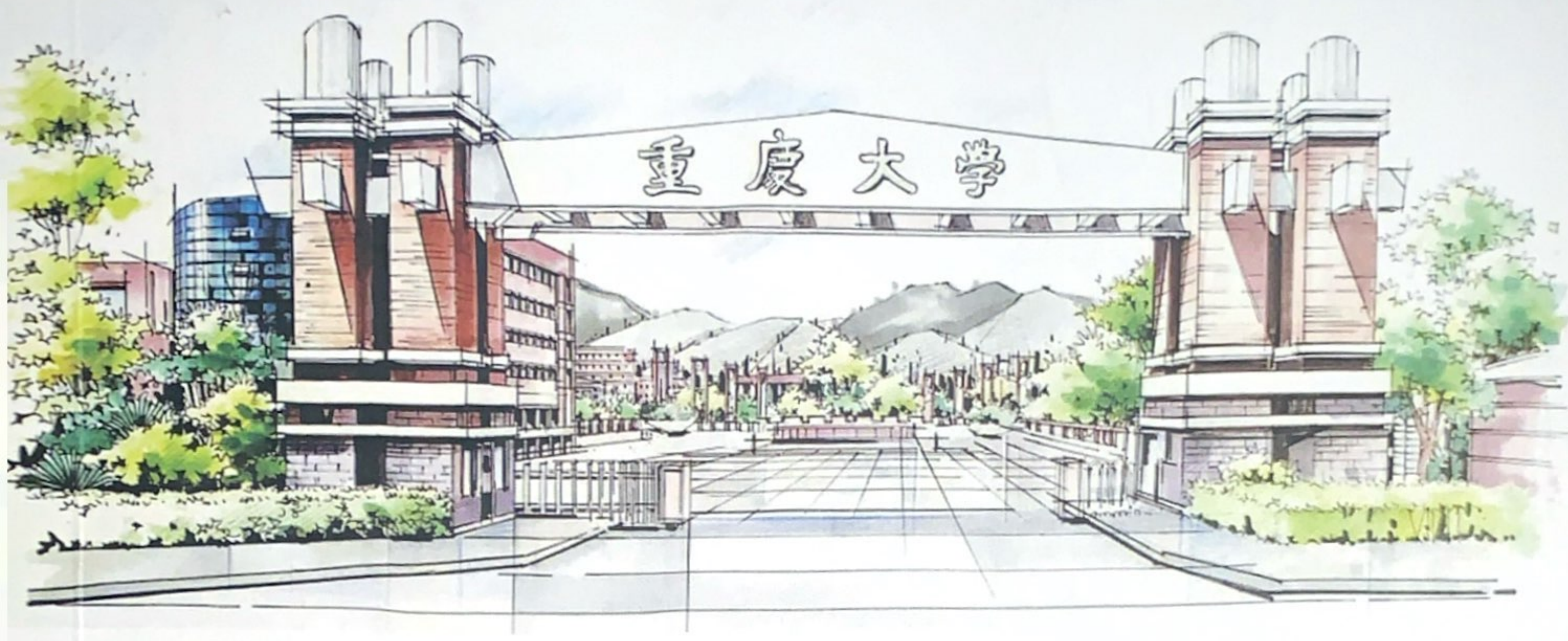

Proceedings

SOMP 2024

The 13th Regional Meeting of the Society of Mining Professors
May 8-12, Chongqing University, Chongqing, China

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Dewatering the fine coal using the lab-scale conventional pressure filtration and steam pressure filtration: A case study from Cua-Ong Coal Washing plant, Vietnam.

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Abstract: Cua-Ong coal washing plant produces a large amount of coal for domestic demand and export. One of the products after washing is fine coal, which is used for thermal power plants. This type of coal has 20-25% of residual moisture content after filtration. This issue leads to difficulties in storage, transportation as well as utilization directly. In order to improve the dewatering efficiency after filtration, fine coal is chosen for the study. The result shows the effect of solid volume fraction and filter cake height on the residual moisture content using conventional pressure filtration (CPF) and steam pressure filtration (SPF). The optimal operational parameters are suggested. Furthermore, some tests with the whole circle steam pressure filtration are conducted to show the residual moisture content reduced to 12%.

Keywords: fine coal, Cua-Ong coal washing plant, steam pressure filtration, conventional pressure filtration, filtration operational parameters

1. Introduction

Coal plays an important role in the economy and the development of Vietnam. The demand of coal for the domestic market has increased steadily every year. In five years, domestic coal demand has risen from 18 million tons (in 2007) to 24.8 million tons (in 2012). According to the master plan for coal industry development in Vietnam 2020, with perspective 2030, the total coal will get up to 60 million tons in 2020, 65-70 million tons in 2025, and 65-75 million tons in 2030. According to the balance of supply and demand, if the power plants put into operation on schedule under the master plan VII (National Master Plan For Power Development – Vietnam Government), Vietnam will need 62-72 million tons of coal, in which coal for power need 42-72 million tons, coal for other industries need 20-22 million tons. Vietnam has to import energy coal with the amount from 10-12 million tons in 2020 [1]. The supply and demand of coal are predicted for 2030, shown in Figure 9.

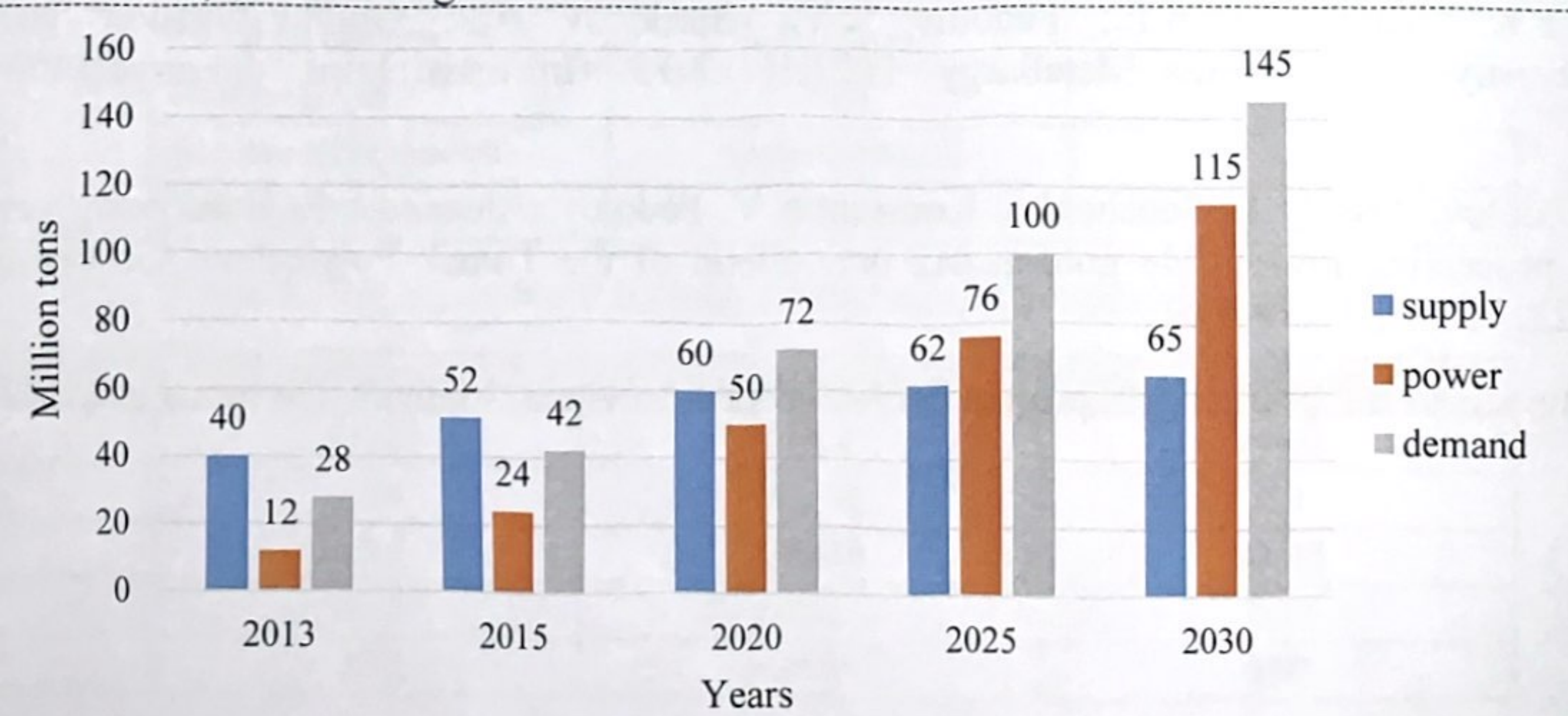

Figure 9. The predicted supply and demand of coal until 2030.

Vietnam is one of the most important producers of anthracite. Currency available data show that the coal reserves in Vietnam are about 49.8 billion tons. Coals reserve are classified into a few categories (according to the Vietnam standard): measured and indicated reserves (categories A, B, and C_1) is 33 %, inferred 39 %, and prognostic resource (B) is 28 %. Vietnam has almost types of coal such as anthracite (already mined), bituminous, sub-bituminous coal, lignite coal, and peat coal. Coal is located along Vietnam such as Quangninh, Red River Delta, Mekong River Delta, etc. (Figure 10).

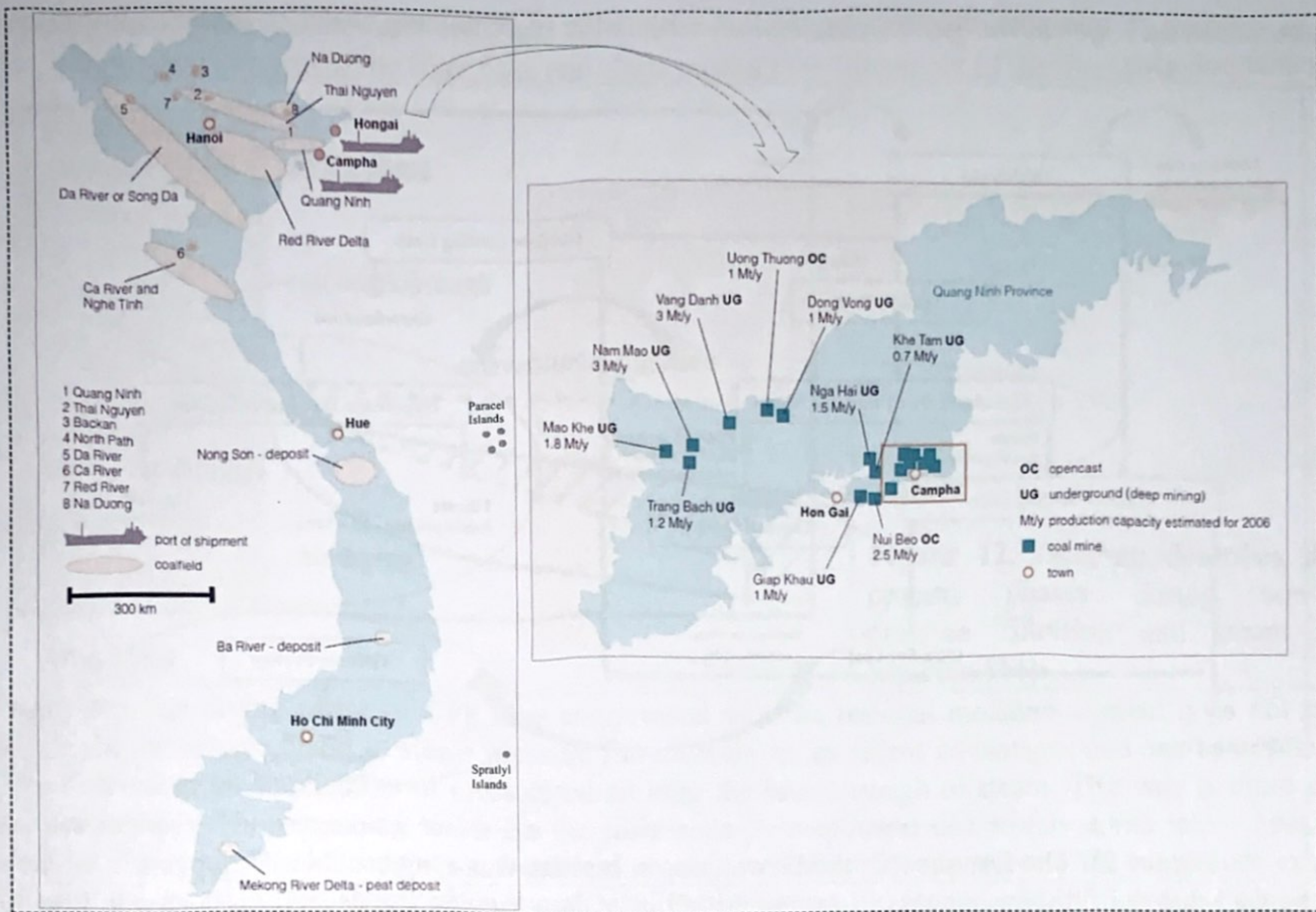

Figure 10. The distribution of coal reserves in Vietnam and Quangninh province [2] [3] [4] [5].

The most important coal basin in Viet Nam is Quang Ninh. Quang Ninh is in the northeast part of the country with an area of about 5900 km^2. Coalfields are located near the coast, so it is convenient for transportation. Coal has been exploited from 1839 to today. Figure 10 shows the main coal deposit in the Quang Ninh basin. Otherwise, the major coal mines around Campha, where supply run-of-mine coal (ROM coal) for the Cua-Ong Coal Washing Plant.

Cua-Ong Coal Washing Plant (CCWP) is operated by Vietnam National Coal-Mineral Industries Holding Corporation Limited and is located in the Quang Ninh coal basin of north-earthen Vietnam. The plant began its operation in 1924 by French and washing anthracite coal to produce coal with different size ranges and ash content. After washing by Jigging, Dense Medium Cyclone, coal is separated into various sizes such as 0.5-6 mm; 6-15 mm; 15-35 mm; 35-50 mm; and 50-100 mm. A large amount of fine coal, below 0.5 mm fine coal is dewatering by thickening before going to filtration by high-pressure filters. In the Vietnam coal industry, coal is usually prepared before consumption. There are two stages of preparation. The first one is that two implement the ROM coal pre-treatment system by hand-sorting, screening, grinding and blending. In the second stage, coal is upgraded in the preparation plant. In Quang Ninh, there are three big plants, including the Cua Ong coal-washing plant, the Nam Cau Trang coal-washing plant and the Vang Danh coal-washing plant. The former is the greatest plant, with more than 10 million tons per year. The Cua Ong plants include two modules (factory 1 and 2) with many methods for enrichment like Jigs, spiral separators, cyclones, dense medium separators. The products are diverse in types and quality such as clean coal below 6mm, 6-15 mm; 15-35 mm; 35–50 mm with an ash content of 5–6 %, moisture content of 6 %. For fines coal products, the ash content can reach 8-45 %, the moisture content is from 8 to 11.5 %. The quality of coal is achieved by separation technologies in factories 1 and 2. The residual moisture content of coarse coal products can be reduced easily by the screen. Fine coal from two factories is collected to the Dewatering sub-plant. The flowsheet for this factory is shown in Figure 11. The Dewatering sub-plant (also called the Environment sub-plant) was built by the Chinese in 2010. The annual capacity is up to 1 million tons per year with the designed residual moisture content of products 20-22 % after filtration and continuing to reduce to 10 % after thermal drying. The plant has three hyperbaric filters of 90 tons/hour, three air compressors of 2.52 m^3/minute, nine air compressors of 40 m^3/minute, three disk feeders with conveyor belts, and other transportation equipment. Before coming to the dewatering stage, below 1 mm fine coal is pumped to thickener with flocculant aid. A significant amount of water is separated. The remaining water with fine coal is pumped to the filter. After filtration, fine coal is transported to the thermal rotary drum dryer. The residual moisture content of fine coal is expected, to reduce to 10 %. However, the actual production shows the residual moisture content after filtration and drying is 25 and 15 %, respectively. This issue affects the quality of products, is difficult to transport, increases production costs (due to remaining water in products not reused), and environmental pollution.

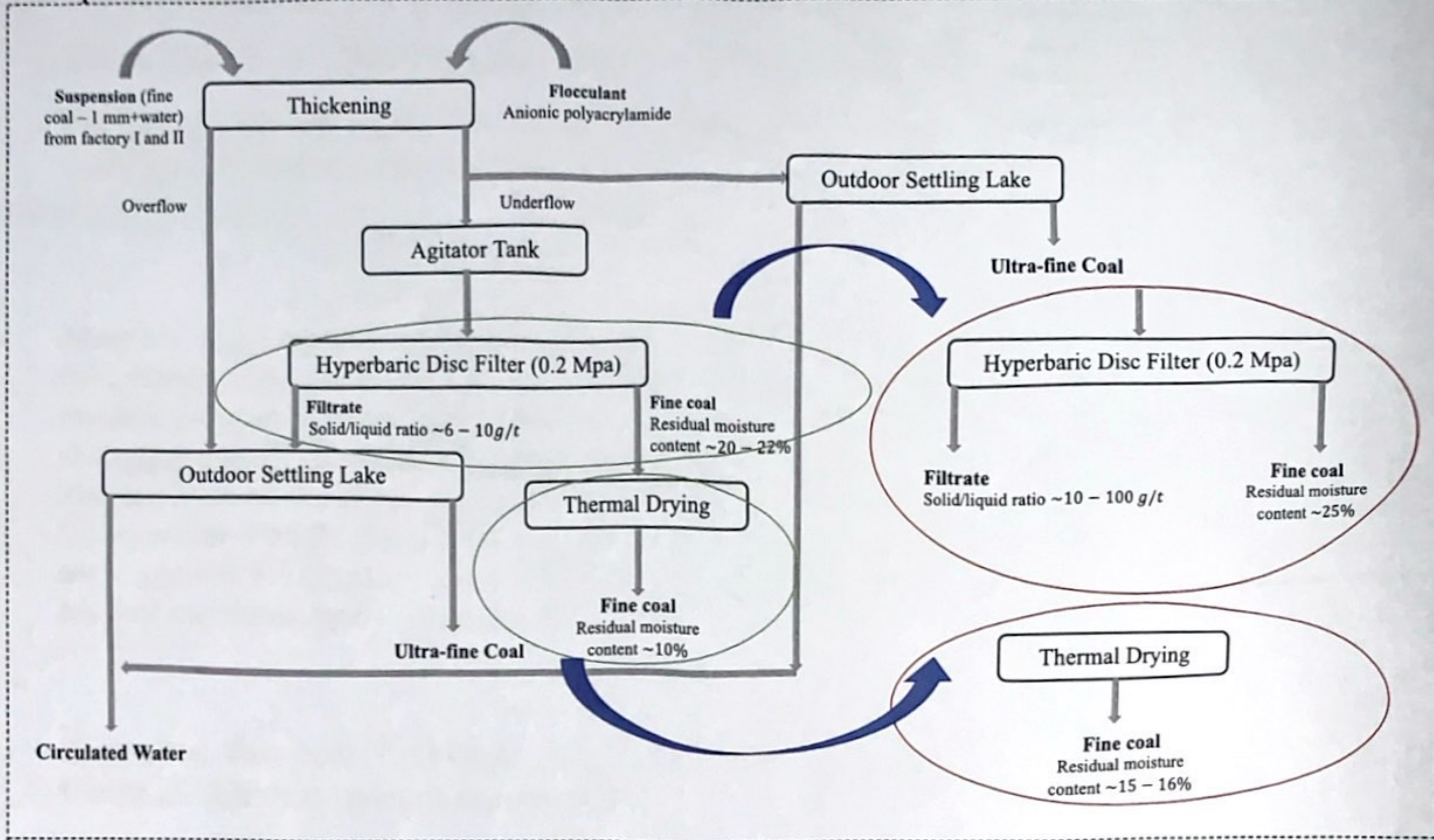

Figure 11. The flowsheet of the Dewatering sub-plant, Cua-Ong coal Washing plant.

It can be said that the filtration process is currently inefficient in achieving the desired product with low moisture of the coal that makes it suitable for mixing with other good quality coal before sending it to power stations, other domestic consumers and export or storage. The residual moisture content of dewatered fine coals is still higher (20-22 %) in some periods up to 25 %, which makes them too difficult to mix with other coals. Otherwise, water in filter cake cannot be recycled and reused, leading to higher overall production costs, higher transport costs, and reduced product value. From the above production situations, this type of coal is selected as the primary research material.

The most popular technology to filter coal is vacuum filtration and pressure filtration. While vacuum filtration shows unreasonable and outdated technology, high-pressure filtration gets some trouble with fine and ultra-fine coal contaminated by clay. This issue leads to the inefficiency of dewatering by filtration. Nowadays, steam pressure filtration is known as the new countermeasure in order to reduce the water remaining in fine coal slurry and improve the dewatering efficiency. This article shows the test results on the lab-scale conventional pressure filtration and steam pressure filtration in specific types of coal. The research work does not only contribute the academic values but also solves current problems based on the technology site.

2. Basic principles

The filtration process can be divided into three main phases: cake formation, mechanical displacement, and drying [6].

For the first steps, the slurry is fed and distributed over the filter cloth. The pressure gradient for filtration is applied. These forces are compressed air, vacuum or even gravity as well as centrifugal pressure. Filtrate begins to pass through the filter medium and the filter cake starts to grow. At this period, the resistance of the system increases gradually. The cake formation phase finishes when the pores of the filter cake are filled with mother liquid but no more water is on the surface of the filter cake. When the cake is exposed directly to driving de-watering forces, the water is pushed out of the pores of the filter cake. The difference between conventional pressure filtration and steam pressure filtration is in the mechanical displacement phase Figure 12.

For the conventional filtration, compressed air is applied and penetrates the pores. When the pressure difference between the upper side and the lower side exceeds the capillary entry pressure, the mother liquid drains. The model of capillaries describes the mechanical displacement of a liquid out of a porous system. The displacement in pores with different sizes has different velocities. The larger the pore, the faster the flow becomes. The air breaks through in the gas flow in the largest pore resulting in higher gas consumption. The mechanical displacement in smaller pores is decelerated after the breakthrough of air. This phase also finishes when the airflow through the filter cake and the system achieves a dynamic equilibrium. For steam pressure filtration, steam pressure is applied and first comes in contact with the cold surface of the filter cake. Superheated [7] or saturated steam is used in order to replace the air pressure in conventional pressure filtration [8] [9] [10] [11], as also mentioned in the research of Esser and Peuker [12] [13]. No air is permitted in this system because air can not condense. Condensation of steam creates a displacement front [14] [15]. Steam intrudes the filter cake and condenses continuously during advancing. The displacement front moves down through the system of the filter cake and starts pushing the filtrate out of the filter cake.

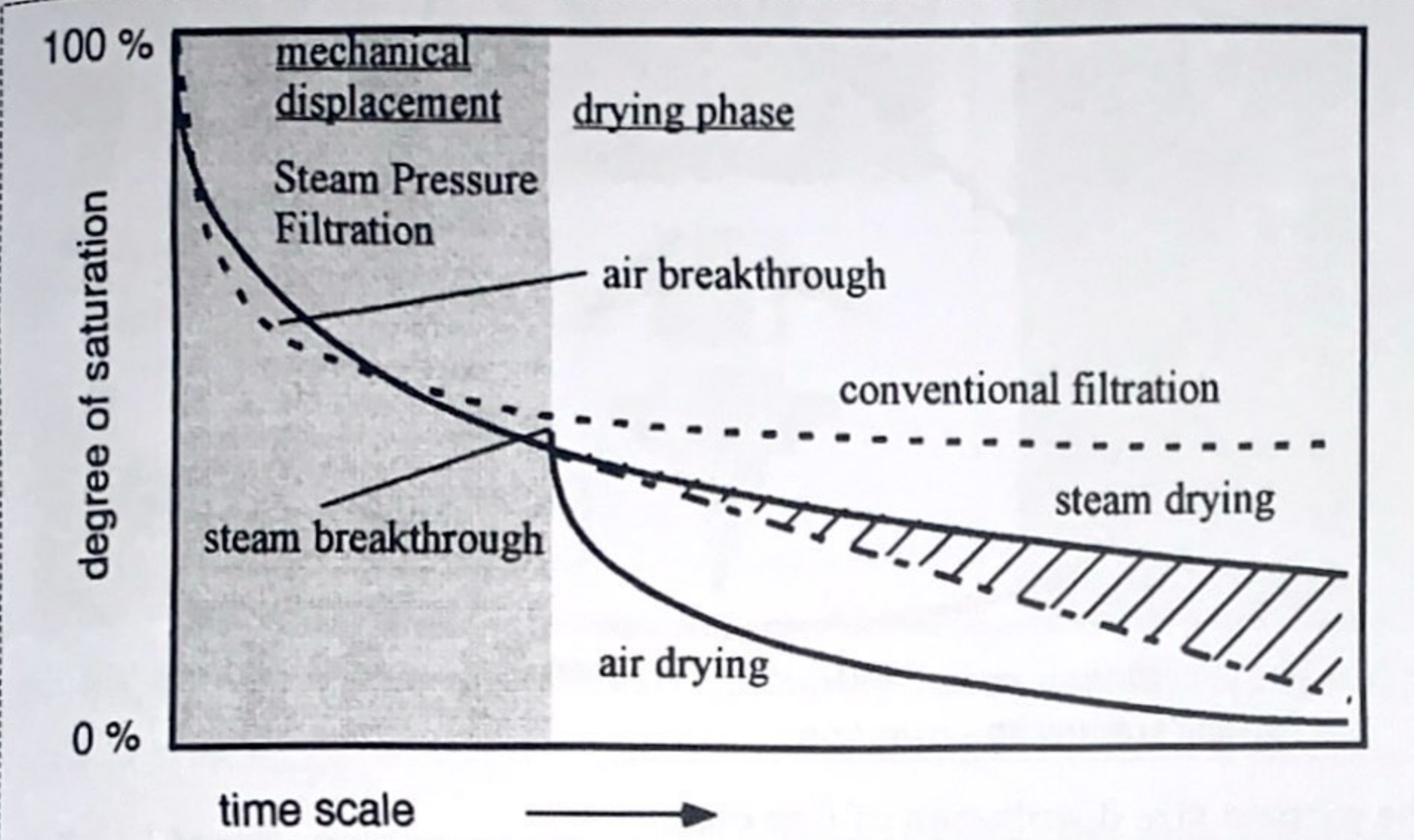

Figure 12. Diagram describes the main process phases during conventional pressure filtration and steam pressure filtration [14].

The next step, the drying phase of CPF uses compressed air. The residual moisture content does not reduce as much. While the successive phase in steam pressure filtration shows excellent advantages and can be applied in two ways. The first one is the application of pressurized air after the breakthrough of steam. This way is more effective, rapid and economical. The remaining water on the filter cake is evaporated due to the stored latent heat. The air treatment after the steam breakthrough is the optimal process to reduce the moisture to the maximum extent. The second way is the maintain the saturated or superheated steam during the second and third process phases. Steam pressure filtration should be operated in this way in case of washing and extraction of the volatile component in the filter cake and the residual moisture content [12] [13] [14].

3. Samples and research methodology

3.1. Coal sample

The test material is anthracite coal which is sampled from the Cua Ong Coal Washing plant. This material is collected from feed suspension before thickening and drying afterward. Suspension for all tests laboratory is coal powder and distilled water to re-slurry. Types of coal are insoluble in the water at all temperatures. Anthracite is not explosive; the amount of sulfur (S) content and the amount of volatile matter are small. The burning temperature is 350-400 °C. In the outdoor temperature, under the sunlight, coal can not burn on its own. The amount of clay in fine coal is small, around 0.5-1 %. The density of coal is typically around 1400-1550 kg/m^3. This value can be changed to 1250 kg/m^3 and 1200 kg/m^3 in the moisture content of 20 and 40-50 %, respectively. The coal sample used for research is low-quality coal with an ash content of around 35 %, and the measured density (dry state) is 1497 kg/m^3. The measured density in the laboratory is used for all calculations in this research. The particle size distribution of coal powder is measured by laser diffraction, which is shown in Table 3 and Figure 13.

Table 3. Coal particles properties.

x_{10} in µm	x_{16} in µm	x_{50} in µm	x_{80} in µm	x_{90} in µm	x_{97} in µm
2.03	2.94	11.78	62.85	119.84	210.52

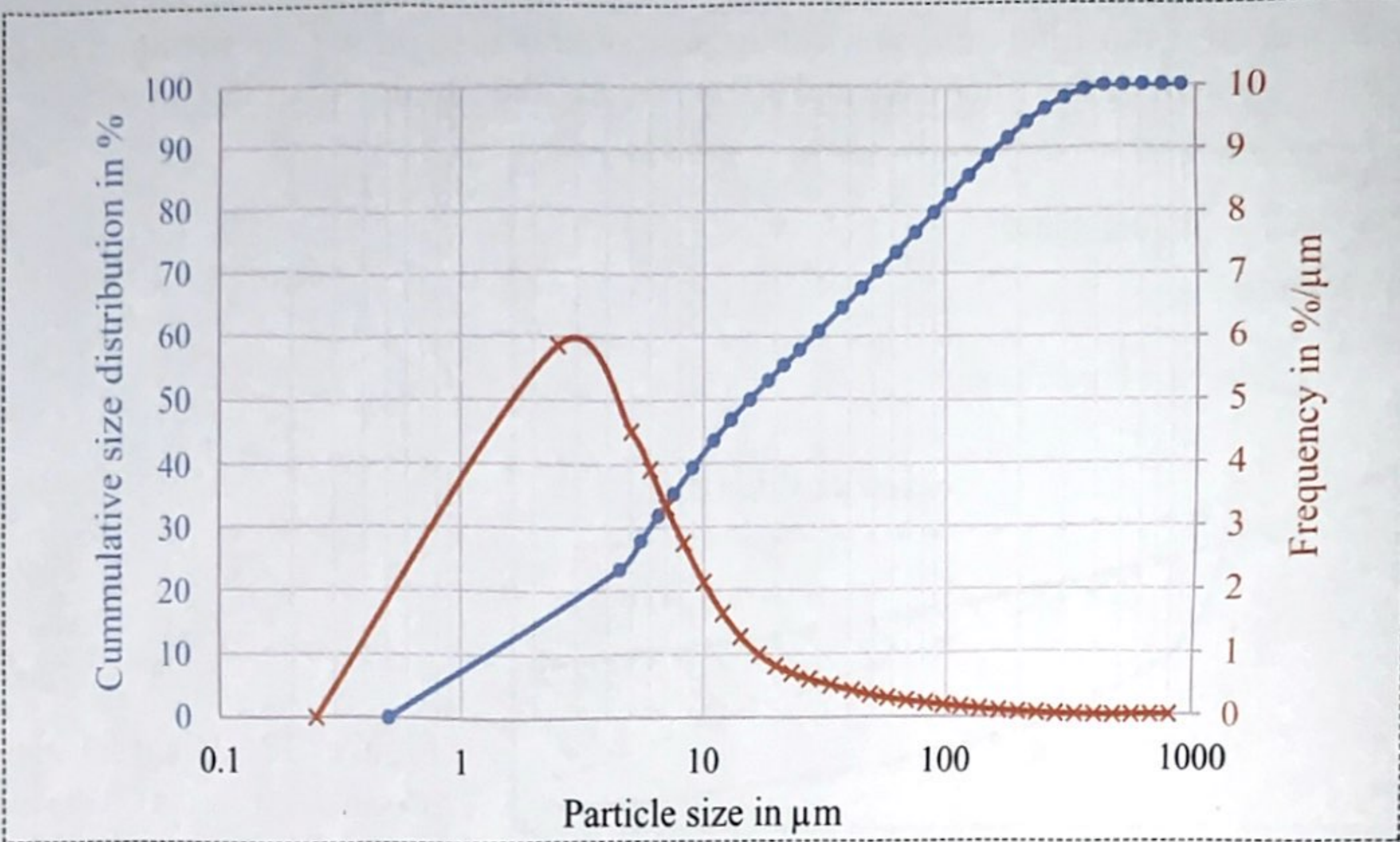

Figure 13. The particle size distribution of fine coal.

The median particle size $x_{50,3}$ is 11.78 µm, The particle size distribution of materials has a span $(x_{90}-x_{10})/x_{50}$ of 1 The coal sample shows a broader distribution. The below 10 µm particle size accounts for 45 % and 90 % of particle are below 0.125 mm. This amount of very fine particles in coal samples is significant. This issue may be the ma reason for poor dewatering, as can be shown next part.

By the SEM technique, the images for the irregular shape of big coal particles and the flake shape of fine and ultra fine particles are also shown in Figure 14.

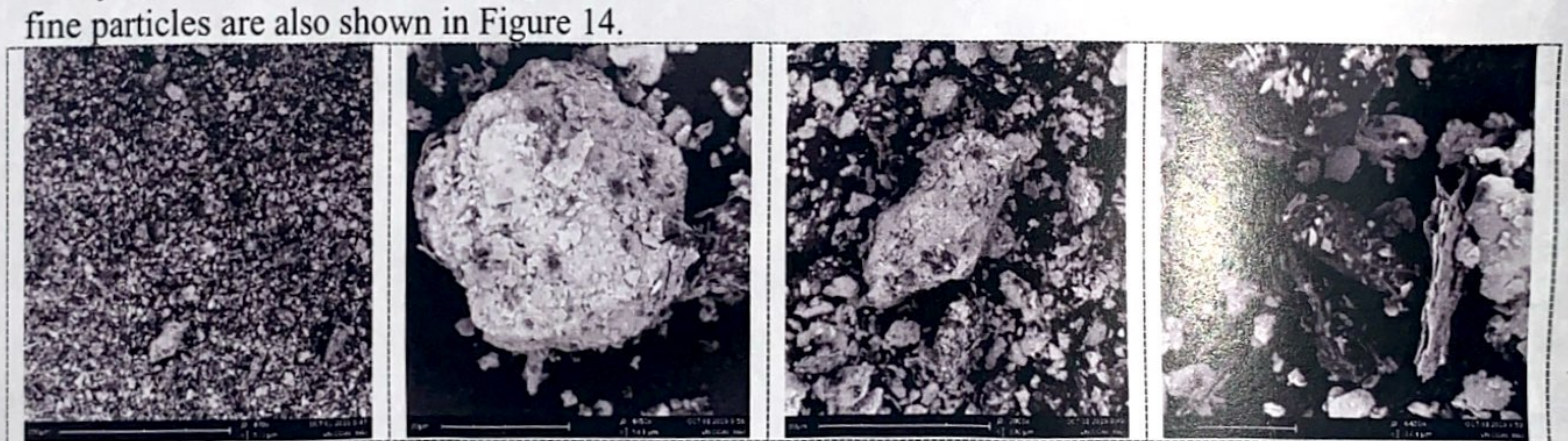

Figure 14. SEM images for coal particles.

3.2. Method

3.2.1. Conventional filtration rig. The filtration rig is built according to VDI 2762-2 [16]. Gas-driven filtration experiments were conducted in a stainless steel pressure filter Nutsche with an area of 19.64 cm^2, as shown in Figure 15 (on the left side). The filter medium has support from a perforated medium sheet with a large open cross-section area. There is a cake formation unit connected Nutsche long tube and filter medium support unit. By disassembling this unit, the filter cake can be removed easily. Otherwise, the device possesses a quick connection for the lid and is equipped with a valve to regulate the pressure and a pressure gauge. The lid has a sight glass to look inside and attached light. The quantity of filtrate is measured by using a scale connected to a computer [16].

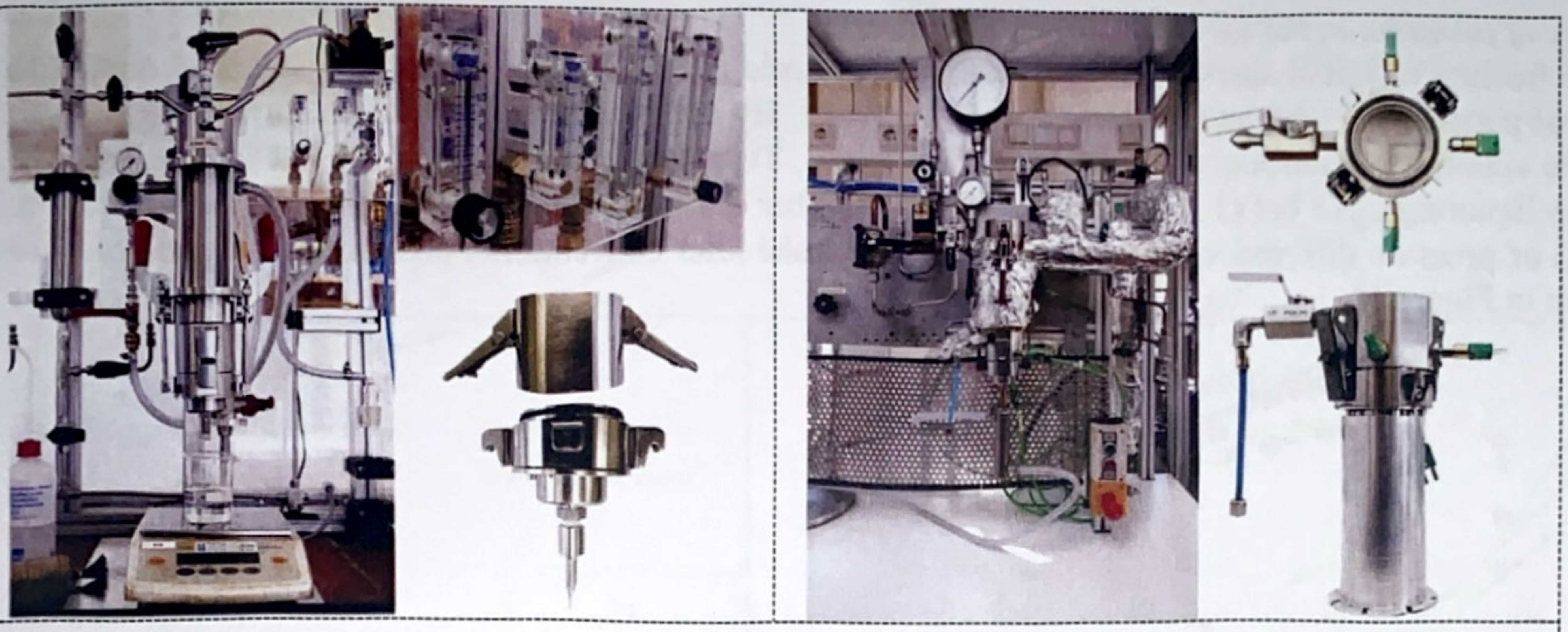

Figure 15. Images for the Conventional filtration apparatus [16] and Steam pressure filtration apparatus [12, 13].

3.2.2. Steam pressure filtration. The steam pressure filtration rig (Figure 15 - the right image) was built based on the standard Nutsche with the same length tube and cake formation unit, which has been described above [15]. The different things are the compressed air and compressed saturated steam from the steam source to supply to Nutsche. The steam is provided by the evaporator. This steam and the entrained water from the evaporator are separated. The steam can be a little superheated if the temperature of the pipes is higher than the steam temperature. The tube, the cake formation unit and all pipes are covered by Styrofoam to avoid heat transfer into the ambient environment. Nutsche and cake formation unit are heated by an oil heater to approximately 160 °C. There is a thermocouple that is installed to control and maintain the temperature stable. Four thermocouples are remaining in the cake formation unit, which is built to measure each layer temperature profile of filter cake during filtration. The thermocouple contact with the cake formation unit to measure the filter medium's temperature and filtrate's temperature [12].

3.3. Test procedure

The preparation of the feed suspensions was conducted as follows: solid is dispersed in the amount of distilled water at room temperature (approximately 20 °C) and is stirred until well mixed. The amount of water depends on the mass of the solid and the amount of solid volume fraction for tests. After that, the slurry is poured into the Nutsche, and the top cover is closed. The compressed air is applied. The filtrate flows through and particles also are built on filter cloth (SK 006). This step will be finished when the saturation of the filter cake reaches 1. It is observed through the light glass until no water surface on the filter cake. As soon as the saturation reaches 1, the air is vented. The filtrate mass was recorded by the electronic scale during filtration. The collected filtrate is recorded by Diadem software. This result is used to calculate specific resistance cake [16]. The second stage is the mechanical displacement phase. Depending on the kind of filtration, the compressed air or the saturated steam is applied.

For conventional pressure filtration, compressed air, which is regulated by a valve and pressure gauge, is applied to push water flow out from pores. The test is ended when there is no water flow through the filter cake (the end of the mechanical displacement phase).

For steam pressure filtration, the steam outlet and magnetite valve are opened to allow the steam entering the Nutsche. After the instant time (1 or 2 seconds), the steam outlet is closed, and steam starts to displace water from the pores. Tests were conducted until the steam broke through the filter cake, which was observed as well as by the temperature of the filter cloth thermocouple. The steam flux is stopped by closing the magnetic valve. Afterward, the residual moisture content of the filter cake was measured.

The filter cake then is quickly removed from the cake formation unit to dry. The filter cake is dried at 50 °C (± 5 °C) until the constant weight. The amount of water remaining in the filter cake is also expressed by the residual moisture content in mass % (which is denoted M). This parameter is defined as:

$$M = \frac{the\ mass\ of\ wet\ filter\ cake - the\ mass\ of\ dry\ filter\ cake}{the\ mass\ of\ wet\ filter\ cake} \cdot 100\% \qquad (1)$$

Based on the mechanical of two kinds of filtration, it is unnecessary to survey the drying phase deeply because the dewatering efficiency in the mechanical displacement phase would be a precursor to reducing the moisture further in the successive phases. The result just only focuses on the efficiency of the mechanical mechanism of filtration.

4. Result and discussion

4.1. The efficiency of filtration in the variety of volume fraction

The solid volume fraction of initial suspension plays an important role in the efficiency of dewatering. It is relate the stratification of particles as well as the structure of filter cake. By the change of the mass of liquid in fixe grams of coal, the volume fraction has changed from 0.05 to 0.4. Tests were conducted in 1-1 bar (1 bar for formation, 1 bar deliquoring), 1-3 bar (1 bar for cake formation, 3 bar deliquoring), 3-3 bar (3 bar for cake forma 3 bar deliquoring) of pressure difference. The result of the filter cake after conventional pressure and steam pres filtering are shown in Figure 16.

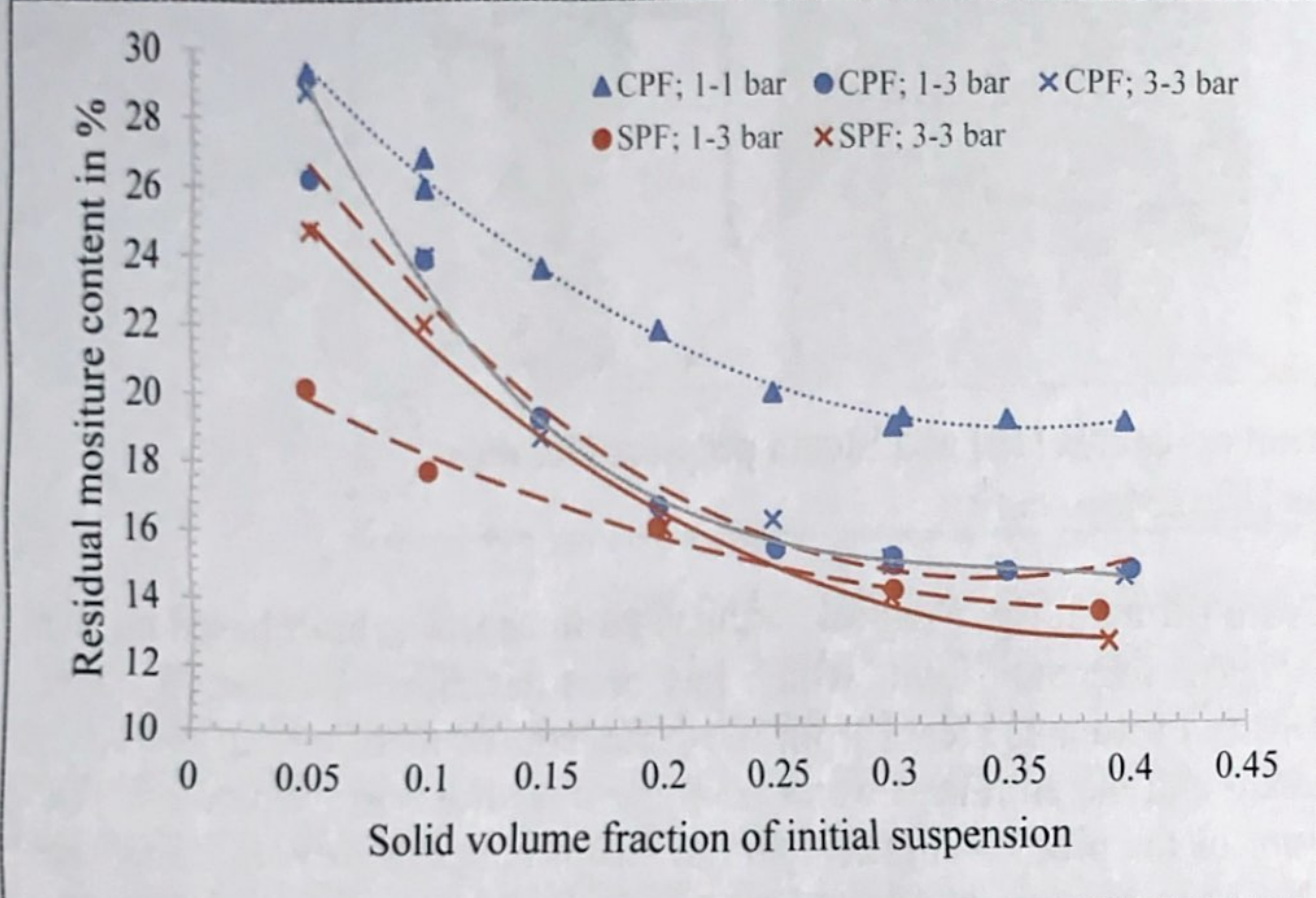

Figure 16. The residual of filter cake using SPF and CPF in variety of solid volume fraction; the mass of coal: 30 grams.

It can be seen by increasing the volume fraction, the residual moisture content reduces. Normally, when the so volume fraction of feed suspension increases, the filter cake becomes more homogeneous. The uniformity of the s of capillaries inside the structure of the filter cake led to the water flowing simultaneously out from every positi The result is using the SPF is more efficient compared to CPF. The result also shows a little lower value of resid moisture content when using steam pressure filtration in comparison using conventional pressure filtration. This lo value is caused by the mechanism of steam pressure filtration. While the water prefers pushing out of the filter ca from the large pores (also from large capillaries) when using CPF, the mother liquid in both large and small capillar flows easily without any obstacle as well as the negative effect of the finger ring phenomenon when using SPF.

It can be said that when the solid volume concentration of the slurry in the filter reaches 30-40 %, the moistu content of the filter cake does not change with values ranging from 14-16 % (for both CPF and SPF). A differe result is when the tests are conducted with a pressure difference (1-1 bar using CPF). Moisture values are around 2 30 %. This issue can be explained in terms of the capillary entry pressure theory. The requirement pressure f mechanical displacement must be higher than the capillary entry pressure (which has the magnitude depending on th structure of the filter cake, particle size, particle size distribution, and characterization of solid and liquid). It can b concluded that for the coal in the Cua-Ong area, the optimal sludge concentration should be in the range of 30-40 with the pressure difference should be as large as 1 bar.

4.2. The efficiency of filtration in the variety of filter cake height

The second test is the effect of filter cake height on the amount of water remaining. This parameter is essential fo scale-up and is directly related to the filter equipment's performance. Choosing the right filter cake height has technical meaning and brings higher economic efficiency and higher productivity. The amount of solid chang depends on the various heights of the filter cake. The pressure difference is similar to the above tests. The volum fraction of the initial suspension is fixed to survey the effect of the height of the filter cake on crack formatio Because of the limitation of the filtration rig, the filter cake's maximal height is 25 mm. The result is shown in Figur 17.

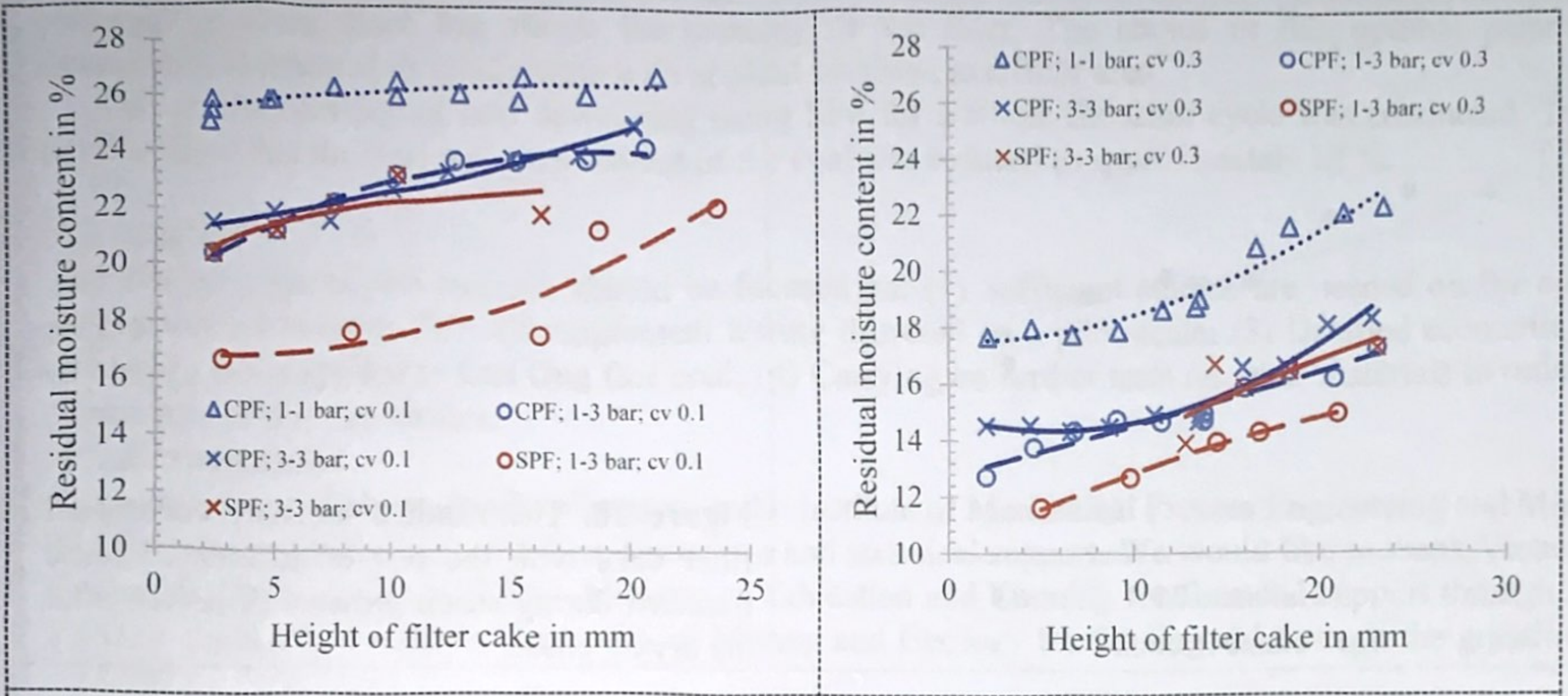

Figure 17. The residual moisture content of filter cake using CPF and SPF in variety of filter cake height; volume fraction of 0.1 and 0.3

In general, the effect of filter cake height on deliquoring efficiency is not clear. Looking at Figure 17, it can be seen that, when the filter cake increases from 3 to 22 mm, the moisture content increase is about a maximal 2 % of the value (in some specific tests, the residual moisture contents are unchanged). The reason for this stability is that the filter cake thickness does not affect the capillary entry pressure. Although the operational parameter height of the filter cake has less affected the dewatering efficiency, the filtration equipment capacity is greatly affected. The reason is that the filter cake will need a longer time in the equipment for the mother liquid inside the filter cake to have enough time to flow out. Therefore, in order to choose the optimal parameters in this case, it is necessary to take into account the relationship between filter cake height, filter pressure and filter area.

One thing that can be noticed is that in the same survey condition, the result using SPF always has a value of about 4 % less moisture content than the result using CPF. This consequence demonstrates the advantageous technical aspect of SPF in dewatering the second phase of filtration and furthermore.

4.3. Test for steam pressure filtration including drying phase

The purpose of these tests show the outstanding efficiency in dewatering using SPF. By applying steam pressure filtration on the mechanical displacement phase, the water in both small and large pores is pushed out. Much water is removed, and the residual moisture content is smaller. Moreover, during the deliquoring phase, the filter cake as well as the mother liquor remaining is heated due to the heat convection and conduction of condensate water. When air pressure is applied leads to evaporation, resulting in further moisture loss. The result can be seen in Figure 18 and Figure 19. These tests were conducted in 3-3-3 bar of pressure differences, 150 seconds of drying time. For the tests of the effect of solid volume fraction: the mass of the solid is 30 grams (equivalent to approximately 15 mm of filter cake height); the solid volume fraction changes from 0.05 to 0.4. For the tests of the filter cake height effect, the solid volume fraction of suspension is fixed at 0.1 and 0.3. The change filter cake height is modified by the mass of coal in suspension. Most tests are conducted on the same equipment with the same area of 19.64 cm^2.

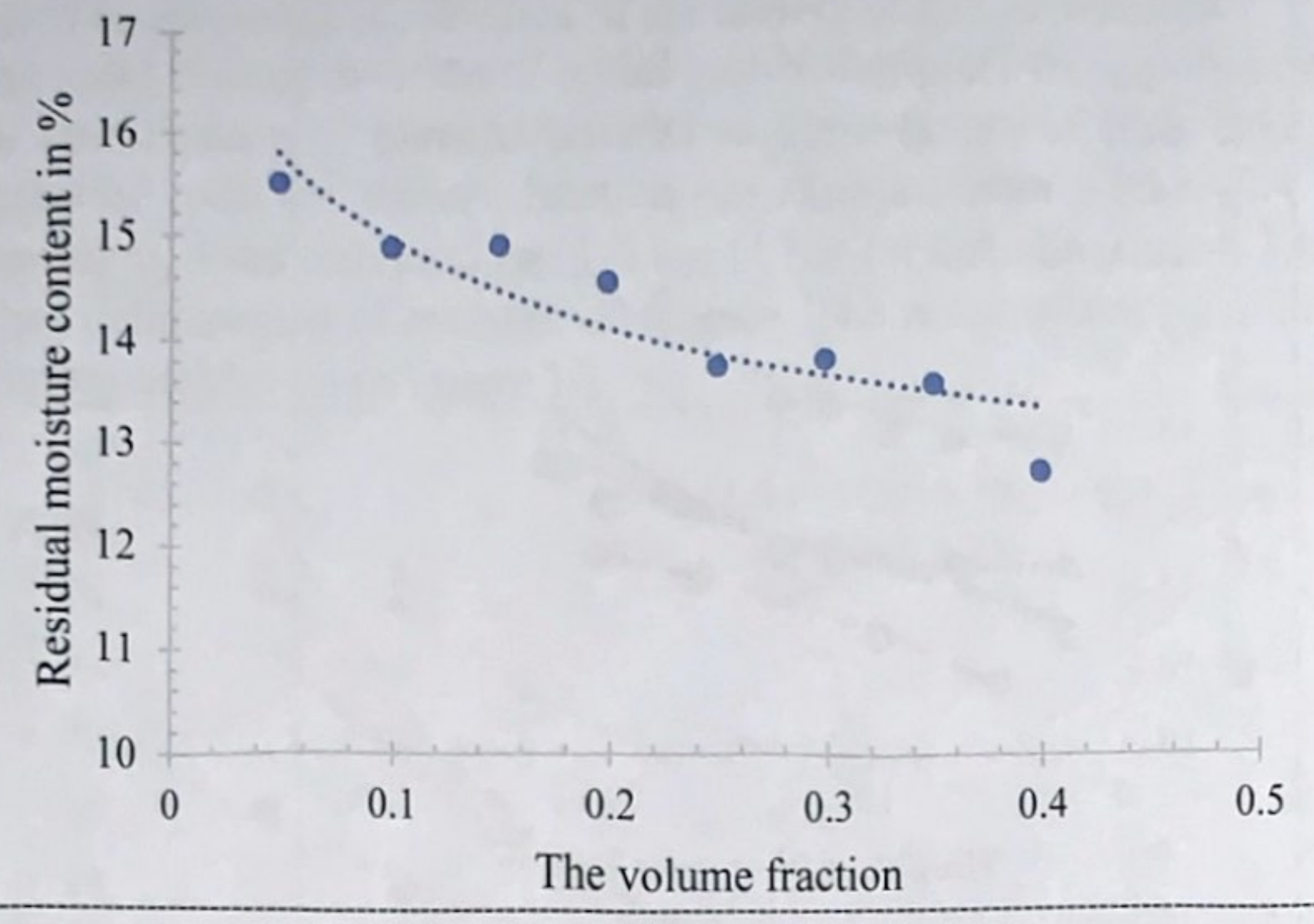

Figure 18. The residual moisture content filter cake with the test of different volu fractions during steam pressure filtration, af the drying phase.

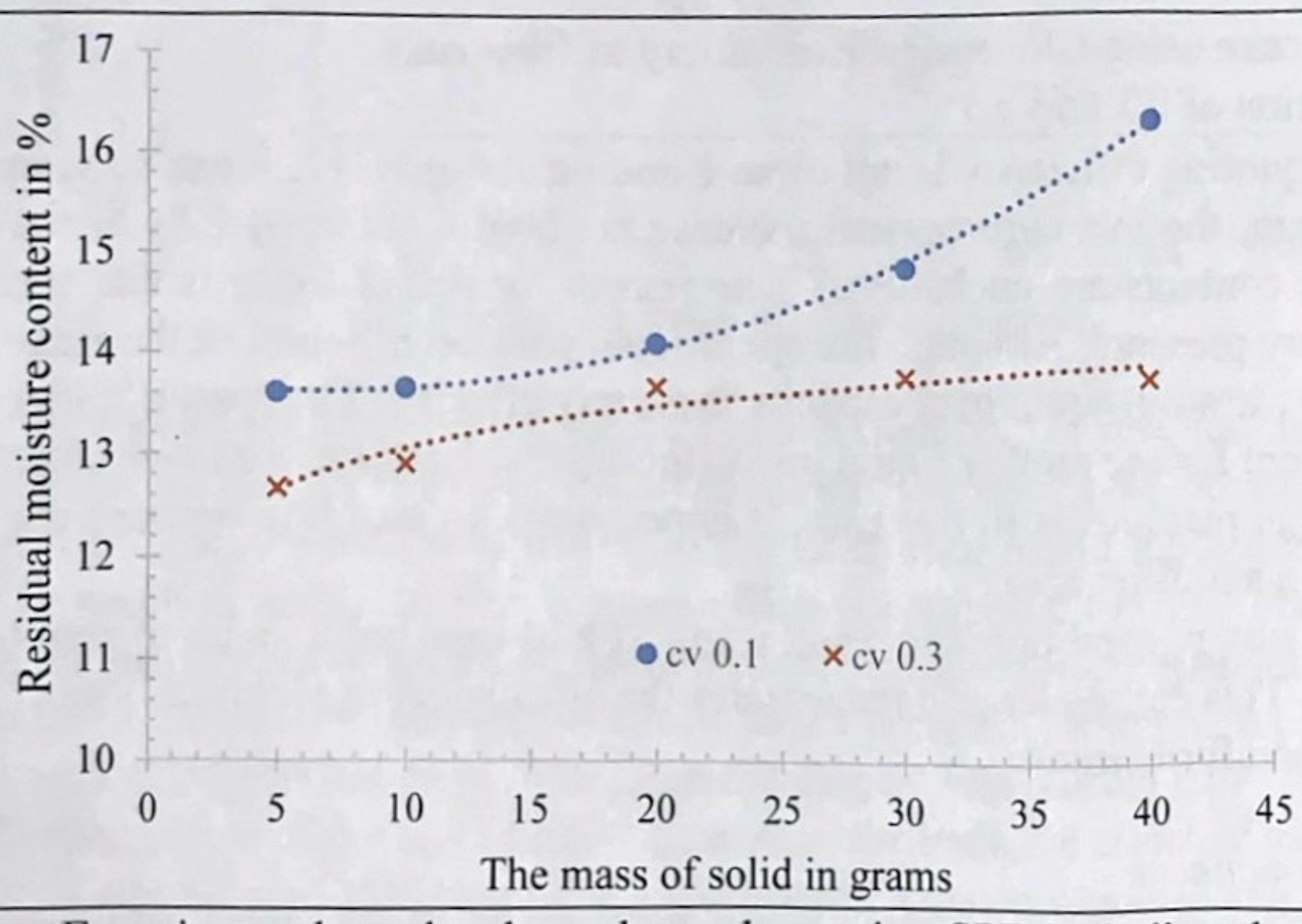

Figure 19. The residual moisture content with the test of different filter cake heights during steam pressure filtration, after the drying phase

Experimental results show that, when using SPF including the 3rd phase of filtration (drying phase), the resid moisture content of the material is significantly reduced. For the 15 mm filter cake and the 40% solid volu concentration, the moisture content of the filter cake is reduced to approximately 12 %. For the survey cases changing filter cake thickness and slurry concentrations of 10 and 30 %, the final material moisture content fluctuat between 12-16 %. Those results show superior efficiency in comparison to the CPF result (the practical values a about 22-25 % moisture content).

However, it is also necessary to recognize that the experimental results in this section are only at the prelimina assessment level. It is necessary to have a deep study of the drying time and drying pressure to select the optim parameters. In addition, the performance comparisons mentioned above should be carried out at the same sca (laboratory scale). Another issue to remark on is the prospect of applying SPF in the dewatering of ultra-fine coal the Cua Ong area. The use of steam pressure filters has technical advantages, but it may not be economically viabl especially when applied to coal dewatering. The authors also recommend that there be more specific assessments this aspect in the future.

5. Conclusion and outlook

5.1. Conclusion

Fine coal is one of the products of the coal-washing process at the Cua Ong Coal Washing Plant. A large amount this material needs to be dewatered before being transported, stored, mixed, or used directly. The residual moistu content of coal after filtration is still high. In order to improve the process, it is necessary to have a deep understandin of filtration as well as the application of advanced technologies in production.

The Cua Ong fine coal has dominant fine and ultra-fine sizes and wide particle size distribution. They are collect at the pipes before thickening in order to avoid the presence of flocculant.

Experiments to study the influence of some technological parameters on the dewatering efficiency (filter ca height and solids volume concentration of the feed slurry) were conducted on CPF and SPF. The results show that th dewatering efficiency increases by increasing the solid volume fraction. The filter cake thickness does not affect the material moisture much but affects the capacity of the filter. The choice of this optimal parameter should be considered in terms of its relationship with applied pressure, and filter area.

The preliminary test of coal dewatering using SPF for a whole filtration cycle was conducted. The experimental results show that the final moisture content of the coal was reduced to approximately 12 %.

5.2. Outlook

The further steps of this research should be focused on: (1) Sufficient studies are needed on the optimal operating parameters when using SPF; (2) Implement testing this coal on a pilot-scale; (3) Detailed economic evaluations are necessary when applied to Cua Ong fine coal; (4) Carrying on further tests on other materials in order to confirm the superiority of this new device.

Acknowledgement

The authors would like to thank colleagues in the Institute of Mechanical Process Engineering and Mineral Processing, TU Bergakademie Freiberg, for their discussion and technical support. We would like to thank Vietnam International Education Development (VIED) – Ministry of Education and Training for financial support through the 911 Project. Further, thanks to the Hanoi University of Mining and Geology for funding aid through the grassroots project code T23-30.

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