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DEWATERING THE CUA-ONG FINE COAL (VIETNAM) USING THE ADVANCE FILTRATION TECHNOLOGY

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Abstract: *Cua-Ong coal-washing plant produces much coal for domestic demand and export. After washing, one of the products 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, and direct utilization. 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 for 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 (Le, 2011). The supply and demand of coal are predicted for 2030, as shown in Figure 1. According to the latest National Master Plan For Power Development - Vietnam Government (Power Master Plan VIII), the coal-fired power plants still account for 30,127 MW (20% of the total capacity of power plants) with the policy of urgently completing projects already adjusted Power Master Plan VII and under construction. Therefore, it can be seen that the demand for coal power is still high, and it is necessary to prepare enough of this fuel source to ensure the country's energy security.

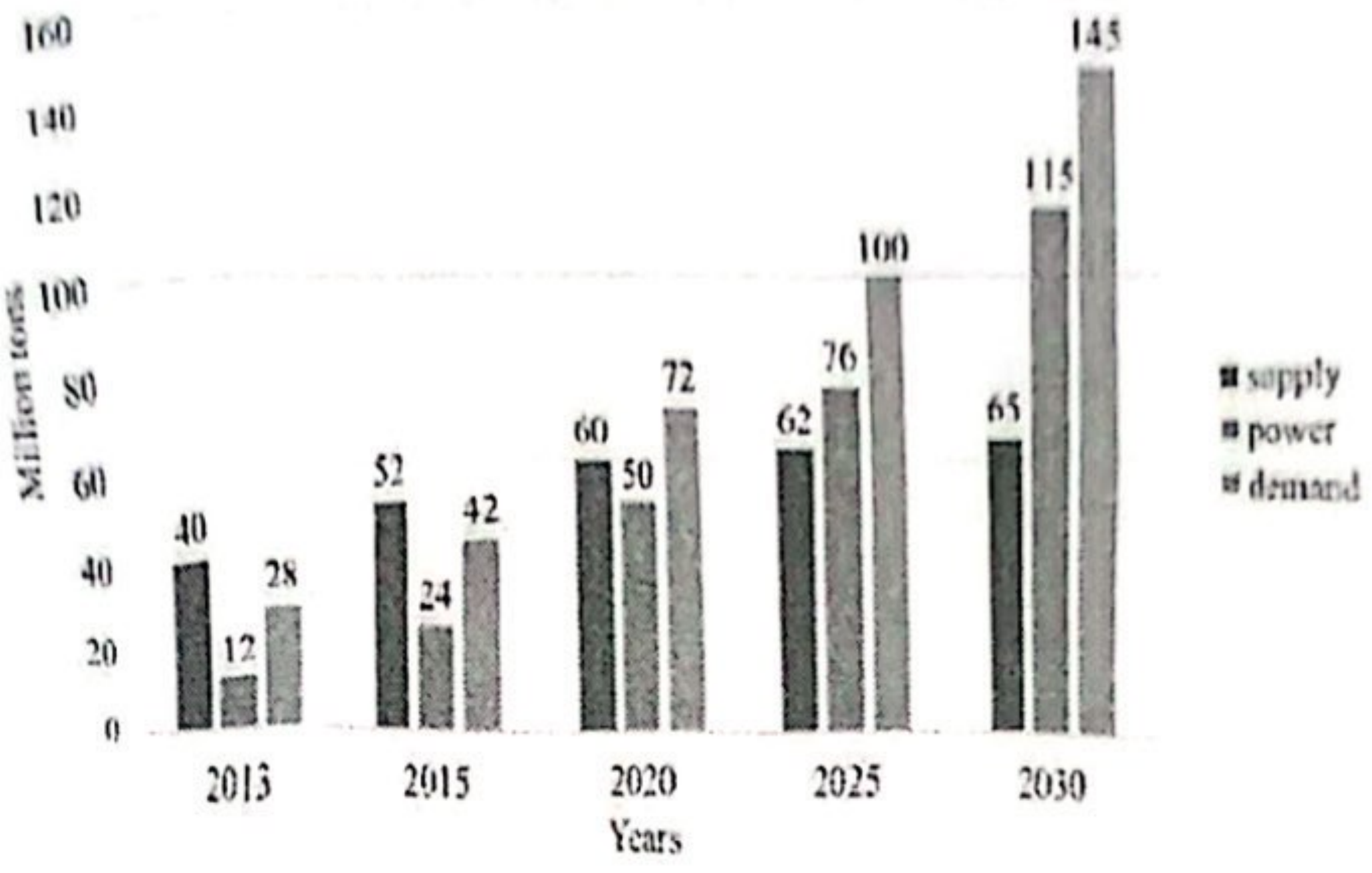

Fig 1. The predicted supply and demand of coal until 2030

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 many 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 2).

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 km². Coalfields are located near the coast, so it is convenient for transportation. Coal has been exploited from 1839 to today. Figure 2 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.

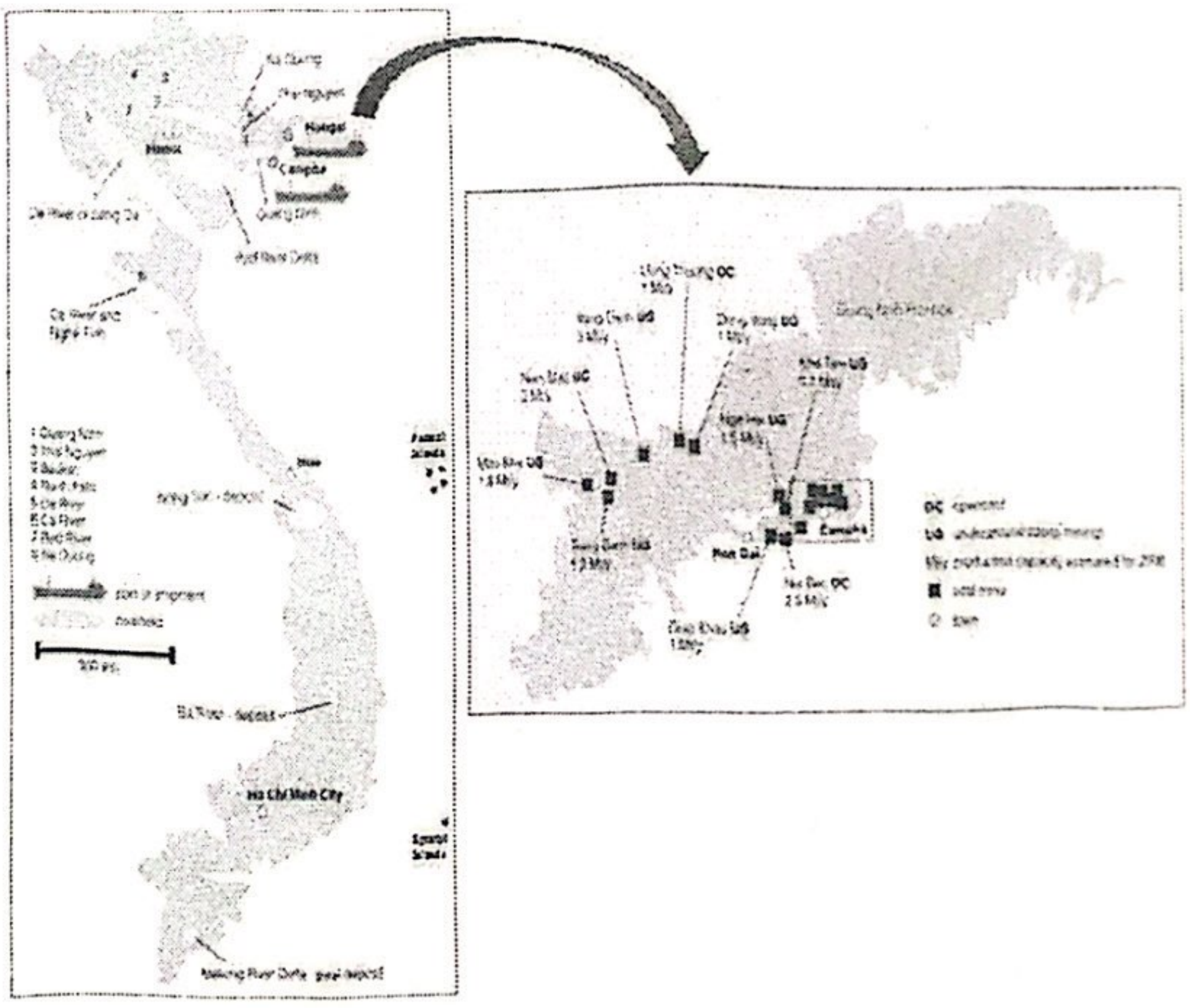

Fig 2. The distribution of coal reserves in Vietnam and Quang Ninh province (Mijal, 2018) (Baruya, 2009) (Bui & Drebenstedt, 2004) (Wolfgang Ritschel, 2007).

Cua-Ong Coal-Washing Plant (CCWP) is operated by Vietnam National Coal-Mineral Industries Holding Corporation Limited and is in northern Vietnam's Quang Ninh coal basin. The plant began operating 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 Vietnamese coal industry, coal is usually prepared before consumption. There are two stages of preparation. The first 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: the Cua Ong coal-washing plant, the Nam Cau Trang coal-washing plant, and the Vang Danh coal-washing plant. The former is the most significant plant, with more than 10 million tons annually. The CCWP includes two modules (Factory 1 and 2) with many methods for enrichment like Jigs, spiral separators, cyclones, and dense medium separators. The products are diverse in types and quality, such as clean coal below 6mm, 6-15 mm, 15-35 mm, and 35–50 mm, with an ash content of 5–6 % and moisture content of 6 %. For fine 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 screen can quickly reduce the residual moisture content of coarse coal products. Fine coal from two factories is collected and sent to the dewatering sub-plant. The flowsheet for this factory is shown in Figure 3. The Chinese built the Dewatering sub-plant (the Environment sub-plant) in 2010. The annual capacity is up to one million tons annually, with products designed with residual moisture content of 20-22% after filtration and reduced 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 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 be reduced 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 challenging to transport, increases production costs (due to remaining water in products not reused), and environmental pollution.

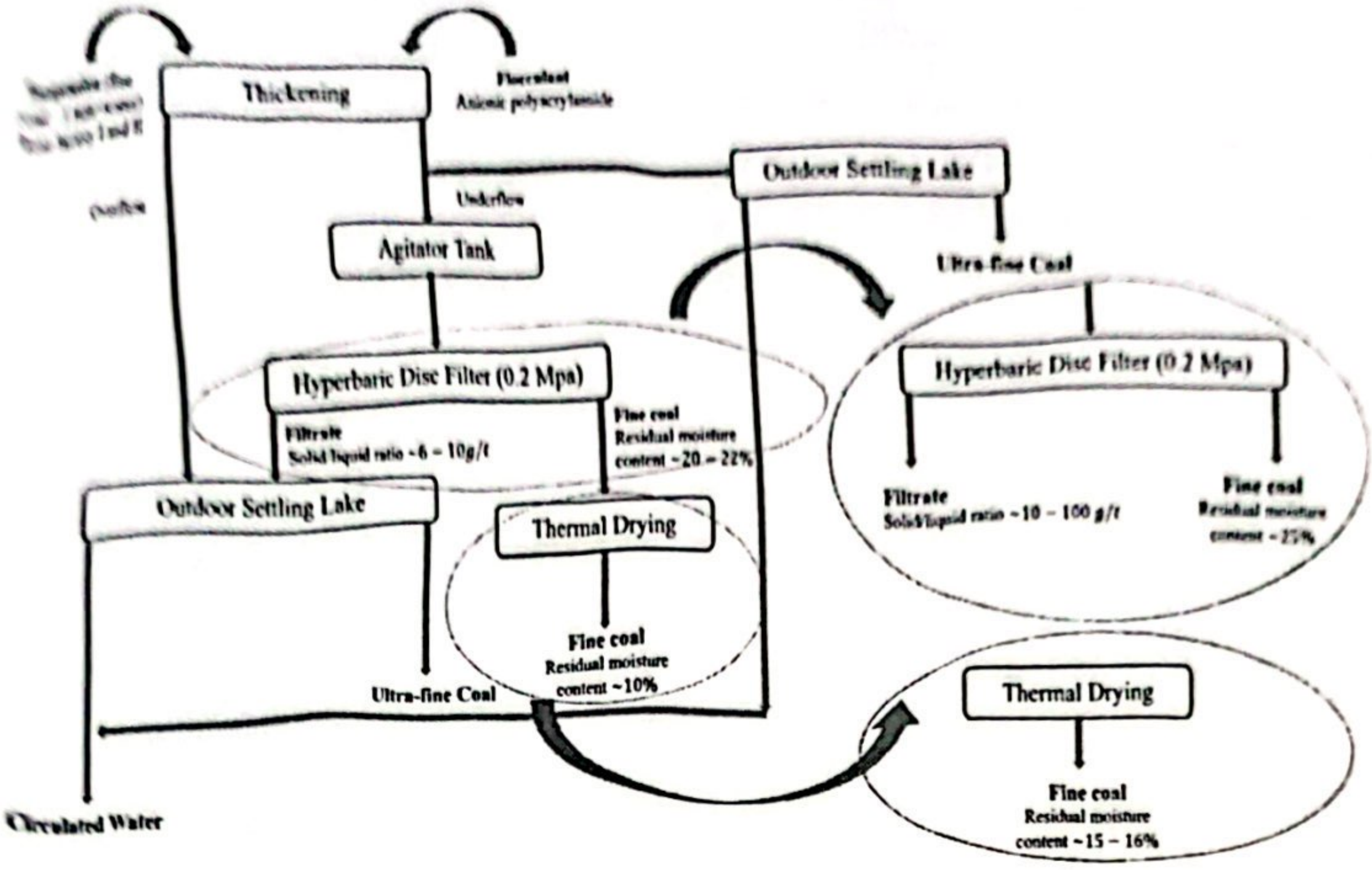

Fig 3. The flowsheet of the Dewatering sub-plant, Cua-Ong coal Washing plant.

It can be said that the filtration process is currently inefficient in achieving the desired product with low moisture of the coal, making 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, transport costs, and reduced product value. This type of coal was selected as the primary research material for the above production situations.

The most popular technology to filter coal is vacuum filtration and pressure filtration. While vacuum filtration is an unreasonable and outdated technology, high-pressure filtration causes some trouble with fine and ultra-fine coal contaminated by clay. This issue leads to the inefficiency of dewatering by filtration. Steam pressure filtration is known as the new countermeasure 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 and steam pressure filtration in specific types of coal. The research work contributes to academic values and 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. (Rushton, A.S.W., & Holdich, 2015).

The slurry is fed and distributed over the filter cloth for the first steps. 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 grows. 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 the 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 and steam pressure filtration is in the mechanical displacement phase. Figure 4.

For conventional filtration, compressed air is applied to penetrate the pores. The mother liquid drains when the pressure difference between the upper and lower sides exceeds the capillary entry pressure. 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 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 it first comes into contact with the cold surface of the filter cake. Superheated (Svarovsky, 2001) or saturated steam is used to replace the air pressure in conventional pressure filtration (Sparks, 2016) (Anlauf, 2019) (Bott & Langeloh, 1996) (Bott, Langeloh, & Meck, 2002), as also mentioned in the research of Esser and Peuker (Esser & Peuker, 2020 (a)) (Esser & Peuker, 2020 (b)). No air is permitted in this system because air can not condense. Condensation of steam creates a displacement front (Peuker & Stahl, 2001) (Gerl S. , 1997). Steam intrudes the filter cake and condenses continuously during advancing. The displacement front moves down through the filter cake system and starts pushing the filtrate out of the filter cake.

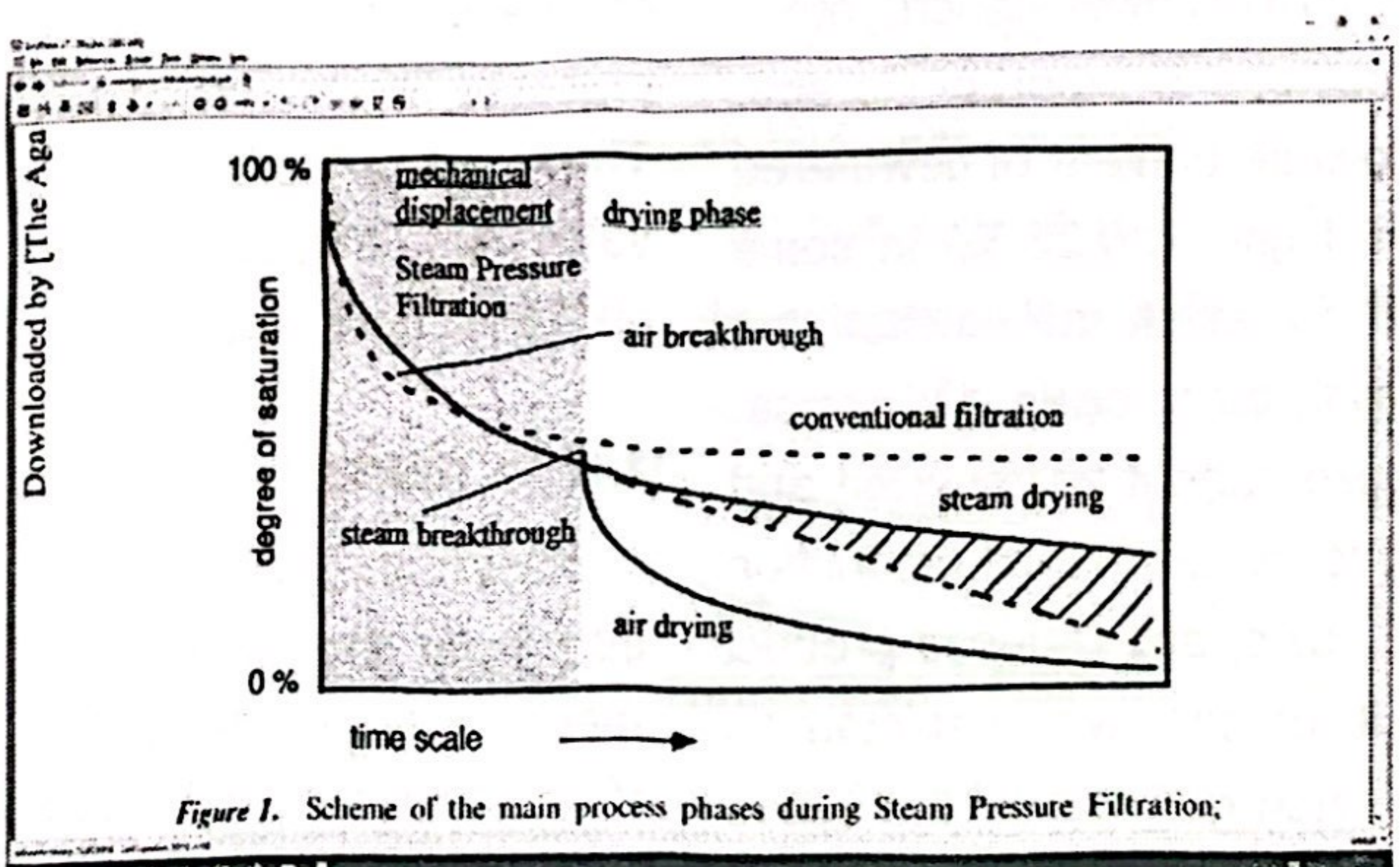

Fig 4. The diagram describes the main process phases during conventional and steam pressure filtration. (Peuker & Stahl, 2001)

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 method 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 to maintain the saturated or superheated steam during the second and third phases. Steam pressure filtration should be operated when washing and extracting the volatile component in the filter cake and the residual moisture content. (Esser & Peuker, 2020 (a)) (Esser & Peuker, 2020 (b)) (Peuker & Stahl, 2001).

3. SAMPLES AND RESEARCH METHODOLOGY

3.1. Coal sample

The test material is anthracite coal 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 volatile matter are small. The burning temperature is 350-400 °C. In the outdoor temperature, coal can not burn on its own under the sunlight. The amount of clay in fine coal is small, around 0.5-1 %. The density of coal is typically around 1400-1550 kg/m³. This value can be changed to 1250 kg/m³ and 1200 kg/m³ in the 20 and 40-50 % moisture content, 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/m³. The calculated 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 1 and Figure 5.

Table 1. Coal particles properties

Unit: µm

X_{10}	X_{16}	X_{50}	X_{80}	X_{90}	X_{97}
2.03	2.94	11.78	62.85	119.84	210.52

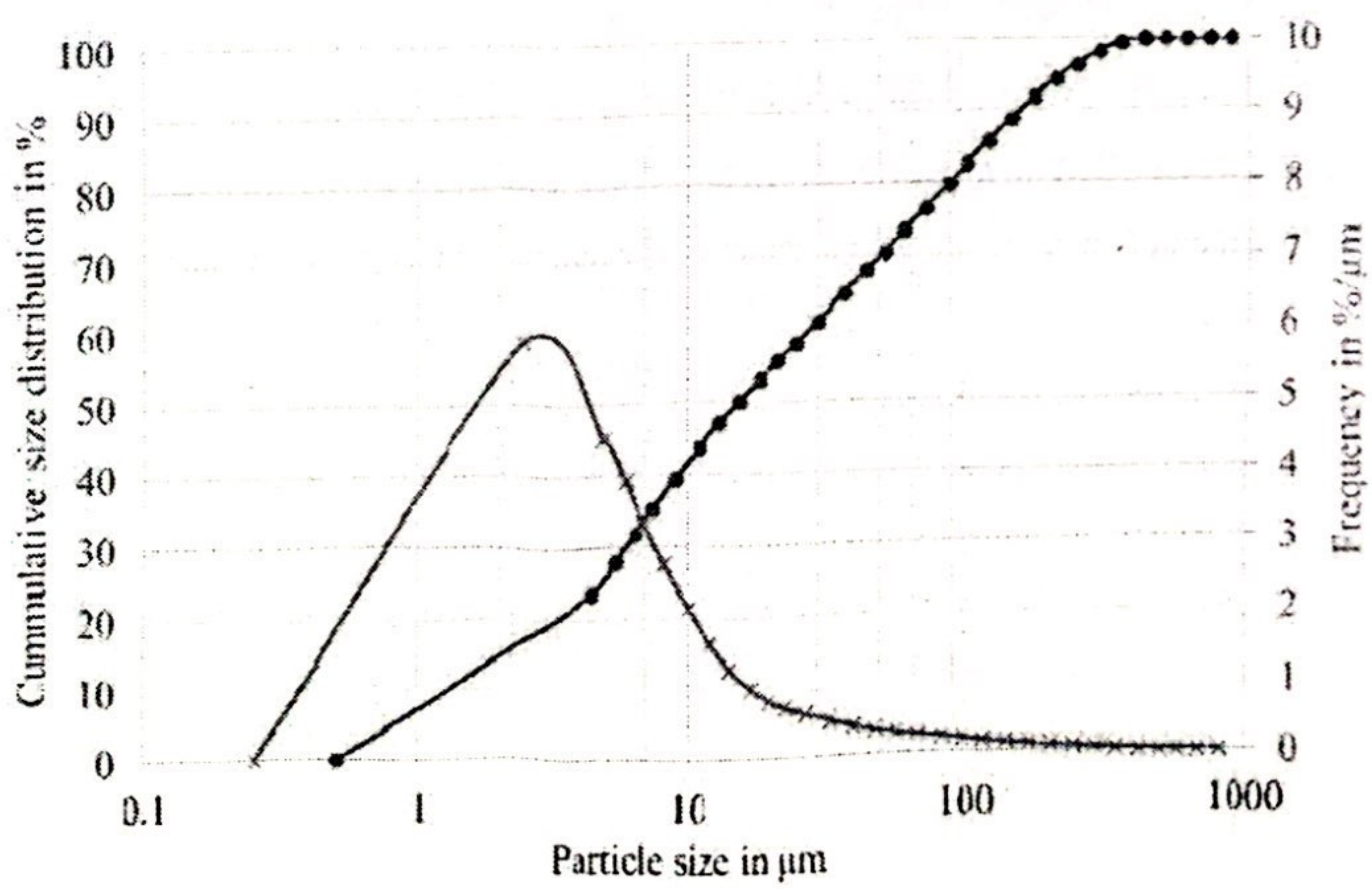

Fig 5. The particle size distribution of fine coal

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 10. The coal sample shows a broader distribution. The below 10 µm particle size accounts for 45 %, and 90 % of particles are below 0.125 mm. This amount of very fine particles in coal samples is significant. This issue may be the main reason for poor dewatering, as can be shown in the next part.

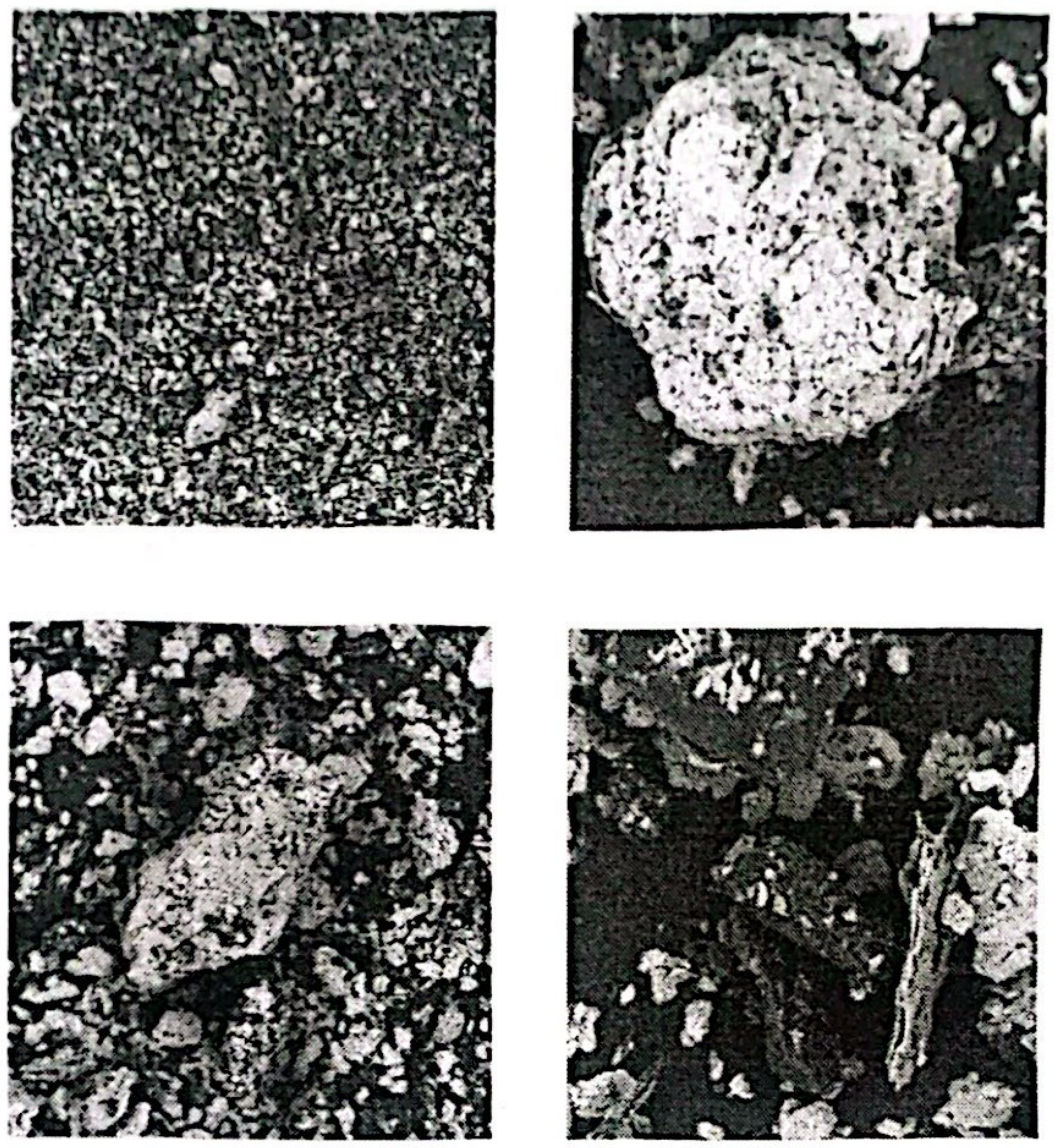

Fig 6. SEM images for coal particles.

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 6.

3.2. Method

3.2.1. Conventional filtration rig

The filtration rig is built according to VDI 2762-2 (VDI2762, 2010). Gas-driven filtration experiments were conducted in a stainless-steel pressure filter Nutsche with an area of 19.64 cm², as shown in Figure 7 (on the left side). The filter medium has support from a perforated medium sheet with a large open cross-section area. 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 filtrate quantity is measured using a scale connected to a computer. (VDI2762, 2010).

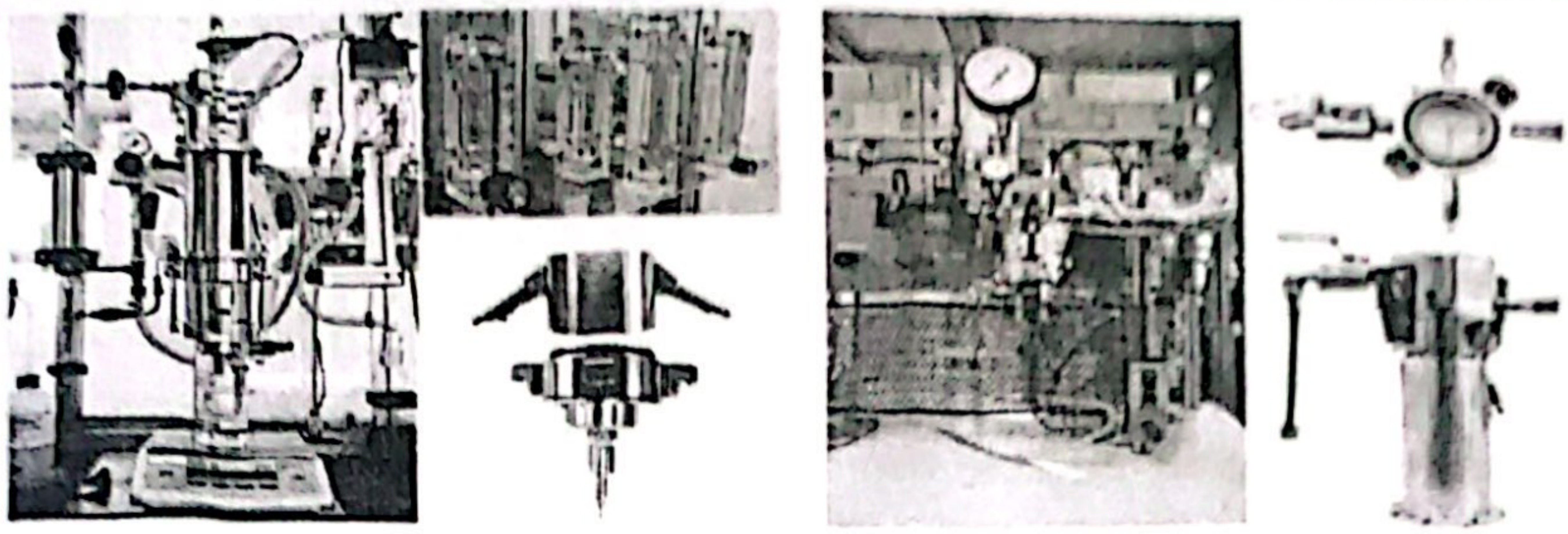

Fig 7. Images for the Conventional filtration apparatus and Steam pressure filtration apparatus

3.2.2. Steam pressure filtration

The steam pressure filtration rig (Figure 7 - the right image) was built based on the standard Nutsche with the same length tube and cake formation unit, which has been described above. The different things are the compressed air and compressed saturated steam from the steam source to supply to Nutsche. The evaporator provides the steam. 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. Styrofoam covers the tube, the cake formation unit, and all pipes to avoid heat transfer into the ambient environment. An oil heater heats Nutsche and cake formation unit to approximately 160 oC. A thermocouple is installed to control and maintain the temperature stable. Four thermocouples remain in the cake formation unit, built to measure each layer's 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 (Esser & Peuker, 2020 (a)).

3.2.3. Test procedure

The feed suspensions were prepared as follows: solid is dispersed in distilled water at room temperature (approximately 20 oC) 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 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 electronic scale recorded the filtrate mass during filtration. The collected filtrate is recorded by Diadem software. This result is used to calculate specific resistance cake. (VDI2762, 2010). The second stage is the mechanical displacement phase. Depending on the kind of filtration, the compressed air or the saturated steam is applied.

Compressed air, regulated by a valve and pressure gauge, is applied for conventional pressure filtration to push water out from pores. The test ends when no water flows through the filter cake (the end of the mechanical displacement phase).

The steam outlet and magnetite valve are opened for steam pressure filtration to allow the steam to enter 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 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 is quickly removed from the cake formation unit to dry. The filter cake is dried at 50 oC (± 5 oC) 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:

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

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 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 a vital role in dewatering efficiency. It is related to the stratification of particles as well as the structure of filter cake. By changing the liquid mass in fixed 30 grams of coal, the volume fraction has changed from 0.05 to 0.4. Tests were conducted in 1-1 bar (1 bar for cake formation, 1 bar de-liquoring), 1-3 bar (1 bar for cake formation, 3 bar de-liquoring), 3-3 bar (3 bar for cake formation, 3 bar de-liquoring) of pressure difference. The result of the filter cake after conventional pressure and steam pressure filtering are shown in Figure 8.

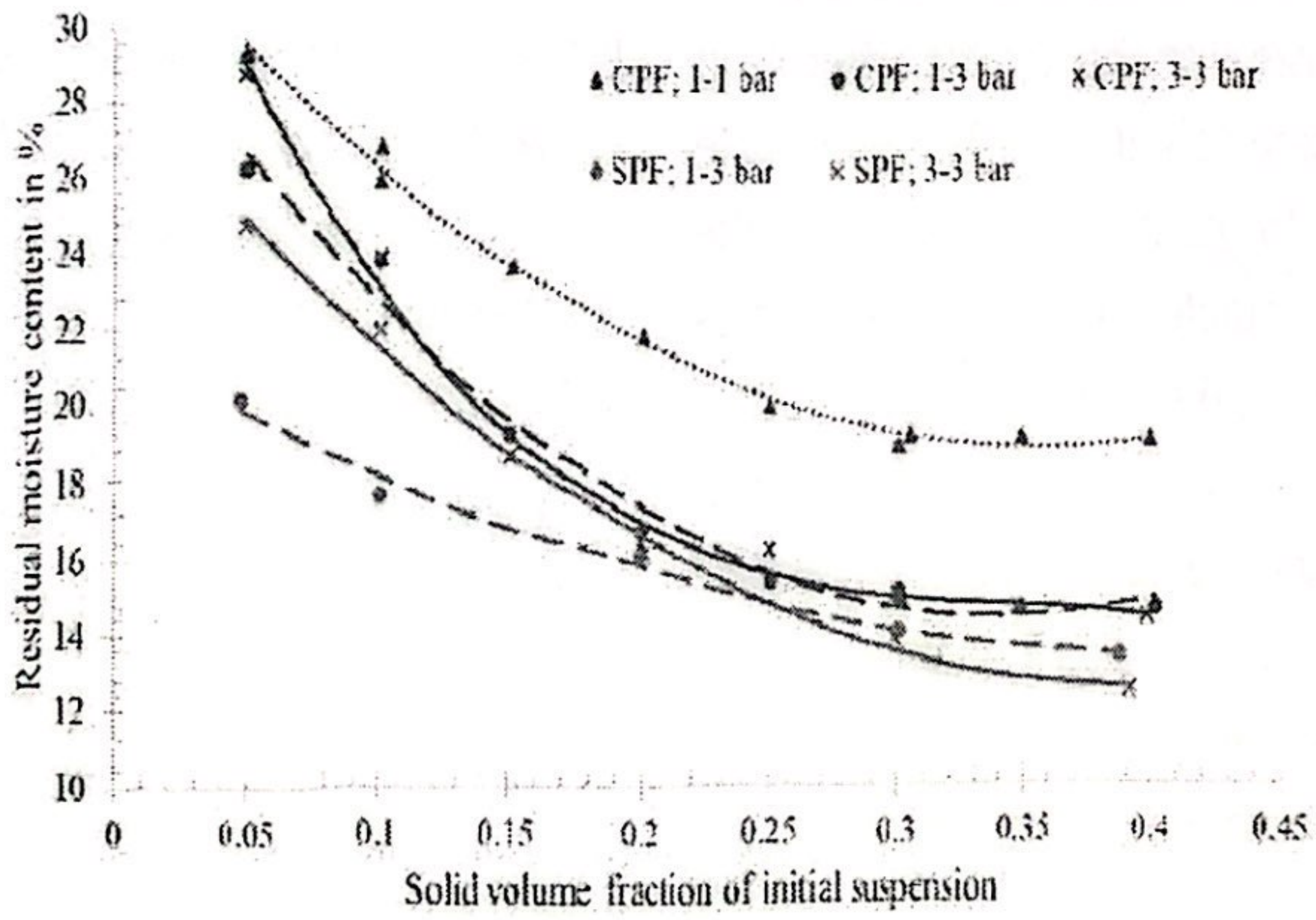

Fig 8. The residual of filter cake using SPF and CPF in various solid volume fractions; the mass of coal: 30 grams.

It can be seen that by increasing the volume fraction, the residual moisture content is reduced. Usually, when the solid volume fraction of feed suspension increases, the filter cake becomes more homogeneous. The uniformity of the size of capillaries inside the structure of the filter cake led to the water flowing simultaneously out from every position. The result is that using the SPF is more efficient than using CPF. The result also shows a slightly lower value of residual moisture content when using steam pressure filtration compared to conventional pressure filtration. The mechanism of steam pressure filtration causes this lower value. While the water prefers pushing out of the filter cake from the large pores (also from large capillaries) when using CPF, the mother liquid in both large and small capillaries 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 moisture content of the filter cake does not change, with values ranging from 14-16 % (for both CPF and SPF). A different result is when the tests are conducted with a pressure difference (1-1 bar using CPF). Moisture values are around 20-30 %. This issue can be explained in terms of the capillary entry pressure theory. The requirement pressure for mechanical displacement must be higher than the capillary entry pressure (which has the magnitude depending on the structure of the filter cake, particle size, particle size distribution, and characterization of solid and liquid). It can be concluded that for the coal in the Cua-Ong area, the optimal sludge concentration should be 30-40 %, with the pressure difference being 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 for scale-up and directly relates to the filter equipment's performance. Choosing the right filter cake height has a technical meaning and brings higher economic efficiency and productivity. The amount of solid change depends on the various heights of the filter cake. The pressure difference is similar to the above tests. The volume fraction of the initial suspension is fixed to survey the effect of the height of the filter cake on crack formation. Because of the limitation of the filtration rig, the filter cake's maximal height is 25 mm. The result is shown in Figure 9.

In general, the effect of filter cake height on deliquoring efficiency is unclear. Looking at Figure 9It can be seen that when the filter cake increases from 3 to 22 mm, the moisture content increases by about a maximum of 2 % of the value (in some specific tests, the residual moisture contents are unchanged). This stability is because 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, to choose the optimal parameters in this case, it is necessary to consider the relationship between filter cake height, filter pressure, and filter area.

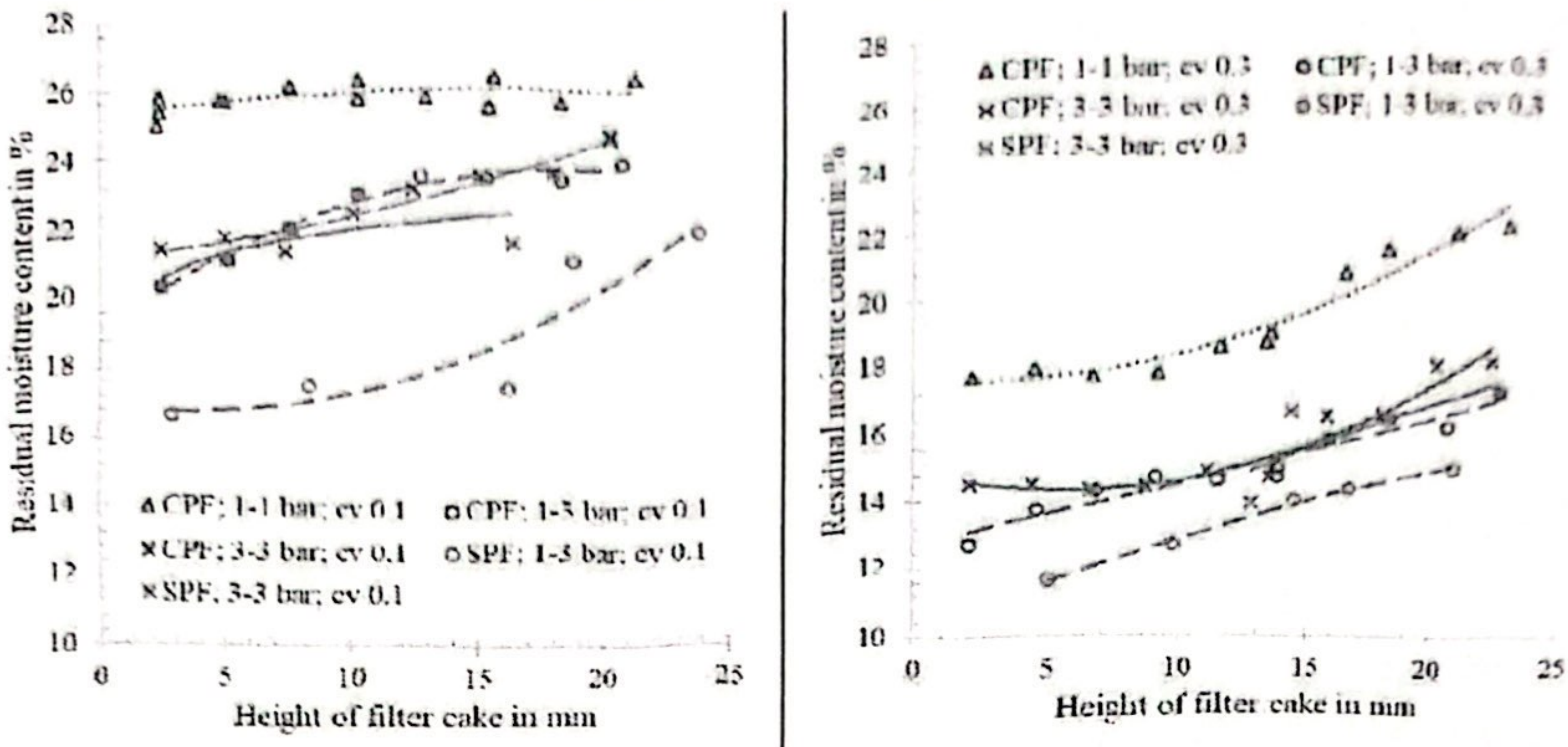

Fig 9. The residual moisture content of filter cake using CPF and SPF in a variety of filter cake heights; volume fractions of 0.1 and 0.3

One thing that can be noticed is that in the same survey condition, the result using SPF always has 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.

4.3. Test for steam pressure filtration, including drying phase

The purpose of these tests is to show the outstanding efficiency in dewatering using SPF. Applying steam pressure filtration on the mechanical displacement phase pushes the water out of small and large pores. Much water is removed, and the residual moisture content is more minor. Moreover, during the deliquoring phase, the filter cake and the remaining mother liquor are heated due to the heat convection and conduction of condensate water. When applied, air pressure leads to evaporation, resulting in further moisture loss. The result can be seen in Figure 10 and Figure 11. 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 filter cake height effect tests, 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 equipment with the same area of 19.64 cm^2.

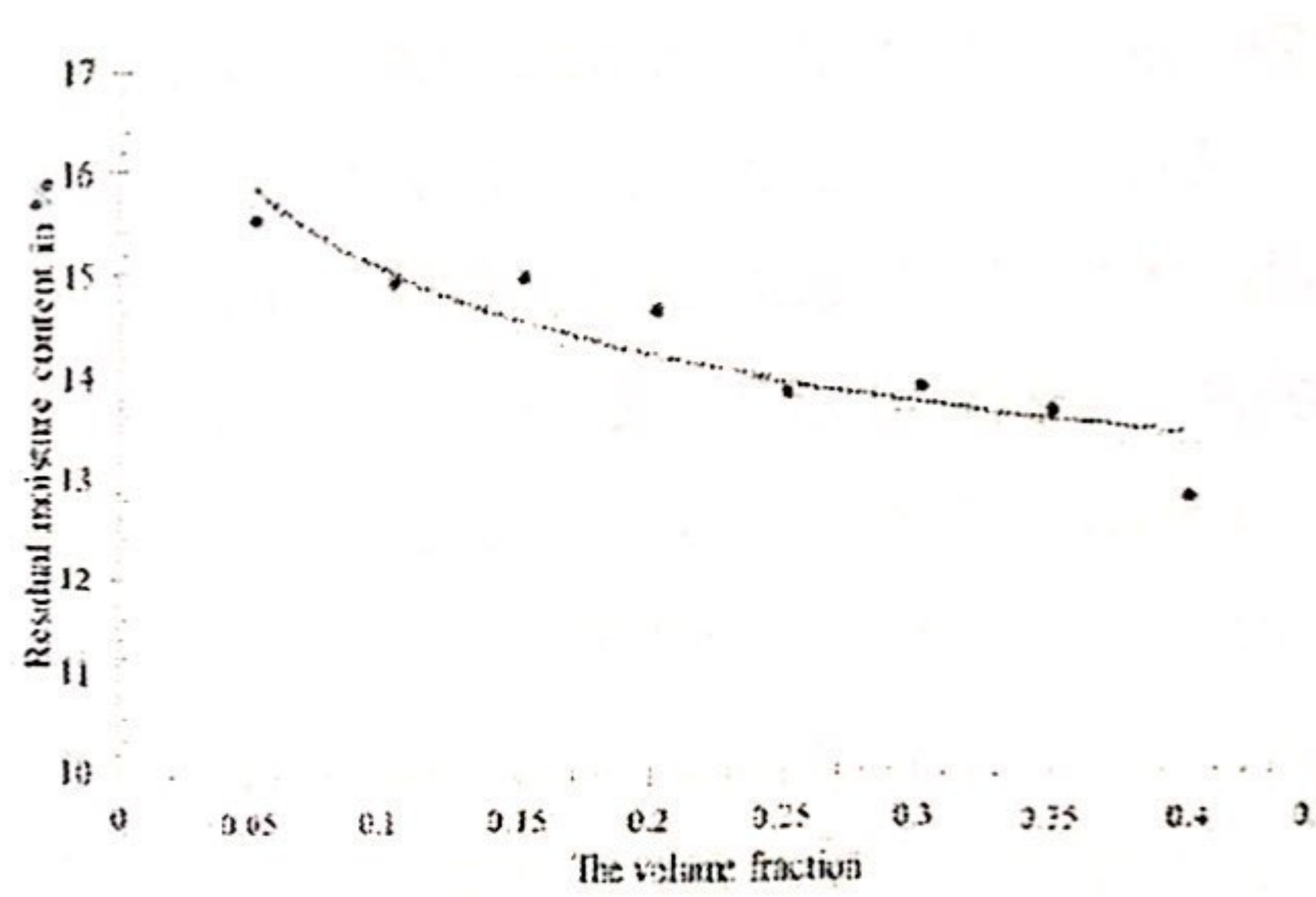

Fig 10. The residual moisture content of filter cake with the test of different volume fractions during steam pressure filtration after the drying phase

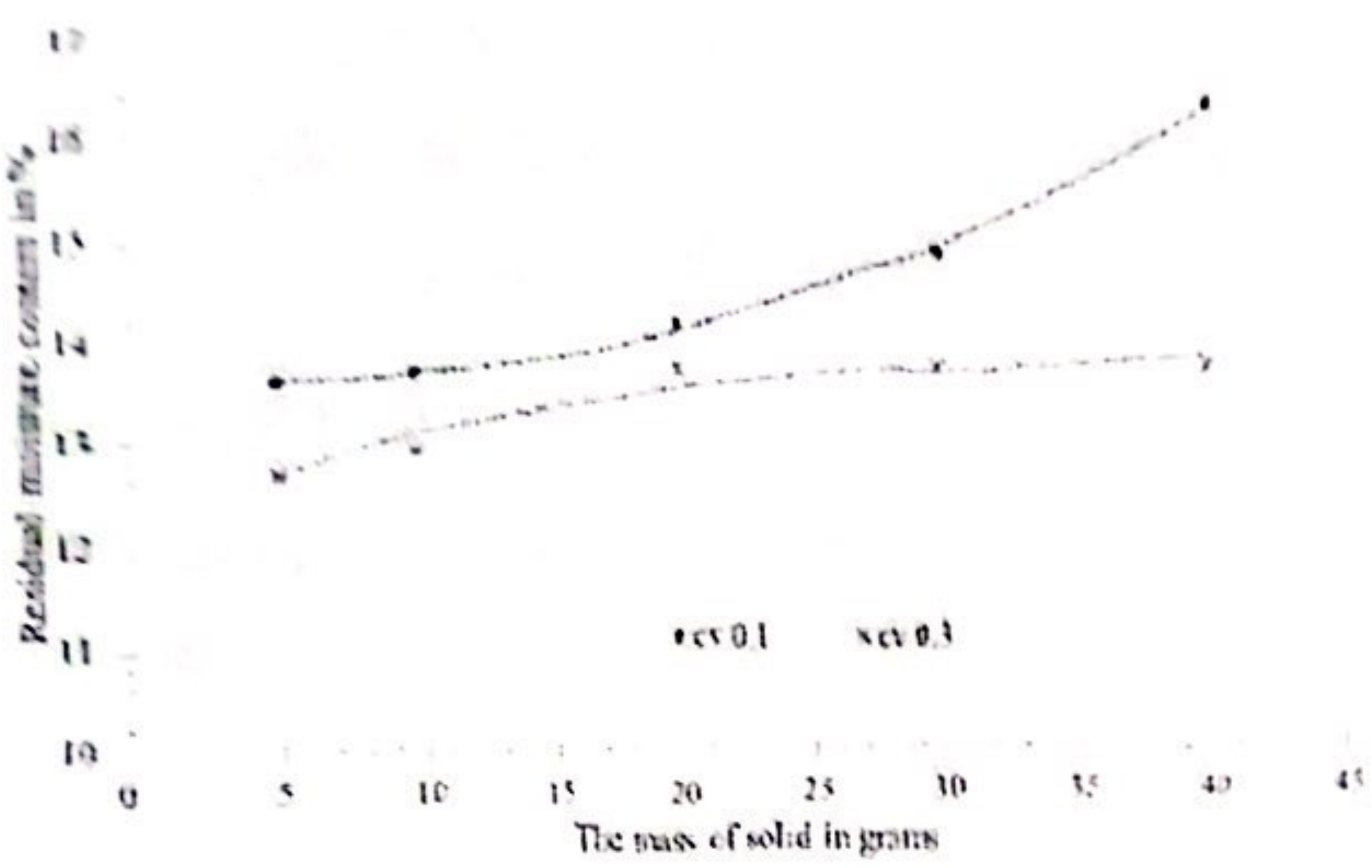

Fig 11. The residual moisture content with the test of different filter cake heights during steam pressure filtration after the drying phase

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

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

5. CONCLUSION AND OUTLOOK

5.1. Conclusion

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

Fine coal from the CCWP has dominant fine and ultra-fine sizes and a broad particle size distribution. It is collected in the pipes before thickening to avoid the presence of flocculant.

Experiments were conducted to study the influence of some technological parameters (filter cake height and solids volume concentration of the feed slurry) on the dewatering efficiency of CPF and SPF. The results show that the dewatering efficiency increases by increasing the solid volume fraction. The filter cake thickness does not affect the material moisture much but affects the filter's capacity. 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.

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