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# Development of dry coal gravity separation techniques

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**Abstract**. Dry separation method was used at the beginning of 20$^{th}$ century to separate coal separation process. First industrial applications of dry separation took place in the middle of 1930s. At that time air separator Frazer-Yankey, based on aero suspension was used in in Pittsburgh and Lundale, West Wirginia coal preparation plants. Later, some more constructions like RAW air jig, air table "V" type Birtley, air jig type Kirkup, air table "V" type Peale-Davis or air jig type Bruay-Soulary were constructed. Fast development of wet technologies of processes, especially jigging and heavy dense medium separation caused the discontinuation of the further development of dry separation methods and replacement of dry preparation plants with plants based on wet methods of enrichment. At the end of 20$^{th}$ century and beginning of 21$^{st}$ century dry separation method started once again to be widely used in the world. New types of equipment like FGX vibrating air table, TFX air jig or KAT process technology were introduced to wide applications in Asian countries. The paper describes few constructions of old air separators and new ones, used nowadays. It contains comparison of the separation results obtained by means of various equipment and shows possibility to separate coal in laboratory scale air jig.

## 1. Introduction

Many different kinds of enrichment methods are used in coal preparation, like for example gravity separation processes conducted in heavy dense media, in jigs or on shaking tables or physico-chemicals processes like flotation process. One of the methods used in coal beneficiation process is dry method. This method was popular at the beginning of the 20th century. Then it was successfully used in the United States (1919). Separator Frazer-Yancey was used in USA and it was working as a heavy dense medium (air and sand suspension). The first big coal preparation plant was built in 1930 in Pittsburgh. First type of this device was equipped with rigidly placed working bed of small angle. The working bed consisted of sieve with very small mesh and big working chamber was situated above of it. 5 coal preparation plants with this technological solution were built in the early 1930s in USA. The biggest separator in this plants was used in Lundale, West Wirginia with total capacity of 200 Mg/h. In the middle of 1930s Frazer-Yankey separator was modified and the option with moving working bed was added. At the same time dry separation method came also to Europe where it was used in England (1925), followed by Belgium, Germany or Poland (1928). The rule of the dry method is based on separation of the material by ascending or pulsatory air stream. Dry enrichment is usually applied in locations where water shortages occur causing that there is not enough water to conduct wet processes as well in a harsh climate due to the possibility of freezing of the separation products after being separated in a water medium. Nowadays, this method is used in China, Mongolia, India, USA or Russia. The raw materials that can be enriched by means of this method are mainly hard coals with a large proportion of coal-fired or tailings fractions and for lignite (hard types).

Recently, a developing time started for new equipment for dry coal enrichment. It occurred especially in China (CFX, TGX or FGX) and Korea (KAT Process, a dry coal preparation process developed by Korean Institute of Geoscience and Mineral Resources). The air vibrating table type FGX became very popular which is used in United States, Turkey, India, South Africa and a dozen other countries. In 2012 the Institute of Mechanized Construction and Rock Mining purchased a vibrating air separator type FGX-1 through the company WARKOP Sp. z o.o. (this company represent Tangshan Shenzou Machinery Co. Ltd. on the Polish market) [1, 2, 3, 4, 5, 6].

## 2. Dry separation equipment

Dry beneficiation techniques can be divide into two main categories: beneficiation on air table and separation by air jigs. Air tables work by using ever-rising stream of air. Work plate can also vibrate to increase the accuracy of separation. Obtaining of the products depends on construction of the table. Good examples of old separators of this type are air table “V”, type Birtley or air jig type RAW.

Air table “V”, type Birtley consists of two symmetrical parts (with divided work plate) getting V shape. Both parts work independently of each other. Each of the halves has a slope in a direction perpendicular to the axis of the table. The working plate consists of steel net with riffles of decreasing height related to the feed loading inlet. The air chamber is located under the net and the air is supplied to it by the fan through a pipe. The air pressure can be regulated in each part of the air table. Under the influence of the shaking action of the table and blasting air raw material is separated into three products: concentrate, middlings and tailings. Heavy particles (tailings) are transported on the surface of the net by riffles and are unloaded at the end of working plate. Concentrate is unloaded at the beginning part of the table.

The RAW air type jig is one of the precursors of air jigs currently used. Its construction is based on box equipped with steel sieve arranged in a staircase-like way. Each subsequent sieve is thinner than sieve before (3 parts of sieves, together). The box of air jig is located on steel construction by spring levers (as a result the box shakes). The air chamber is located under the sieve and is supplied by pulsatory air stream. Raw feed is separated on upper part of sieve by air pulsation during working plate motion. Firstly, fine coal secondly coarse coal and lastly middlings and tailings are separated. Clean coal and middlings are separated at the bottom of the box. Tailings are unloaded at the end of the last sieve to a belt conveyor.

In the past some works on constructing air separator with aero suspension were also performed As a load sand or magnetite were used. One of the devices used to separate coal by aero suspension was Frazer-Yankey separator used in USA in 1930s. The sand was used here as a load. The comparison of the results of coal separation in dense medium separator with aero suspension and typical dense medium liquid are shown in table 1. The research was conducted by W.I. Korszunov in USSR [5, 6, 7, 8, 9].

**Table 1.** Comparison of the results of coal separation by heavy liquid and aero suspension [7].

| Type of coal | Separation in heavy liquid with density 2.0 g/cm$^3$ | | | | Separation in aero suspension (concentration of the solid phase 33.4%) | | | |
|---|---|---|---|---|---|---|---|---|
| | Light product | | Heavy product | | Light product | | Heavy product | |
| | Yield [%] | Ash [%] | Yield [%] | Ash [%] | Yield [%] | Ash [%] | Yield [%] | Ash [%] |
| Anthracite | 91.2 | 10.7 | 8.8 | 83.4 | 92.2 | 10.8 | 7.8 | 90.7 |
| Coking coal | 69.6 | 15.0 | 30.4 | 80.5 | 72.6 | 17.4 | 27.4 | 82.2 |

Results showed that raw feed of coal can be separated by aero suspension with similar efficiency comparing to separation in heavy dense medium. Very good results were obtained after separation of anthracite coal. Aero suspension helps to get final product with ash content >90% in tailings and around 10.8% of ash in concentrate. This result was better than in case of separation in heavy liquid. It showed that separation in air separators can be efficient.

After many years construction of air tables was modified and now two good constructions exist: vibrating air table, type FGX from China and TFX air jig for small particles and KAT (Korean Advanced Technology) technology developed by Korea.

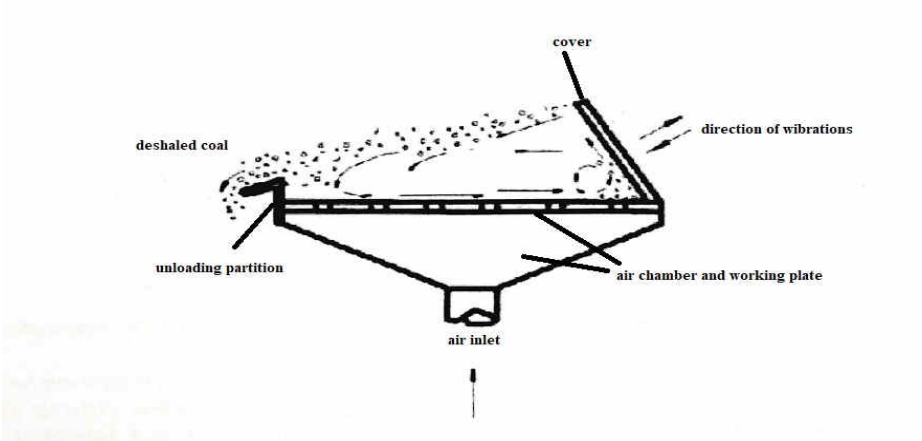


**Figure 1.** Material distribution on FGX working plate.

Vibrating air separator FGX consists of a funnel feed, dosing feeder, perforated work plate, vibrator, air chambers, dust removal module and a mechanism that allows to change the angle of inclination of the working plate and the frequency of vibrations. The feed is fed on the installation by means of a vibratory feeder and then it goes to a working plate inclined at various lateral and longitudinal angles set in a vibrating motion by means of a vibratory drive.

In order to ensure air supply under the working plate the air chambers are located which are fed by a centrifugal fan. The fine coal material forms a fluidized bed (air-solid slurry) as a result of contact with air. Thanks to it, individual particles can fall relatively to each other dependably on their size or density. Under the influence of combined forces: air current and vibrations the coal bed is raised and becomes stratified according to the density. The lighter material is suspended on the surface of the fluidized bed and the particles of higher density sink deeper. An additional phenomenon is the liquefaction effect resulting from the interaction between small particles. This phenomenon improves the efficiency of the separation of coarse fractions. Fine material located on the surface of the layer tends to slide over its surface and falls continuously under the influence of gravity through the partition at the edge of the plate (dumping of enriched coal). The heavy material falls to the bottom of the layer and is moved towards the waste collection point (gangue). Figure 1 shows the distribution on FGX working plate.

KAT (Korean Advanced Technology) table is a type of pneumatic table separator. In this separation process the differences in density between grains in ROM coal are used. Figure 2 shows the separation scheme. The denser material falls down on deck to form a lower layer and moves to the oscillating direction of the table deck by the influence of eccentric motion. The upper layer of light particles roll down with help of airflow and shaking table to the lower part of the deck and accumulates along the blocking wall. When the level of accumulated light particles exceeds the height of blocking wall it starts to overflow. This specific design of KAT table generates an autogenetic medium of light particles along the lower end of the deck thus increases a product quality. KAT table separates coal into 3 different fractions. The light fraction-coal, the heavy fraction-tailing and the middling.

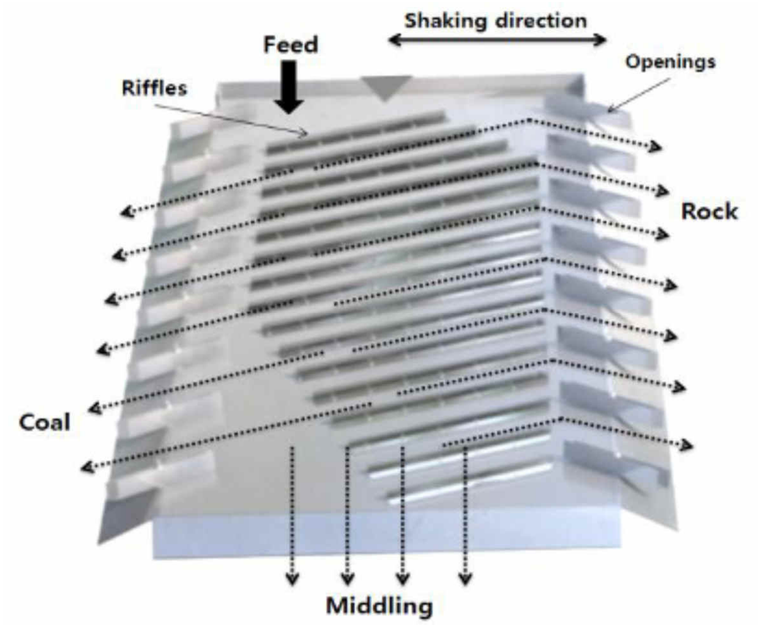


**Figure 2.** KAT air table deck – trajectory of separated products [13].

As an example of modern air jig a TFX air jig will be described. The dry cleaning jig operates on a principle which is basically similar to that of a wet cleaning jigging machine. The fine size material on the deck tends to become gradually loosened and stratified under the combined effect of vibration force and the pulsation produced by the upward air-stream coming from deck bottom. The heavier material gradually sinks down to bed bottom while the lighter material gradually floats up to the top of the bed. During the proper jigging process, a table material bed is finally formed. The heavier material at bed bottom is discharged through the discharge unit while the other materials move forward to go through further separating process under the effect of vibration force. The TFX air jig unit is shown in figure 3 [10, 11, 12, 13, 14].

**Figure 3.** Air jig TFX unit [14].

## 3. Results

To show the quality of dry separation all results from TFX, FGX and KAT will be compared with result from laboratory scale air jig created in Silesian University of Science and Technology. This small jig have a periodic activity, working chamber consists of rings, dust extraction system is attached to the bottom of working chamber. To collect the separation products whole working chamber is dismantled into smaller parts. Every ring is a one of final products (usually 3 products: clean coal, middlings and tailings).

**Table 2.** Results of separation by using KAT Process technology for coal in particle size fraction 1-5 mm [13].

| Test | Clean coal | | Middlings | | Tailings | |
|---|---|---|---|---|---|---|
| | Yield [%] | Ash [%] | Yield [%] | Ash [%] | Yield [%] | Ash [%] |
| 1 | 57.20 | 16.00 | 20.40 | 44.50 | 22.40 | 86.10 |
| 2 | 53.40 | 9.40 | 22.90 | 37.90 | 23.70 | 88.70 |
| 3 | 58.30 | 10.70 | 14.00 | 37.30 | 27.60 | 84.00 |

**Table 3.** Results of separation by using KAT Process technology for coal in particle size fraction 5-10 mm [13].

| Test | Clean coal | | Middlings | | Tailings | |
|---|---|---|---|---|---|---|
| | Yield [%] | Ash [%] | Yield [%] | Ash [%] | Yield [%] | Ash [%] |
| 1 | 41.10 | 13.30 | 18.20 | 52.90 | 40.70 | 88.60 |
| 2 | 34.50 | 6.90 | 32.80 | 53.40 | 32.70 | 89.80 |
| 3 | 36.70 | 7.70 | 26.10 | 46.10 | 37.20 | 89.60 |
| 4 | 44.40 | 8.40 | 18.90 | 56.80 | 36.60 | 87.00 |
| 5 | 47.80 | 10.60 | 13.50 | 66.90 | 38.60 | 84.70 |

KAT Process technology for separation of coal particle size fractions 1-5 mm and 5-10 mm showed that specific construction and motion of working plate can help to get final tailings with high quality. Most of separated tailings have ash content higher than 85%. The stone separated by the dry stone method can find application in the building materials industry or engineering works. Concentrate can be used as final product in coal power plants or by regular customers at home.

**Table 4.** Results of separation by using TFX air jig for coal in particle size fraction 13-0 mm [14].

| Coal | Raw coal ash [%] | Clean coal | | Middlings | | Tailings | |
|---|---|---|---|---|---|---|---|
| | | Yield [%] | Ash [%] | Yield [%] | Ash [%] | Yield [%] | Ash [%] |
| Coking coal | 19.75 | 77.49 | 9.10 | 7.50 | 28.43 | 15.01 | 70.41 |
| Power coal | 42.53 | 58.73 | 27.26 | 21.93 | 54.88 | 19.39 | 73.47 |
| Power coal | 35.85 | 60.97 | 20.71 | 20.90 | 46.27 | 18.13 | 74.73 |

Table 4 shows that air jig can be used for coking coal or steam coal as well. Final products fulfill the requirements of users. Results show that the air jig can help to get good results during separation of coking and steam coals. There is still some amount of coal in tailings - the ash content is too low <75%. Concentrate of ash content higher than 25% is unacceptable.

**Table 5.** Results of separation by using laboratory air jig for coal in particle size fraction 2-20 mm [15].

| Test | Clean coal | | Middlings | | Tailings | |
|---|---|---|---|---|---|---|
| | Yield [%] | Ash [%] | Yield [%] | Ash [%] | Yield [%] | Ash [%] |
| 1 | 77.40 | 10.60 | 11.40 | 17.50 | 11.20 | 78.20 |
| 2 | 67.70 | 11.70 | 16.20 | 20.10 | 16.10 | 46.10 |

**Table 6.** Results of separation by using laboratory air jig for coal in particle size fraction 12-6 mm [15].

| Test | Clean coal | | Middlings | | Tailings | |
|---|---|---|---|---|---|---|
| | Yield [%] | Ash [%] | Yield [%] | Ash [%] | Yield [%] | Ash [%] |
| 1 | 72.11 | 6.01 | 9.10 | 12.39 | 18.80 | 67.47 |
| 2 | 74.90 | 8.91 | 10.60 | 14.59 | 14.50 | 68.62 |

Tests on laboratory scale jigs show that dry separation is a good process to get final products of low ash content. In particle fraction 20-2 mm ash content level in concentrate is between 10-12%. Ash content in tailings shows that coal particles can occur in heavy product.

**Table 7.** Results of separation by using vibrating air table type FGX for coal in particle size fraction 20-0 mm [16].

| | Parameter | Feed | Concentrate | Middlings | Tailings |
|---|---|---|---|---|---|
| **1.** | Ash content [%] | 31,7 | 21,2 | 29,5 | 80,5 |
| **2.** | Moisture content [%] | 9,6 | 9,0 | 8,4 | 5,3 |
| **3.** | Sulphur content [%] | 0,56 | 0,62 | 0,68 | 0,44 |
| **4.** | Calorific value [kJ/kg] | 17 151 | 21 558 | 18 885 | 1 860 |
| **5.** | Yield [%] | 100 | 77 | 3 | 18 |

Table 7 showed that coal in particle size fraction 20-0 mm can be enriched with good results. Concentrate can be used by commercial sector (ash content around or a little bit more than 20% and good calorific value >21000kJ/kg). Coal-fired boilers in Polish energetic sector are adapted for using coal of higher content of ash. Middlings can be sold to energetic sector or can be used to produce energetic mixes.

## 4. Conclusions

Dry separation is one the old methods used before introduction of wet processes such as beneficiation in jigs, heavy dense medium or flotation process. Among the advantages of this method can be mentioned that they:

- Eliminate water and sludge circulation from processing plant. As an example the solution showed by scientists from China University of Mining and Geology and Tangshan Shenzhou Manufacturing Company can be presented (figure 4):

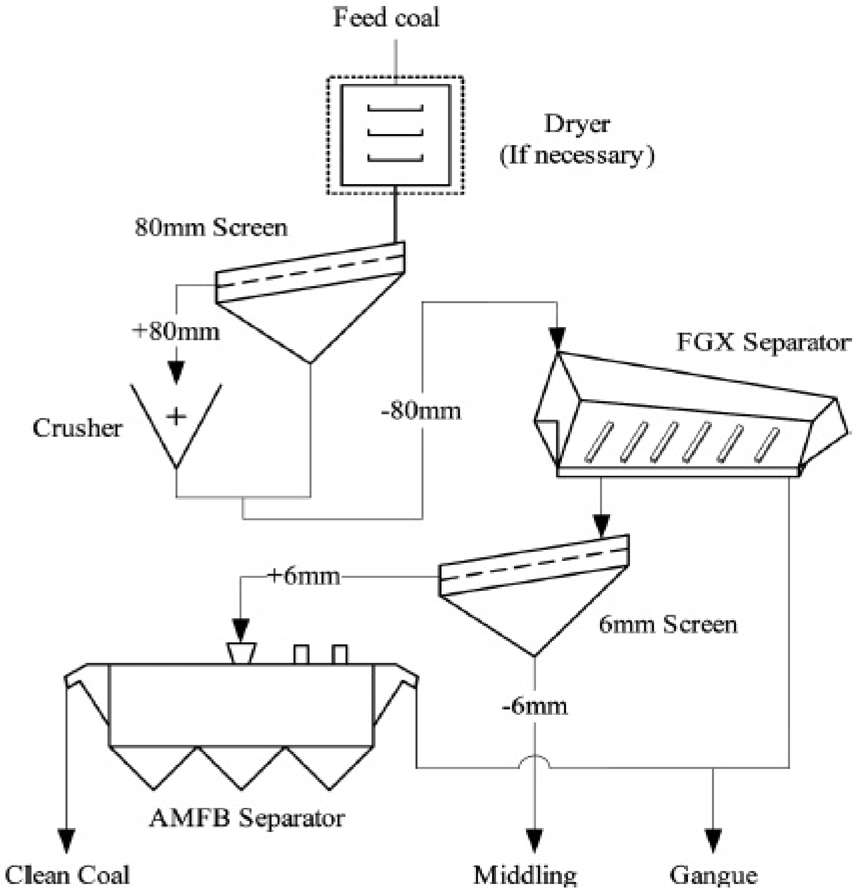


**Figure 4.** Flowsheet with full technological line based on FGX air table and AMFB separator [12].

Raw feed will enter into dryer to reduce moisture content (if it is necessary). Feed goes onto 80 mm screen where +80 mm particles from screen are crushed. Mixture of crushed product and particle size fraction -80 mm is directed to FGX separator. Coarse coal is separated into gangue and cleaned coal. After beneficiation coal is separated on 6 mm screen. Particle size fraction <6 mm is treated as middlings. Particles >6 mm are separated in AMFB separator (air fluidized bed separator). Gangues from AMFB and FGX are mixed together. Cleaned coal is obtained after beneficiation process conducted in AMFB Separator.

- There is a possibility of beneficiation of very small coal particles. Contact of these small particles with water can have negative effect for later use.
- Big simplification of the technological economy considering the smallest particles by eliminating them from water. It results in elimination of sludge thickening and dewatering of fine grain products.
- Elimination of drying and dewatering of final beneficiation products (roughly grained products).
- Dry separation can find wide applications in places of harsh climate like Mongolia, Russia, some parts of China etc., places with water shortages so it eliminates wet beneficiation methods.

The most important disadvantages are:

- Limited upper dimension of particle size fraction directed into beneficiation process. The maximum limit of particles directed to dry separation process is around 70(80) mm.
- Losses of carbonaceous substance in tailings and semi-products from enrichment processes. The best results are obtained by separation in devices working with aero suspension or with fluidized bed. The quality of tailings was better than in case of separation conducted in typical dry device (jig).
- Dry separation is dedicated for coals with low moisture content and for easily beneficiated coals. Coals harder to beneficiate, of higher ash content or of higher content of middlings are more difficult to separate by dry methods. Final results for separation this kind of coals is not satisfying. Coals with moisture content higher than 5% need to be dry before the enrichment process (increasing production costs).
- Due to the low settling coefficient it is necessary to classify raw feed into narrow particles fractions. It is necessary to develop the first step of classification by sieves etc.

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