



# FGX Air-Vibrating Separators for Cleaning Steam Coal – Functional and Economical Parameters

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## Abstract

FGX – Dry Separators are a construction developed at the turn of the 20th century. It was created in China as a combination of a vertical jet air classifier and a vibration screen with a tapered channel. This structure has been modified (Figure 1). These separators proved to be very effective in deshaling of excavated coal. They are designed to remove as many grains of stone as possible. For this reason, separation is carried out in the thickness range above 2.0 g/cm<sup>3</sup>. The article describes the structure of dry separator as well as the principle of its operation. The factors influencing the enrichment efficiency and the separation accuracy of feed parameters have also been listed here. Moreover, the technical parameters of the separator which are subject to regulation and influence the course of the separation process have been discussed. Synthetic information on economic efficiency has been provided. The possibilities of application of FGX separators in the systems of existing enrichment plants or as independent processing plants have been presented. There are currently three FGX separators working in Poland. In the Institute of Mechanised Construction and Rock Mining in the Katowice Branch, the bituminous coal of some mines is tested on an installation with a capacity of up to 10 Mg/h. The results of the research confirm the possibility of implementing FGX separators in the bituminous coal mining in Poland. Two separators, with a capacity of about 30 Mg/h, improve the parameters of imported coal intended for individual customers; they are owned by private companies. More than 2000 FGX separators in more than a dozen countries are in operation in the world. They are effective and are referred to as '21st century technology'.

Keywords: hard coal, dry separation, deshaling, functional and economical parameters

## Introduction

Dry blowing is one of the oldest methods of steam coal enrichment. In the 1920s, there were SKB or Buray-Soulyar air concentration tables working in reciprocating motion. Pneumatic jiggers called Raw or Humbolt air separation plants were also used. There were also gravitational vertical air jet classifiers separating the materials of different denseness. These devices were withdrawn in the 1950 because of low accuracy of separation and replaced with water jigs (Blaschke 1976).

At the break of the 20th and the 21st century, Chinese company Tangshan Shenzhou Manufacturing Ltd. constructed dry separators which are sometimes erroneously referred to as air concentration tables. Their construction combines a vertical jet air classifier and a vibration screen.

Vibration screens were used in UK and USA in the 1940s and 1950s. They were used to dry blow the excavated coal. An example of a vibrating screen type FMC is shown in Figure 1.

It consisted of a tapered channel, whose back wall was connected to a vibrator. The material moving within the channel was rotating. Thus it divided into lighter (coal) layer, which was fed to the separator. The heavier layers were fed into further parts of the working channel. In order to improve the separation accuracy, the channel was tapered. These separators were not highly accurate, therefore they were gradually removed from facilities and replaced with jiggers.

In the Chinese construction, the plate is perforated and air is fed through the holes just like in gravitational vertical air jet classifiers. Additionally, there are several slats placed at an angle in relation to the plate. Just like in the vibration screens, the back wall is attached to a vibrator which makes the coal grain rotate. The slats facilitate lifting of the grain and the air jets allow for formation of the suspension layer. How the separator works is described in more detail further in this article.

Air-Vibrating separators like this are marked FGX. It is an acronym of the Chinese name Fuhe Ganfa Xuan mei. According to the producer's information (Gongamin Li. 2006; Mijał, Tora 2018; Tangshan Shenzhou...2012), FGX separators are commonly used in China (more than 1800). The producer manufactures eleven types of those separators with the capacities of 10 through 1000 Mg/h. In Poland, there is an experimental installation in the Katowice branch of IMBiGS (Institute of Mechanised Construction and Rock Mining) and two industrial installations – FGX3 in Gdańsk and Toruń (Baic, Blaschke 2017).

## Construction of the air-vibrating separators

FGX air-vibrating separators are devices for dry enrichment of coal. Because they work in the thickness range from 2.0–2.2 g/cm<sup>3</sup>, they are commonly called devices for dry deshaling of excavated coal. FGX devices consist of two modules: enrichment and dust removal modules (Baic et al., Mijał et al. 2018).

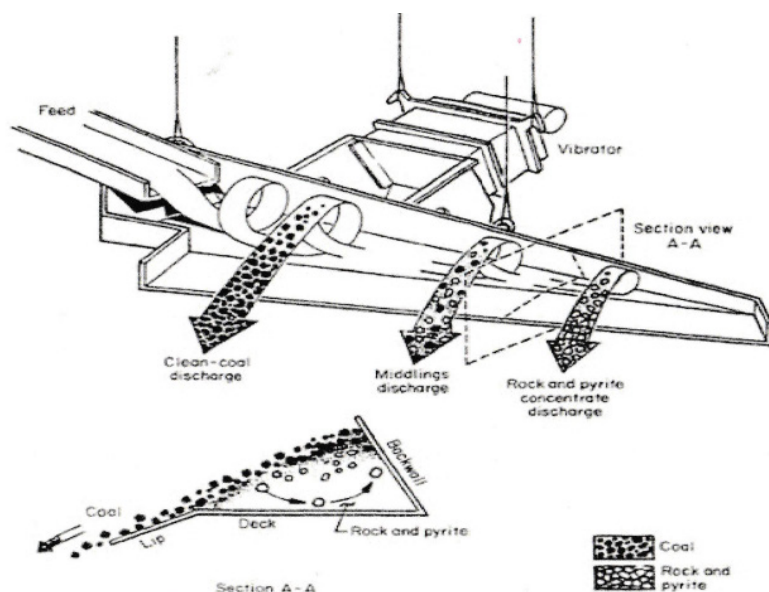


Fig. 1. FMC – Vibrating separator (Blaschke 1976)

Rys. 1. Separator wibracyjny (Blaschke 1976)



Fig. 2. Enrichment module [photo IMBiGS]

Rys. 2. Moduł wzbogacania [fot. IMBiGS]

**ENRICHMENT MODULE** – it consists of: conveyor feeding the material to the chute; vibrating conveyor feeding the material to the plate, equipped with a scale; perforated slatted plate mounted on slings; mechanism for changing the position of the plate and vibration frequency; air jet blowing a stream of air with regulation system under the plate; collector collecting the separated products with quantity regulation. The module is additionally equipped with: conveyor belt for collection of coal product, conveyor belt for collection of intermediate products; conveyor belt for collection of waste products. All conveyors are equipped with scales. Thus, each of the dry separation materials is an individual product. The module has a control panel and can be additionally equipped with mobile laboratory module for examining the quality parameters of the raw and processed materials (Figure 2).

**DUST REMOVAL MODULE** - its task is catching the dust from the air circulation within FGX, and thus protecting the natural environment against contamination. The module consists of: rubber sealing screen (hood) over the working plate; collector transporting the contaminated air from the area above the plate to the dust extraction cyclone; the vertical vacuum cyclone extracts the grains of dust, which are discharged from the cyclone through a screw conveyor; a collector discharging the contaminated air from the remaining

space above the working plate to a series of bag filters; the series of bag filters is closed with a container for the collected dust with a vibrating device – periodically run vibrating mechanism empties dust grains from filtration bags; the series of filters include an independent (auxiliary) exhaust fan used to create vacuum in the end part of the space above the working plate and to create a draught in the direction allowing to transport the air to the filtration process; the main exhaust fan used to create vacuum in the first part of the space covered by the rubber screen over the working plate and in the cyclone. According to the manufacturer's data, about 75% of the air is circulating in the system, i.e. it is driven by the exhaust fan to the cyclone dust extractor and is reused. The remaining part, about 25% of the air, is cleaned by a bag dust remover and is released to the atmosphere. The efficiency of the applied dust removal process is about 99.5%. The dust grains discharged from the dust extraction system are an individual product of the dry separation process (Figure 3).

### Separator operation

Excavated coal is transported by the feeder to a perforated and slatted separator working plate, which is made to vibrate by a vibrator. Under the plate, there are several air chambers fuelled by a centrifugal fan. The air passes through holes in the plate and creates air jets. Under the combined forces of



Fig. 3. Dust removal module [photo IMBiGS]

Rys. 3. Moduł odpylający [fot. IMBiGS]

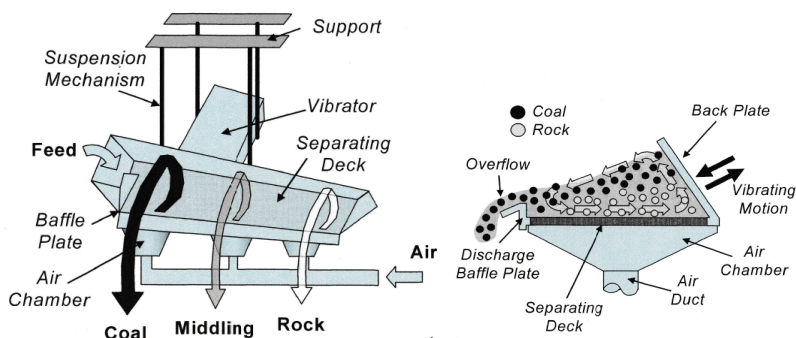


Fig. 4. FGX Air-Vibrating Separator (Baic et al., 2014)

Rys. 4. Separator powietrzno-wibracyjny (Baic i in., 2014)

vibration and air jets, the excavated material is lifted. Owing to the vibration and proper slating of the working plate, the material is rotating, which allows the grains to pass into separate containers and forces the grains to pass between separate slates (Figure 4).

Depending on the thickness of grains, the materials are divided. Lighter material goes to the surface of the suspension layer, and fractions of grains with higher densities are in the lower parts. Fine material and air is an autogenic medium. A suspension of air and solids is formed, sometimes referred to as fluidized bed. There are condition for restricted movement within the bed, depending on their size and thickness. Fluidization effect is used which occurs as effect of the density of fine grains forming the suspension and the bigger grains, which causes improvement of separation of thick grained fractions. Deshaling process is similar to the enrichment process in heavy fluid suspension. Because the working plate is slanting transversely, material with low density goes to the surface of the fluidized bed and has the tendency to move along that surface. Then, under gravity force, it falls through a partition located at the edge of the plate (dumping of enriched coal). Higher density material is concentrated in the bottom part of the fluidized bed and moves towards the waste material discharge outlet and falls through a driving plate to the waste chute. Depending on the type of raw materials and the settings of the device, more dumpings can be installed. Thus, more types of products can be obtained fulfilling the user requirements.

#### Factors affecting deshaling efficiency (Baic et al. 2015a, Gongamin 2006, Ghost et al. 2013)

Process of deshaling separation on FGX dry separators depends on many factors. The most important factors are:

- pre-processing of raw materials including the grain sedimentation (small heavy grains will fall with the same speed as large light grains),
- grain size (grain composition),
- grain thickness (density composition),
- quantity of fed air,
- altitude, number and manner of slat mounting,
- slanting angles (transverse and longitudinal) of the working plate,
- working plate vibration frequency,
- load (efficiency) of the separator.

These factors are determined on the basis of enrichment capacity of raw coal, including the required quality of separation products. On this basis, technological regime of the enrichment is selected. Experiments prove that strict observance of set technological regime is necessary to obtain the assumed quality parameters of separation products.

Foreign experiments show that the separation efficiency also depends on technological parameters of the raw materials. It was noticed that separation accuracy are affected by the following raw materials parameters:

- total humidity,
- size of biggest grains,
- range of grain class,
- relation of quantity of stone to quantity of coal,
- ash content,
- pyrite sulphur content,
- quantity of intermediate material (excess).

Manufacturer of the FGX dry separators, on the basis of his own tests and industrial experience of the operating pro-



Fig. 5. Crusher & classification unit [photo IMBiGS]  
Rys. 5. Moduł krusząco-klasyfikujący [fot. IMBiGS]



Fig. 6. Feeder unit [photo IMBiGS]  
Rys. 6. Zbiornik zasypowy (fot. IMBiGS)

cessing facilities (using the dry deshaling technology) developed general recommendation regarding performance of the separation process. In these recommendations, the manufacturer emphasizes the possibility of regulating the following technical parameters of the separator:

- altitude of dumping bars in the collection zones: of low-density product (coal), intermediate product and high-density product (waste materials),
- longitudinal angle of the working plate within the range of  $0^\circ$  through  $-2^\circ$ ,
- transverse angle of the working plate within the range of  $0^\circ$  through  $-10^\circ$ ,
- quantity of air fed under the individual separation zones,
- settings of flaps regulating directing the separated materials to specified and defined separation products.

Regulation of individual named technical parameters must be executed during preliminary testing in order to obtain the best possible raw material separation into individual products.

#### Auxiliary equipment in the dry separation installation

Dry shaling (enrichment) installations operating as independent processing facilities or research installations can be equipped with additional modules (Baic et al. 2016; Mijał, Tora 2018). They can be classification, crushing or feeder modules. Their aim is to prepare the raw material (obtainment of proper grain class and elimination of excessively large grains of excavated coal) for separation in accordance with the accepted process regime.

**CLASSIFICATION MODULE** – Classification module includes: two-deck vibrating screen and conveyor collecting the lower classification product. Raw material has various granulometric composition, which has considerable impact on the dry separation process results. Two-deck vibrating screen optimizes the grain content in the material from the feeder module. It allows for limiting the upper limit of grains to, e.g.  $>50$  mm, by sifting them from the upper deck and setting of the lower limit of grains to, e.g.  $<25$  mm or  $<6$  mm or others, specified experimentally, by sifting them with the lower deck. Lower class grains,  $<25$  mm or  $<6$  mm, are then removed from the installation with use of the conveyor belt (Figure 5).

**CRUSHING MODULE** – Crushing module includes: vibrating conveyor; jaw crusher; conveyor belt (reverse) to collect the crushed material and transport it to the feeder module. Sifted large material, e.g.  $>50$  mm, unacceptable in the shaling procedure, from the upper deck of the vibrating screen is transported by vibrating conveyor (chute) to the jaw crusher. Properly regulated range of the crusher outlet allows for crushing of excessively large grains. Crushed material is then transported from the jaw crusher by a conveyor to the feeder module. Crushing module in such device configuration allows for crushing of the grains and thus obtaining grain size acceptable for the dry blowing in the dry separator (Figure 5).

**FEEDER MODULE** – Feeder module includes: intake container; belt dozer with inverter; raw material conveyor belt and integrated scale. The intake container stores a portion of the excavated coal. From the container, it is transported by belt dozer with regulated feeding speed, which allows for,



Tab. 1. Approximate investment outlays and operating costs – USA (Honaker, Luttrell 2009; Honaker 2007)

Tab. 1. Szacunkowe nakłady inwestycyjne i koszty operacyjne – USA (Honaker, Luttrell 2009; Honaker 2007)

Type of process	Investment expenditures	Operating costs
	\$/Mg/hour	\$/Mg
Dry separation (FGX air-vibrating separator)	6.200,00	0.50
Wet enrichment methods	13.000,00	1.95

Tab. 2. Approximate investment expenditures and operating costs – Republic of South Africa (de Korte 2014)

Tab. 2. Szacunkowe nakłady inwestycyjne i koszty operacyjne – RPA(de Korte 2014)

Type of process	Investment expenditures	Operating costs
	\$	\$/year
Dry separation (FGX air-vibrating separator)	1.250.000,00	825.000,00
Wet enrichment methods (Cyclones with heavy liquid)	5.000.000,00	2.480.500,00

if necessary, various loads on the deshaling installation. The feeder conveyor in the feeder module is used to transport the quantity of material specified by the deshaling regime to further installation modules. The integrated scale on the conveyor or belt is used to register and monitor the quantity of material from the feeder module transported to the further installation modules (Figure 6).

**CONTROL MODULE** – Control module is a control panel allowing for consecutive running of devices in individual modules of dry coal separation installation. Control panel, in case of a complex installation, allows for setting the order of operation of chosen individual modules. It also constitutes an important element of safety conditions during startup and shutdown of the devices.

#### Uses of dry enrichment process in FGX devices

Installations of dry coal separators can be individual facilities for enrichment of excavated coal. This is the case for several hundred such installations in China and individual installation in several other countries (Tangshan...2012). The enriched grain classes have the maximum grain size of 100, 80, 75, 50, 25 mm. Minimum grain size is most often 25, 12, 6 or close to 0 mm. Width of grain classes will be specified according to experience or result the granulation of raw materials.

FGX separators may replace the process of water-based enrichment in jiggers in a technological system of a processing facility. Replacement of jiggers or even cyclones with heavy liquids to dry separators was researched in USA and South Africa (Baic et al. 2015a). Considerable economic effects were found. Summary of that information is in the next section.

Dry shaling installations can also be a bypass in the enrichment sections of the existing processing plants. Such solutions are applied in China (Tangshan...2012) in coking coal processing facilities. They are used to reduce the quantity of gangue before feeding of partially enriched raw materials to the water-based enrichment processes. FGX separators operating with separation density of at least 2.0 g/cm<sup>3</sup> guarantee obtainment of low ash contents in the concentrate for easily enrichable coals, which is required by the coking industry. In case of hard-enrichable coals, dry separation should be supplemented by water-based enrichment.

FGX separators, owing to the dust removal modules, allow for removal of the finest grains of the raw materials, which will not be introduced into the water system. Owing to this, coal sludge management is much less problematic. Dry dust can be a trading product and can be added to a concentrate.

Dry separators can be used to adjust the raw material if it has varying levels of gangue. This happens in case of mining several layers and lack of selective feeding of the raw material to the processing facility (Blaschke, Baic 2018)

#### Economic efficiency

Economic efficiency analysis of dry coal separation technology was a subject of many reports developed in USA and Republic of South Africa. The simplified results of the economic analysis obtained for a single dry separation installation operating in the USA are shown in Table 1.

The summary presented in Table 1 shows that investment outlays of dry coal separation technology account for 48% of investment outlays of wet enrichment methods (2 times lower). Whereas operating costs of dry coal separation technology account for 25% of operating costs of wet enrichment methods (4 times lower) (Honaker, Luttrell 2009; Honaker 2007). However, it should be emphasized here that the data presented in Table 1 reflect legal and environmental conditions as well as the location of coal mining plants and coal enrichment, quality parameters of coal, technological infrastructure as well as requirements set by the power sector in USA.

While the report developed in Republic of South Africa (de Korte 2014) presents, among others, approximate investment outlays and operating costs of dry separation technology in comparison to wet enrichment methods using cyclones with heavy liquid – Table 2.

The summary in Table 2 shows that the investment outlays of dry separation technology account for 25% of investment outlays of wet enrichment methods (4 times lower). While operating costs of dry separation technology account for 32% of operating costs of wet enrichment methods (3 times lower). The economic efficiency measures – PP (Payback Period) and ROI (Return on Investment) as well as NPV (Net Present Value) of the aforementioned technology were also compared – Table 3 and Table 4.

Tab. 3. Approximate values [PP] and [ROI] (de Korte 2014)

Tab. 3. Szacunkowe wartości okresu zwrotu PP i zwrotu z inwestycji (ROI) (de Korte 2014)

Type of process	Payback Period	Return on Investment
	years	%
Dry separation (FGX air-vibrating separator)	0.72	39
Wet enrichment methods (Cyclones with heavy liquid)	0.92	9

Tab. 4. Net Present Value [NPV] versus time (de Korte 2014)

Tab. 4. Wartość bieżąca netto (NPV) w czasie (de Korte 2014)

Years	Dry separation (FGX air-vibrating separator)	Wet enrichment methods (Cyclones with heavy liquid)
	\$	\$
1	563.377,00	- 182.269,00
2	3.139.096,00	5.075.908,00
5	9.325.539,00	17.705.164,00
10	15.934.341,00	31.196.642,00
15	19.684.353,00	38.852.068,00
20	21.812.210,00	43.195.963,00

The results presented in Table 3 show that dry separation systems using air-vibrating separators of the FGX type have a shorter payback period [PP] than those using for separation the cyclones with dense liquid. Moreover, they have a higher return on investment ratio [ROI].

Low investment outlays and operating costs of installations with FGX separators allow to obtain a positive NPV value already at the end of the 1st year of operation, whereas for installations using cyclones with dense liquid the NPV value at the end of the 1st year of operation is negative. After the second year of operation, the value of NPV index for installations using cyclones with dense liquid takes a higher value than NPV value for systems with FGX separators. As can be seen from the data presented in Table 4, the value of the NPV index also increases in the following years, whereas the increase of NPV for installations using cyclones with dense liquid is faster than increase of NPV for installations with FGX separators, due to the higher value of annual outlays.

The analysis shows that dry coal separation installations could be a good solution for short-term or low-capacity investments in South Africa. In case of long-term or high-capacity investments, installations based on wet separation technologies could be more economical, despite higher investment outlays and operating costs.

The author of the report (de Korte 2014) emphasizes that the selection of a given technology, apart from investment outlays and operating costs, is above all influenced by many other factors such as: availability of water for enrichment processes, location of enrichment plant and recipients of commercial products, characteristics of raw coal dispersibility, quality requirements of the clients and the availability of the necessary infrastructure.

Application of the dry separation process allows for (Baic, Blaschke 2013, 2018; Baic et al. 2015b):

- lowering of investment costs of coal processing facilities by full or partial elimination of water-based enrichment methods,
- reduction of operational costs connected with the production of traded coal products and increasing of market competitiveness,

- reduction of exploitation costs of the water-based enrichment process with the use of by-passes thanks to limitation of the water and sludge use and reduction of water and energy consumption,
- limitation of number of installations and devices, and prolonging their life by constructing individual dry separation facilities replacing the traditional processing facilities,
- application of a technological solution auxiliary to the existing technological installations for energy industry coals enrichment using the water methods, reducing the load on jigs, which allows for increasing the quantity of enriched material,
- effective deshaling (removing gangue), improvement of calorific value of the concentrate, desulphurization (removing pyrite sulphur and mercury),
- secondary enrichment of the trade product for high quality ecological production of qualified fuels,
- effective use of fuel products from this technological solution, used as substitutes for natural crushed stone in road and engineering works and as materials for filling the post-mining voids,
- recovery of coal substances from excavated materials distributed in the environment and crushed stone production.

## Conclusion

In USA and South Africa (and many other countries), enrichment is not executed in cyclones with heavy liquids. The reason is relatively low accuracy if separation causing losses in coal substances placed among the waste materials and intermediate materials. Research performed in Australia, South Africa, USA and by ITG KOMAG (presented during KOMAKO conferences) confirm the above opinion. According to the reference materials, separation accuracy rate (probable dispersion) in cyclones with heavy liquids falls within the range of 0.04–0.12, in jiggers: 0.14–0.2, and for FGX separators it reaches the level of 0.2. However, often in the industrial conditions, the separation accuracy rate for jiggers can reach the level of 0.31 as result of their improper

functioning (Blaschke, Baic 2018). High probable dispersion of jiggers caused their replacement in USA, South Africa, Australia and many other countries, and replacing them with heavy liquid cyclones. Deshaling in FGX installations occurs in the fraction zone with the density above 2.0 g/cm<sup>3</sup>. Thus, lower accuracy of separation does not matter that much, because under the separation conditions the coal substance (with regulated device operation) is not removed with the waste. Therefore, dry deshaling of excavated coal in FGX separators can replace jiggers in coal enrichment facilities and in designed new enrichment sections of middle and fine class. This also allows for considerable economic benefits. It

is worth mentioning that the partially deshaled coal product fulfils the quality requirements (guarantee parameters of the boilers) of the domestic recipients from power plants and heat and power plants. FGX dry separators are perfect for improving the quality of traded energy industry coal products for individual recipients. This is confirmed by the fact that two FGX3 installations are currently active in Poland.

The advantages of dry separation technology fully justify the opinion of the American authors presented at the World Coal Processing Congress (Ghost et al. 2013) that the enrichment process in FGX installations is the „21st century technology”.

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### *Powietrzno-wibracyjne separatory typu FGX do oczyszczania urobku węgla kamiennego – parametry funkcjonalne i ekonomiczne*

*Wibracyjno-powietrzne separatory typu FGX są konstrukcją opracowaną na przełomie XX i XXI wieku. Powstała ona w Chinach jako połączenie pionowo-prądowego klasyfikatora powietrznego i separatora wibracyjnego o zwężanej rynnie roboczej. Konstrukcja ta została zmodyfikowana (rys. 1). Separatory te okazały się bardzo skuteczne do odkamieniania urobku węglowego. Mają na celu usunięcie możliwie największej ilości ziaren kamienia. Z tego też względu rozdział prowadzony jest przy gęstościach powyżej 2,0 g/cm<sup>3</sup>. W artykule opisano budowę wibracyjno-powietrznego separatora, podano też zasadę jego działania. Wymieniono czynniki wpływające na efektywność wzbogacania oraz wpływające na dokładność rozdziału parametry nadawy. Omówiono parametry techniczne separatora podlegające regulacji a wpływające na przebieg procesu rozdziału. Podano syntetyczne informacje dotyczące efektywności ekonomicznej. Przedstawiono możliwości zastosowania separatorów FGX w układach istniejących zakładów wzbogacania lub jako samodzielnych zakładów przerobczych. W Polsce pracują obecnie trzy separatory FGX. W Instytucie Mechanizacji Budownictwa i Górnictwa Skalnego w Oddziale Katowickim badane są, na instalacji o wydajności do 10 Mg/h, węgle kamienne niektórych kopalń. Rezultaty badań potwierdzają możliwość implementacji separatorów FGX w warunkach krajowego górnictwa węgla kamiennego. Dwa separatory, o wydajności ok. 30 Mg/h, poprawiają parametry węgla importowanego przeznaczonego dla odbiorców indywidualnych; są własnością firm prywatnych. W świecie pracuje już ponad 2000 separatorów FGX w kilkunastu krajach. Są one skuteczne i nazwano je „technologią XXI wieku”.*

*Słowa kluczowe: węgiel kamienny, sucha separacja, odkamienianie, parametry funkcjonalne i ekonomiczne*