sciendo

Management Systems in Production Engineering

2025, Volume 33, Issue 4, pp. 546-553

Date of submission of the article to the Editor: 04/2025
Date of acceptance of the article by the Editor: 10/2025

DOI 10.2478/mspe-2025-0056

THE APPLICATIONS OF VIBRATORY CRUSHERS TO IMPROVE THE EFFICIENCY OF INDUSTRIAL CRUSHING LINES

Marcin Mazur
AGH University of Krakow

Abstract:
The article presents design solutions of currently used vibratory jaw and cone crushers. These crushers operate based on a different type of load exerted on the crushed material than in presently used crushing machines, namely using rapidly changing multiple impacts of relatively short duration. As a result, they enable achieving more beneficial technological results in higher degrees of fragmentation, higher shares of desired fine grain classes, and lower total energy demand. Due to the above-mentioned properties, they can be a more advantageous alternative to currently used crushing machines. Several studies have confirmed the high technological capabilities of vibratory crushers when crushing materials with different physical and mechanical properties. In particular, when crushing hard and very hard materials (very compact rocks, ceramic materials, ferroalloys), these crushers demonstrate significantly better capabilities than the previously used "classic" crusher designs, i.e. jaw, cone, impact. The research results show the technological possibilities of vibratory crushers when used for crushing limestone, for producing sorbents for flue gas desulfurization, and for crushing sanitary ceramic waste for the production of aggregates for concrete. The possibility of using vibratory crushers in a prototype installation for gold extraction is also described. The advantages of implementing vibratory crushers in industrial crushing technological lines are related to increased efficiency, increased technological possibilities, and the simplification of currently used crushing lines. In most cases, this may result in a reduction of the required crushing stages and, consequently, in the simplification of industrial crushing technological lines, directly reducing the required investment and operating costs.

Key words: crushing, vibratory crushers, sorbent production, ceramic waste utilization

INTRODUCTION

Crushing is an indispensable process at many stages of mineral extraction and processing. A crusher's construction and operating principle are closely related to the dominant type of load causing the disintegration of grains. In jaw, cone and roller crushers, the dominant load is characterized by its quasi-static nature. In the case of impact crushers (hammer, rod, centrifugal), the grains of the crushed material are disintegrated mainly as a result of dynamic impacts (usually one-time) on the working elements of the crusher or sometimes impacts on each other (Vertical Shaft Impactor crushers). Crushing processes are also carried out in another group of crushers, in which the dynamic impact of the working elements on the crushed material is also used, but it occurs there multiple times. These machines are based on vibration technology. The main difference between impact and vibration crushers is the frequency of contact of the working elements with the crushed material, which in vibratory crushers is much higher and oscillates in the range of 15 to 35 Hz. The two main groups of these machines are cone and jaw vibratory crushers. There has been a dynamic development of jaw and cone vibratory crushers in recent years. These machines have several advantages over conventional designs. They are characterized by a much higher degree of fragmentation and the ability to effectively process materials with very high values of compressive strength and high abrasion. These factors mean that vibratory crushers are increasingly used for crushing hard and very hard materials and with a high content of crystalline silica inclusions. Thanks to high-frequency cyclic interactions and usually simple movement of the working elements (jaws, cone), the phenomenon of abrasion of the crusher's working elements by the processed material is minimal. The result is minimal wear of the crusher's working elements and, consequently, obtaining a crushing product practically free of contamination. This allows these crushers to be used in new areas, such as food processing, pharmacy, cosmetics production, and others – Fig. 1.

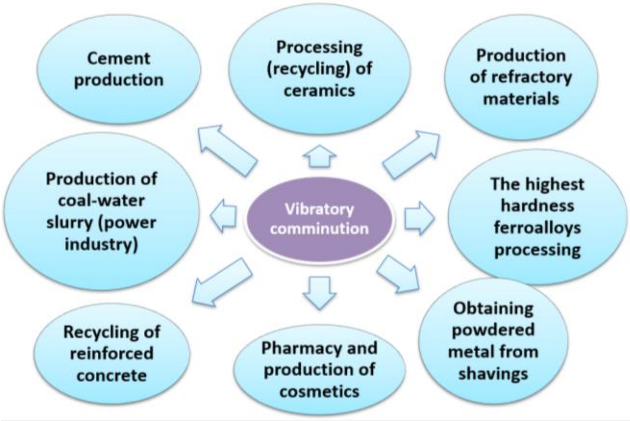

Fig. 1 Possible applications of vibration crushing technology

Very fine crushing of hard and very hard materials also requires significant energy inputs. This is mainly due to the need to use multi-stage crushing technological lines, most often containing jaw, cone or impact crushers. One way to reduce the total amount of energy spent on the crushing process is to reduce the number of machines in the technological line. This is possible by using crushers characterized by much higher degrees of fragmentation than those used so far, i.e. vibratory crushers. The use of vibratory crushers simplifies the technological lines due to the smaller number of crushers and accompanying devices, such as screens, feeders/dispensers, conveyors, control devices, etc. This results in a reduction (sometimes significant) of investment and operating costs.

SYSTEMATICS OF VIBRATORY CRUSHERS – LITERATURE REVIEW

The unambiguous definition of the term "vibratory crusher" poses particular problems. There is no unequivocal definition of this term in the specialist literature; therefore, it is assumed that a vibratory crusher is a crushing machine that meets the following conditions [1, 2]:

- there is a vibrating movement of at least one working element (cone, jaw, pipe),
- the crushing process occurs as a result of dynamic interactions of working elements,
- the minimum vibration frequency of the working elements (element) is at least twice as high as the maximum vibration frequency of the working elements of "classic" crushers, i.e. practically above 15 Hz and up to 25 Hz,

The primary division of vibratory crushers can be presented as follows:

- vibratory cone crushers,
- vibratory jaw crushers.
- The most commonly used are vibratory cone and jaw crushers. There are four types of design solutions for vibratory cone crushers [1]:
- cone crushers with a single-mass inertial vibrator placed in the inner working cone – Fig. 2 [3],

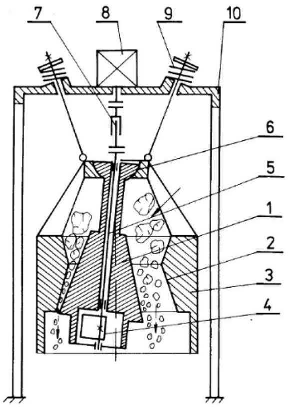

Fig. 2 Vibratory cone crusher with a single-mass inertial vibrator placed in the inner working cone: 1 – inner cone, 2 – outer cone, 3 – inertial body, 4 – vibrator, 5 – vibrator shaft, 6 – joint, 7 – drive shaft, 8 – motor, 9 – body suspension, 10 – crusher frame

Source: [1].

- cone crushers with a dual-mass inertial vibrator placed on the inner shaft of the working cone – Fig. 3 [4],

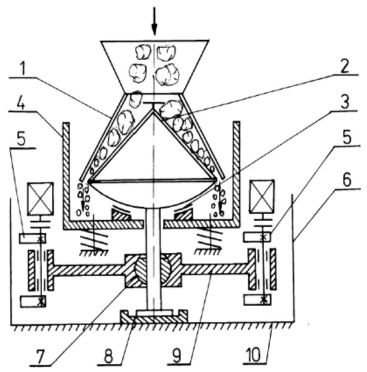

Fig. 3 Vibratory cone crusher with a dual-mass inertial vibrator placed on the shaft of the inner working cone: 1 – outer cone, 2 – inner cone, 3 – cone bearing unit, 4 – crusher body, 5 – vibrator shaft, 6 – cover, 7 – bearing unit, 8 – support, 9 – vibrator mounting, 10 – crusher base

Source: [1].

- cone crushers with a single-mass inertial vibrator placed on the shaft of the inner working cone, Fig. 4 [3],

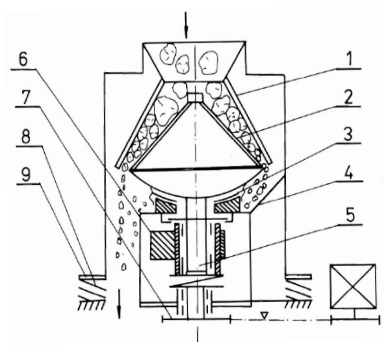

Fig. 4 Vibratory cone crusher with a single-mass inertial vibrator placed on the inner shaft of the working cone: 1 – outer cone, 2 – inner cone, 3 – cone bearing unit, 4 – crusher body, 5 – cone shaft, 6 – vibrator mass, 7 – belt transmission, 8 – spring support, 9 – body support

Source: [1].

Fig. 5 shows a view of a crusher of this type manufactured by Mekhanobr.

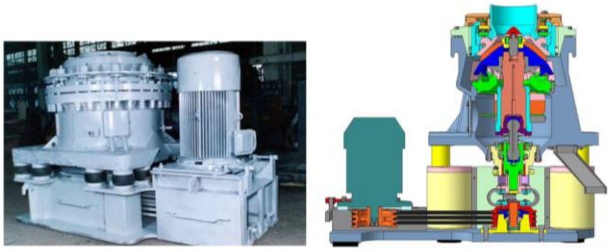

Fig. 5 KID series vibratory cone crusher manufactured by Mekhanobr
Source: [3].

– cone crushers with a dual-mass inertial vibrator driving the outer working cone (with a stationary inner cone) Fig. 6 [3].

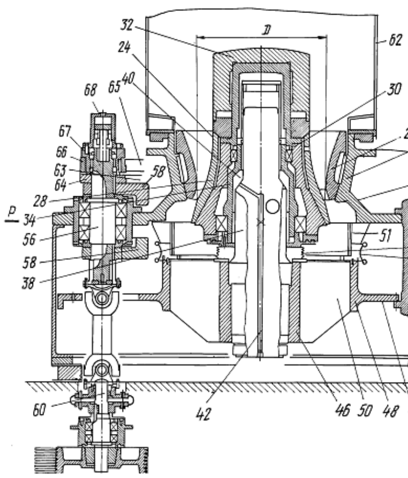

Fig. 6 Vibratory cone crusher with a dual-mass inertial vibrator driving the outer working cone (with a stationary inner cone)
Source: [3].

The inner cone can be driven by one or more inertial vibrators – Fig. 7.

Fig. 7 Vibratory cone crushers with a dual-mass inertial vibrator driving the outer working cone (with a stationary inner cone): WKDC-150 (left – drive by four vibrators) and WKDC-700 (right – drive by one vibrator) manufactured by Mekhanobr
Source: [3].

Greater differentiation of classification occurs in the case of the design of vibratory jaw crushers. The first division includes the number of driven jaws:
– crushers with single jaw drive – Fig. 8,
– crushers with two jaw drive – Fig. 9a and 9b.

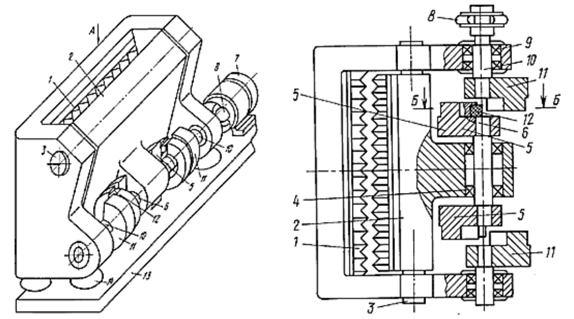

Fig. 8 Single jaw drive vibratory jaw crusher
Source: [3].

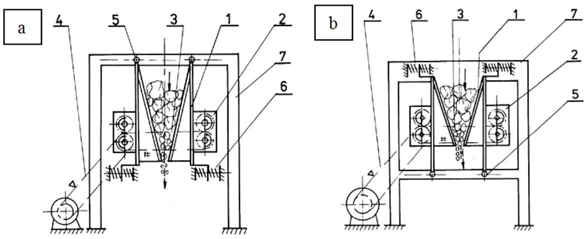

Fig. 9 Design diagram of vibratory jaw crushers with a dual-mass inertial vibrator with upper (a) and lower (b) jaw suspension
Source: [1].

Another division concerns the type of vibrators that drive the jaw, i.e.:
– with a dual-mass inertia vibrator – Fig. 9a, 9b,
– with a single-mass inertia vibrator – Fig. 10,

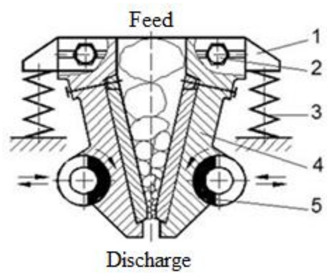

Fig. 10 Design diagram of a vibratory jaw crusher with a single-mass inertial vibrator: 1 – crusher body, 2 – jaw axis, 3 – elastic support, 4 – jaw, 5 – inertial vibrator
Source: [3].

– with a mechanical kinematic vibrator – Fig. 11,
– with hydraulic vibrator.

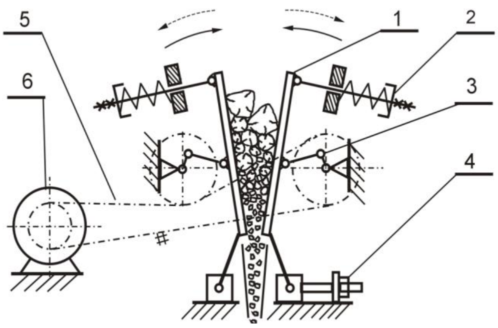

Fig. 11 Design diagram of a vibratory jaw crusher with a kinematic vibrator: 1 – jaw, 2 – elastic system, 3 – kinematic vibrator, 4 – gap adjustment mechanism, 5 – vibrator drive, 6 – motor
Source: [1].

Vibratory jaw crushers can also be divided according to the location of the jaw suspension:

– crushers with upper jaw suspension – Fig. 9a,
– crushers with lower jaw suspension – Fig. 9b.

In addition to the described design solutions of vibratory crushers, there are also vibratory tubular crushers, which, however, have not found wider application in industry and are not included in this article.

A number of studies conducted so far indicate that vibratory crushers are characterized by much higher crushing efficiency than machines operating on the basis of quasi-static compression or dynamic impact [5, 6, 7, 8, 9, 10, 11]. Additionally, vibratory crushers are also characterized by higher "efficiency" of energy use for the crushing process [12, 13, 14, 15, 16]. In other words, a greater amount of energy - than in "classic" crushers - is transferred to the crushed material, causing its more effective disintegration. Therefore, the use of crushers of this type in selected crushing technological lines can bring measurable benefits related to the reduction of investment and operating costs.

METHODOLOGY OF RESEARCH

The test stand of the vibratory jaw crusher (designation KW 40/1) is shown in Fig. 12, while the construction diagram of the crusher and its test stand is shown in Fig. 13.

Fig. 12 Test stand of the KW 40/1 vibratory jaw crusher

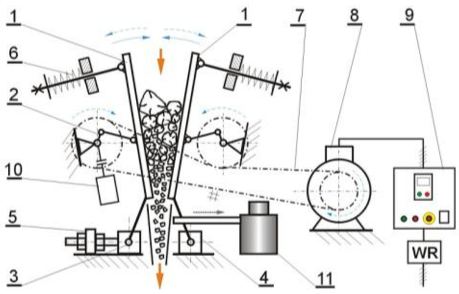

Fig. 13 Construction diagram of the KW-40/1 laboratory vibratory jaw crusher and its test stand: 1 – jaw, 2 – eccentric shaft, 3 – adjustable jaw support, 4 – fixed jaw support, 5 – gap adjustment mechanism, 6 – elastic system, 7 – chain transmission, 8 – motor, 9 – power supply and control system, 10 – rotational speed sensor, 11 – crusher dust removal and air purification system, WR – power consumption recording unit

The stand consists of: the KW40/1 laboratory crusher, the power supply and speed control unit for the crusher motor, the feeder, the power consumption measurement and recording system, the dust removal and air purification system.

The crusher's working unit consists of two movable jaws (1) mounted in an oscillating manner at the bottom. Elastic systems (2) press both jaws against the drive rollers of kinematic vibrators (3). One of the jaws has a mechanism for regulating the outlet gap (4). Both vibrator shafts are coupled with a chain transmission (5), driven by an electric motor (6). The movement of both jaws occurs in a counter-rotating manner, i.e. the jaws simultaneously approach or move away from each other. The crusher jaws have replaceable smooth steel lining, however, it is possible to mount ceramic linings. The crusher's design allows for the adjustment of the stroke of both jaws. The power supply system of the electric motor (9) provides step-less regulation of the rotational speed of the vibrator shafts and, thus, the frequency of jaw vibrations.

The feed for the crushing process in the vibratory crusher was delivered using a vibratory electromagnetic feeder, trying to fill the crushing zone to about half of its height because previous studies [10, 11, 12, 13, 14] showed that with such a filling of the crushing zone, the crusher achieved the highest efficiency. Each test was repeated twice, and the final results are the arithmetic mean of these tests. Granulometric analysis of the feed and crushing product was performed dry in accordance with PN-EN 933-2:2021-01.

Basic parameters of the KW 40/1 vibrating jaw crusher:
Inlet dimensions: 100 x 160 mm, gap adjustment range: 0.5÷10 mm, jaw vibration frequency: 10÷25 Hz, electric motor power 2.2 kW, maximum feed grain size: 40 mm, dimensions 840 x 420 x 980 mm, weight: 145 kg, capacity: 50÷500 kg/h.

APPLICATION OF VIBRATORY CRUSHERS IN SELECTED CRUSHING TECHNOLOGIES

Limestone crushing for the production of sorbents for flue gas desulfurization

The Polish commercial power industry is mainly based on the combustion of hard and brown coal, which generates significant amounts of SO_2 and other gases. Since the 1990s, the Polish power industry has been undergoing an intensive modernization process, which concerned in particular the construction of flue gas desulfurization installations (FGD), or sometimes the introduction of fluidized bed boilers (especially during the modernization of coal-fired units), where the desulfurization process takes place in the boiler immediately after the fuel combustion process (mainly coal). The progressive implementation of desulfurization methods in the Polish power industry (electricity generation and partially in heating) contributed to the development of the domestic demand for limestone sorbents from practically zero at the beginning of the 1990s to approximately 2.5-3 million Mg/year at present [17]. Limestone of appropriate quality is used as the sorbent: in the wet limestone method with finer granulation (limestone flour) and in fluidized bed boilers with slightly coarser granulation (limestone sand). A by-product of flue gas desulphurization is gypsum, which is increasingly used in the construction industry [18, 19, 20].

The limestone sorbent production process usually consists of several stages: after the rock is mined in the deposit, the material is fed to the crushing process line (usually two- or three-stage) and then to the mill (most often a roller-bowl mill). Sometimes, the material requires additional drying before being fed to the mill. In the multi-stage crushing process, jaw or cone crushers are most often used at the first stage, cone or impact crushers at the second stage and usually impact crushers at the third stage. Therefore, it is necessary to build a technological line consisting of a relatively large number of machines because, in addition to crushers and mills, it is necessary to use auxiliary devices (conveyors, screens, separators, control and measurement equipment). One of the methods of simplifying the technological line may be to use a smaller number of machines characterized by higher crushing efficiency than those used so far. The described research aimed to check the possibility of using a vibratory jaw crusher in the limestone sorbent production process.

The feed for the crushing process was limestone from the Czatkowice Mine in Krzeszowice. The grain composition curve of the feed is shown in Fig. 14. It was a product after the second crushing stage (cone crusher) of the technological line used in the Czatkowice Mine – grain size from 5 to 40 mm. Each test was repeated twice, and the final results are the arithmetic mean of these tests. Figure 14 presents the grain size of the feed (FC) and the crushing product in graphic form.

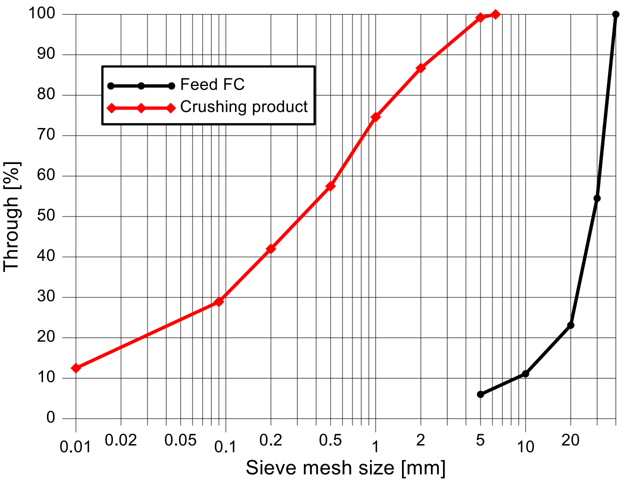

Fig. 14 Limestone granulation: feed and crushing product from the KW-40/1 crusher

The grain size of the crushing product (original sample) from the crusher was 100% in the 0-6.3 mm class, with the share of the 0÷100 µm class being 30.1% and the share of the 0÷400 µm class being 53.9%. The total share of the crushing product with grains smaller than 1 mm was approx. 75% (Fig. 14). The high efficiency of limestone crushing is evidenced by the values of the degrees of crushing i_{90} = 13.8 and i_{50} = 84.7, which is an unheard-of value for currently used crushers. The obtained product can be used to get limestone sands used in fluidized boilers and, to a limited extent, to obtain limestone flours used in the wet method of flue gas desulphurization. Thanks to such ample technological possibilities, the crushing stage based on the vibratory crusher can successfully replace two crushing stages composed of "conventional" crushers (e.g. cone and impact). In certain conditions – when using a closed loop crushing system and with lower total efficiency – the vibratory jaw crusher can be responsible (as an auxiliary) for the grinding process carried out in the roller-bowl mill. Considering the above research results, it can be stated that the vibrating jaw crusher can be used to produce lime sorbents.

Crushing of sanitary ceramic waste to produce concrete aggregates

One of the problems of modern industry is production waste that is not biodegradable. With the growing production scale, attempts to recycle them are particularly important. Among others, sanitary and sanitary-technical ceramics are not biodegradable. The essential products of this group include: washbasins, washbasin posts, toilet bowls and toilet tanks. Other products, constituting 10-15% of production, are medical sanitary installations, laboratory bowls, urinals, bidets, tanks, bathtubs and built-in details such as: hooks for coat racks, soap dishes, shelf brackets, etc. The use of sanitary products creates sanitary ceramic waste, but the production process itself is also waste-generating. Due to production difficulties and rigorous quality control requirements, some products are classified as post-production waste. The most common defects that disqualify the product are: cracks, chips, damage to the glaze, etc. Properly prepared ceramic waste can be successfully used as an aggregate for producing concrete, both as an additive and as the main component [4, 21, 22], and in some cases even for the production of cement clinker [23, 24]. The tests [25, 26] have shown that concrete based on such aggregate has higher strength parameters than concrete based on gravel aggregate.

The technological lines used in construction ceramics waste management plants can be adapted for crushing sanitary ceramic waste. The comminution process in these lines is carried out in two stages. Initially, in jaw or hammer crushers and, finally, in sieve mills or impact disintegrators [27, 28]. There are known solutions using complicated roller-bowl mills to prepare the raw material mass, which is additionally characterized by high investment and operating costs.

The study's main objective was to experimentally confirm the possibility of crushing sanitary ceramic waste to a grain size of the crushing product below 2 mm. The tests were performed using production waste, which was pre-crushed. Similarly to the crushing of limestone for the production of sorbents for flue gas desulphurization, the laboratory stand of the KW 40/1 vibrating jaw crusher was used for the tests (shown in Fig. 11 and 12). A 1 kg sample of material with the same grain size of 20÷50 mm was used for one crushing test (Fig. 15). The final results are the average of two crushing tests.

Fig. 15 Comparison of grain size of ceramic waste before and after crushing
Source: [27].

The research program included, among others, testing the effect of the outlet gap on the grain size of crushing products. Figure 15 compares the grain size of the feed and the crushing product with the outlet gap s=1.0 mm. Figure 16 shows a graph illustrating the effect of the outlet gap size "s" on the grain size of the crushing product.

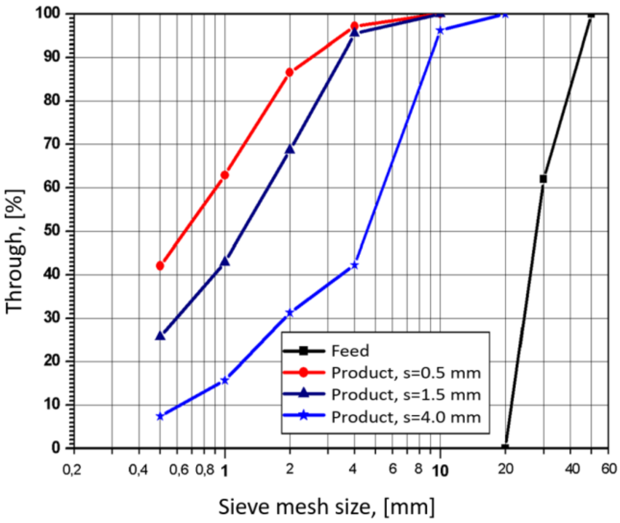

Fig. 16 The influence of the outlet gap s on the grain size of the crushing product
Source: [27].

As seen in the above graph, at the outlet gap s = 0.5 mm, the yield of the grain class below was approximately 87%, while for the gap s = 1.5 mm, this yield was almost 70%.

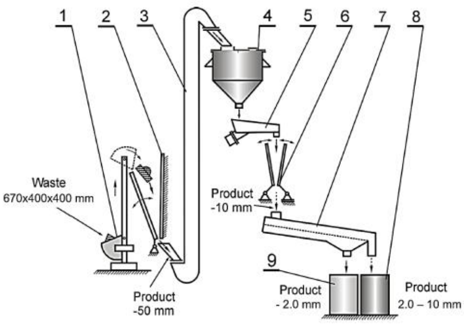

Fig. 17 Proposed solution of the technological line for grinding sanitary ceramic waste
Source: [29].

It should be noted that sanitary ceramic waste is characterized by a relatively high value of compressive strength RC = 400-600 MPa. Considering the above, it can be stated that the vibratory jaw crusher is characterized by a high efficiency of crushing sanitary ceramic waste.
Based on the described research, a solution for a technological line for grinding sanitary ceramic waste was proposed and implemented [29], shown in Fig. 17.

Application of a vibratory crushers in a mobile gold extraction installation

Thanks to dynamic effect (impact) during crushing, vibratory crushers are characterized by higher crushing efficiency and lower weight. This results directly from using the inertia of working elements (jaws) to carry out the crushing process, unlike machines using quasi-static compression. As a result, the design of the jaw drive system transfers smaller forces. In consequence, neither the kinematic system of the jaw drive nor its support has to be designed for such significant loads as in "classic" crushing machines. This results in a significantly lower weight of vibratory crushing machines, allowing them to be used in new applications. Figure 18 shows a unique mobile installation for gold extraction. Using vibratory crushers reduced the number of machines, thus significantly reducing the total weight of the system. This allowed the line to be built on a transportable tyre chassis.

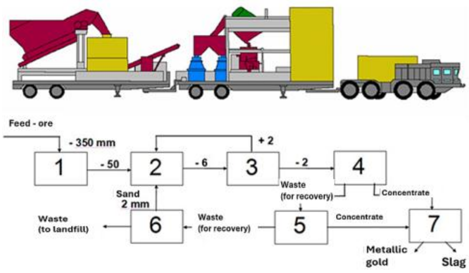

Fig. 18 An example of a gold extraction installation using vibratory crushers: 1 – vibratory jaw crusher, 2 – vibratory cone crusher, 3 – screen, 4 – centrifugal vibrating concentrator, 5 – screen, 6 – hydrocyclone, 7 – gold smelting furnace
Source: [30].

The main elements of the presented solution are vibratory crushers: jaw and cone. The first stage includes a vibratory jaw crusher with high crushing efficiency, which prepares the feed (gold-bearing ore) for the vibratory cone crusher, which acts as the second crushing stage. The cone crusher operates in a closed loop circuit using a screen, ensuring that the crushing product's maximum grain size is less than 2 mm. The obtained product is suitable for further processes enabling gold extraction.

SUMMARY

Vibratory crushers, both jaw and cone, are characterized by much higher crushing efficiency compared to jaw and cone crushers operating on the principle of quasi-static crushing. This is a consequence of the impact mechanism of the machine's working elements on the crushed material and causes vibratory crushers to have several advantages over other crusher designs:

- the ability to obtain high degrees of fragmentation, even above 50 (which allows one vibratory crusher to perform several crushing stages),
- simplification of the construction of the technological line by eliminating auxiliary devices for crushing stages (feed, transport, air purification),
- the ability to almost entirely dynamically balance vibratory crushers (the ability to use smaller foundations),
- significantly smaller mass and dimensions than other crusher designs,
- vibratory crushers with inertial vibration excitation do not require any protection against damage by metal material,
- the ability to crush materials with very high compressive strength (RC even up to 2000 MPa), e.g. ferroalloys, special ceramics, glass, and very compact rocks.

Vibratory crushers are increasingly used for very fine crushing of hard and very hard materials, i.e. those that should not be processed in impact crushers (hammer or rod) due to the high wear of their working elements. The research presented in this article confirms the high suitability of the vibratory jaw crusher for crushing hard sanitary ceramic waste. Thanks to the high degrees of fragmentation and low sensitivity of the working elements to friction wear, building a relatively simple (only two-stage) technological line for utilizing sanitary ceramic waste and producing full-value aggregates for producing high-quality concrete is possible. Also, thanks to the very high efficiency of limestone crushing, manifested by obtaining very high degrees of fragmentation, it is possible to build a simpler and, therefore, less cost-intensive production line for lime sorbents used in desulphurization of boiler flue gases. The low weight of vibratory crushers also allows the construction of mobile or semi-mobile installations based on these machines. This is particularly important when the deposit is small or difficult to access due to terrain conditions. In such a case, small and cheap installations can be easily moved. The perfect example is a mobile installation for gold extraction, as described in the article.

Generally, the advantage of vibratory crushers is the simplification of previously used crushing technological lines. One vibratory crusher can replace two, sometimes even three, crushers of different types. This is also associated with reducing the number of auxiliary machines responsible for supplying and receiving material from crushers (e.g. conveyors, feeders, screens, separators), dust removal and air purification, and devices responsible for power supply and control. The result is reduced investment and operating costs to maintain the technological line. This main factor has led to vibratory crushers being increasingly widely used in various industries.

REFERENCES

[1] Sidor J., (1997) Development of vibratory crushers design, *Maszyny Górnicze*, vol. 77, pp. 30-37.

[2] Sidor J., Mazur M., (2017) Application of vibration technology in crushing processes. *Ceramic Materials,* vol. 69 nr 1, pp. 52-56.

[3] Machines for very fine crushing (1993) *Materials of Mekhanobr-Technogen*, Sankt Petersburg.

[4] Halicka A., Ogrodnik P., Zegardło B., (2013) Using ceramic sanitary ware waste as concrete aggregate, *Construction and Building Materials*, vol. 48, pp. 295-305.

[5] Sidor J., Mazur M., (2015) Comparative studies of vibratory crushing process performed in jaw crusher, *Ceramic Materials,* vol. 67 nr 1, pp. 62-66.

[6] Sidor J., Mazur M., (2015) Application of vibration technology in crushing processes, *Transport Przemysłowy i Maszyny Robocze,* vol. 3, pp. 60-65.

[7] Sidor J., Mazur M., (2014) Examination of crushing rock crystal in a vibratory jaw crusher, *Ceramic Materials*, vol. 66 nr 1, pp. 32-36.

[8] Sidor J., Feliks J., Mazur M., (2013) Crushers for coal disintegration in conditions of underground mines, *Transport Przemysłowy i Maszyny Robocze,* vol. 3, pp. 71-74.

[9] Feliks J., Mazur M., (2022) Application of impact hammer crusher for rock salt purification. *Postępy Techniki Przetwórstwa Spożywczego,* vol. 32/61 nr 2, pp. 11-18.

[10] Mazur M., Feliks J., (2023) The use of vibratory jaw crusher for feed preparing for granulation proces, *Konferencja naukowo-techniczna: przemysł przyjazny dla środowiska: 27-29 marca 2023 Gliwice,* Instytut Techniki Górniczej KOMAG, pp. 43-50.

[11] Mazur M., (2010) Examination of quartzite and diabase vibratory crushing, *Materials of Polish Conference of Young Scientists*, Kraków, vol. 5, pp. 93-101.

[12] Mazur M., (2017) Research of crushing efficiency in vibratory jaw crushers, *Doctoral thesis*, AGH University of Science and Technology, Unpublished.

[13] Mazur M., (2019) Determination of Crushing Energy During Vibratory Crushing, *New Trends in Production Engineering,* vol. 2, pp. 287-294.

[14] Mazur M., (2017) Method of determining the Bond Work Index in vibratory crushing, *SGEM2017 Conference Proceedings*, vol. 17, issue 11, pp. 903-910.

[15] Zawada J., (1995) Obciążenia graniczne i pękanie skał*, Wydawnictwo Naukowe PWN*.

[16] Ballantyne G.R., Powell M.S., (2014) Benchmarking comminution energy consumption for the processing of copper and gold ores, *Minerals Engineering*, vol. 65, pp. 109-114.

[17] Galos K., Szlugaj J., Burkowicz A., (2016) Sources of limestone sorbents for flue gas desulphurization in Poland in the context of the needs of domestic power industry, *Polityka energetyczna – energy policy journal*, Vol. 19, No. 2.

[18] Szlugaj J., Naworyta W., (2015) Analiza zmian podaży gipsu w Polsce w świetle rozwoju odsiarczania spalin w elektrowniach konwencjonalnych, *Gospodarka Surowcami Mineralnymi – Mineral Resources Management,* vol. 31, z. 2.

[19] Roszczynialski W., Gawlicki M., (1997) Kierunki zagospodarowania produktów odsiarczania spalin. Materiały *VII Konferencji „Aktualia i perspektywy gospodarki surowcami mineralnymi".* Polanica Zdrój.

[20] Galos K., Smakowski T., Szlugaj J., (2003) Flue-gas desulphurisation products from Polish coal-fired power plants. *Applied Energy,* vol. 75, pp. 257-265.

[21] Medina C., Sánchez de Rojas M.I., Frías M., (2012) Reuse of sanitary ceramic wastes as coarse aggregate in eco-efficient concretes, *Cement & Concrete Composites*, vol. 34, pp. 48-54.

[22] Silva J., de Brito J., Veiga R., (2008) Fine ceramics replacing cement in mortars partial replacement of cement with fine ceramics in rendering mortars, *Mater Struct*, vol. 41, pp. 1333-1344.

[23] Puertas F., García I., Barba A., Gazulla M.F., Palacios M., Gómez M.P., (2008) Ceramic wastes as alternative raw materials for Portland cement Clinker production, *Cem Concr Compos*, vol. 30, pp. 798-805.

[24] Guerra I., Vivar I., Liamas B., Juan A., Moran J., (2009) Eco-efficient concretes: The efffect of using recycled ceramic material from sanitary installations on the mechanical properties of concrete, *Waste Management* vol. 29, pp. 643-646.

[25] Halicka A., Zegardło B., (2011) Odpady ceramiki sanitarnej jako kruszywo do betonu. *Przegląd budowlany*, vol. 7-8, pp. 50-55.

[26] Najm H.M., Ahmad S., (2022) The use of waste ceramic optimal concrete for a cleaner and sustainable environment – a case study of mechanical properties, *Civil and environmental engineering reports*, vol. 32, pp. 85-115.

[27] Sidor J., (2006) The investigations of the very fine crushing of sanitary ceramic production waste in the vibratory crusher, *Zagadnienia urządzeń ochrony środowiska.* Monografie Akademia Górniczo-Hutnicza im. Stanisława Staszica w Krakowie. Wydział Inżynierii Mechanicznej i Robotyki, vol. 32, pp. 277-286.

[28] Sidor J., Mazur M., Feliks J., (2016) Examination of mineral and ceramic materials vibratory crushing, *Mechanizacja, automatyzacja i robotyzacja w górnictwie: Monografia: praca zbiorowa*, vol. 2, p. 134-141.

[29] Sidor J: (2008) Preliminary investigations of industrial line of mechanical processing of ceramic wastes for recycling, *Polish Journal of Environmental Studies*, vol. 17 no. 3A, pp. 507-510.

[30] Zarogastkij L.P., Azbel J.I. (1993) Universal technique of crushing and separation of primary and secondary raw materials. *Russian-Polish Scientific and Technical Seminar on: "Modern technologies of crushing mineral raw materials."* Lublin.

Marcin Mazur
ORCID ID: 0000-0003-0011-3956
AGH University of Krakow
Department of Machinery Engineering and Transport
e-mail: marcin.mazur@agh.edu.pl