IOP Conf. Series: Materials Science and Engineering **427** (2018) 012034 doi:10.1088/1757-899X/427/1/012034

New technology used to prepare ore for flotation based on impact comminution technique

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Abstract. The paper presents a new design of a high-energy mill and describes a pilot installation equipped with a high-energy mill with an output of 3-7(8) Mg/h. The mill design was developed on the basis of a beater wheel mill used to pulverize coal. The potential of reaching good grinding results has been confirmed for the new mill. Achieved degrees of grinding for copper ore initially crushed in hammer and cone crushers range from over 80 to more than 150. The concept of a procedure based on a single-stage method of ore preparation for flotation process is discussed herein. The main elements of the technology are: preliminary flotation as an element of effective preparation of ore for the roughing flotation process, intensive roughing flotation, conventional cleaning circuit, separate processing of middlings with a grinding circuit involving the new type of mills and flotation with separation of tailings as the second component of the final waste.

1. Introduction

Ore enrichment using the flotation method requires proper comminution, which is usually performed in multi-stage processes of crushing followed by grinding. Grinding is dominated by tumbling mills filled with grinding media or autogenous and semi-autogenous mills. Mills with grinding media are widespread in mineral raw materials processing. At KGHM, grinding is based on mills of this type, as well. Comminution is effected in them by grinding media movement forced by a rotating mill shell. Abrasion is the prevailing grinding method, available in each of possible systems of tumbling mill operation.

Currently, at KGHM research is conducting on applying the new method to prepare ore for flotation using a high-energy mill. This type of mill belongs to impact mills, which use kinetic energy of a beater wheel in the grinding process. It is a new structure, developed on the basis of a beater wheel mill used to pulverize coal.

The examined option using a high-energy mill is planned to replace the system used until now, which involves two-stage grinding in tumbling mills in a wet process, with a single-stage grinding executed by a beater wheel mill in a dry process.

The paper presents the results of grinding tests in a beater wheel mill and a proposed technological solution for the process involving preparation of ore for flotation and enrichment based on the new equipment.

2. Current method used to prepare ore for flotation in the KGHM enrichment plants

The technology used to prepare ore for enrichment constitutes an important element of mineral raw materials processing. It determines the effectiveness of usable minerals recovery resulting from the adequate degree of liberation of minerals being enriched from waste rock, and generally affects concentrate production costs.

Currently, the processes involving preparation of ore for enrichment (flotation) include crushing, screening, grinding in rod and ball mills, as well as hydraulic classification in spiral classifiers and hydrocyclones. Power consumption for comminution and classification processes in the case of KGHM PM SA is ca. 15 kWh/Mg of ore. Therefore, crushing, grinding and classification costs range from 40 to 50% of concentrate production costs.

The product of the system used to prepare ore for enrichment is the flotation feed – its particle size distribution is adapted to the size of copper sulphide grains and specific floatability characteristics [1].

Crushing and screening processes are dry, while grinding with classification is carried out in water environment.

In all three plants, preparation of ore for flotation includes crushing operation in hammer crushers to reach grain size below 25-40 mm, and then screening [3]. Only in Lubin Area, preparation of ore for flotation includes the operation of the 2nd stage of crushing in a cone crusher to which the oversize of screen (class over 20 mm) classifying the crushing product of a hammer crusher is subjected.

Therefore, in terms of preliminary comminution, ore preparation includes:

- ore screening in high-yield vibration screens (sieve mesh 25 mm),
- crushing of coarse screening product in hammer crushers.

Worldwide, graining of ore constituting the feed material for mills usually remains under 15-20 mm, sometimes even 5 mm. In Polish plants, the volume of class exceeding 15 mm, which is sent to the mills, is high and amounts to:

- for Lubin Area: 13-15%,
- for Rudna Area: 22-25%,
- for Polkowice Area: 15-20%.

The new technology used to prepare ore for enrichment is completely different from the solutions used so far in the processing of non-ferrous metal ores, and involves using a high-energy mill in the dry grinding process. The mill is characterized *inter alia* by high kinetic energy of beater wheel working tools [2]. The comminution process is a result of repeated hitting of grains by these tools and ground grains bouncing off the mill housing. The linear speed of the main working tool (beater) exceeds 100 m/s, which guarantees high grinding efficiency. An example solution of a high-speed mill is shown in figure 1.

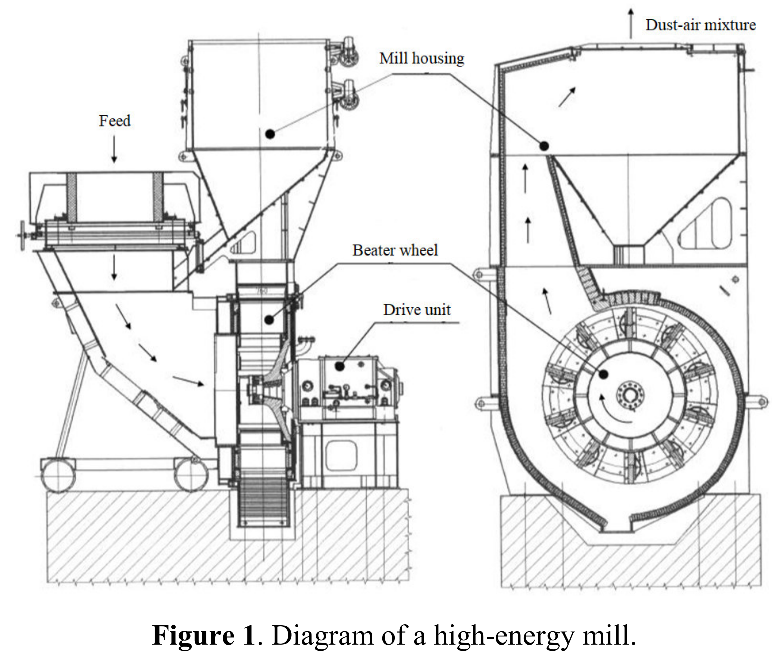

Figure 1. Diagram of a high-energy mill.

The basic components of a high-energy mill with a horizontal beater wheel axis are:

- a two-stage beater wheel, outrigger type, with outside working diameter of ca. 1 m, strengthened for the purpose of grinding non-ferrous metal ores,
- strengthened working chamber walls,
- covering the mill working elements with special materials characterised by high tribological resistance,
- gearless drive using an asynchronous (induction) motor with a thyristor system executing max. speed of the outside beater rim: 150-180 m/s,
- choking the flow through the inlet to the working chamber with a flap,
- aerodynamic emptying of the mill working chamber.

3. Pilot installation equipped with a beater wheel mill

A pilot installation equipped with a high-energy mill has been built in the grinding plant in the Lubin Area (figure 3). It should be stressed that this type of mill for dry impact ore grinding is a prototype design intended for testing purposes.

The installation includes technological circuit from crushed ore container (grain size below 25 (45) mm) to the conditioner preparing pulp for the enrichment process in flotation machines. Schematic diagram of a pilot installation preparing ore for flotation using a high-energy beater wheel mill is shown in figure 2, while in figure 4 the view of the installation in the technology hall is presented.

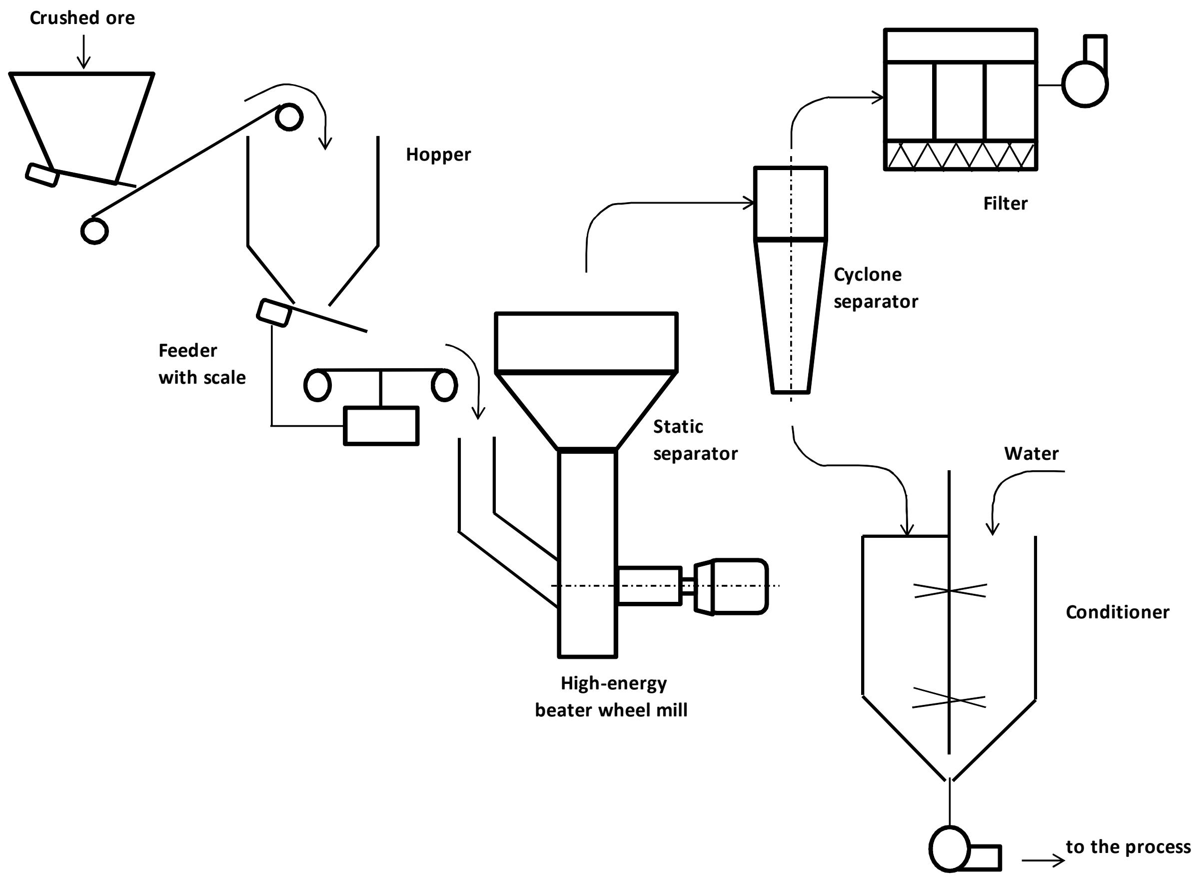

Figure 2. Schematic diagram of the pilot installation.

Copper ore is delivered to the container, and then, through a belt conveyor equipped with a weighing system, it is transported to the feeding opening in the beater wheel mill. The weighing system with a feeder allows for the adjustment of the delivered ore volume between 3 Mg/h and

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10 Mg/h. Ore ground to grain size below 1(0.5) mm is sent via a cyclone separator to the conditioner, which prepares the suspension of ground ore and water for flotation. The weight of 1 dm^3 of the suspension is ca. 1200 g (max. 1400 g).

In order to guarantee the proper air purity, the coarse product of the cyclone separator is sent to the ejector through a filter.

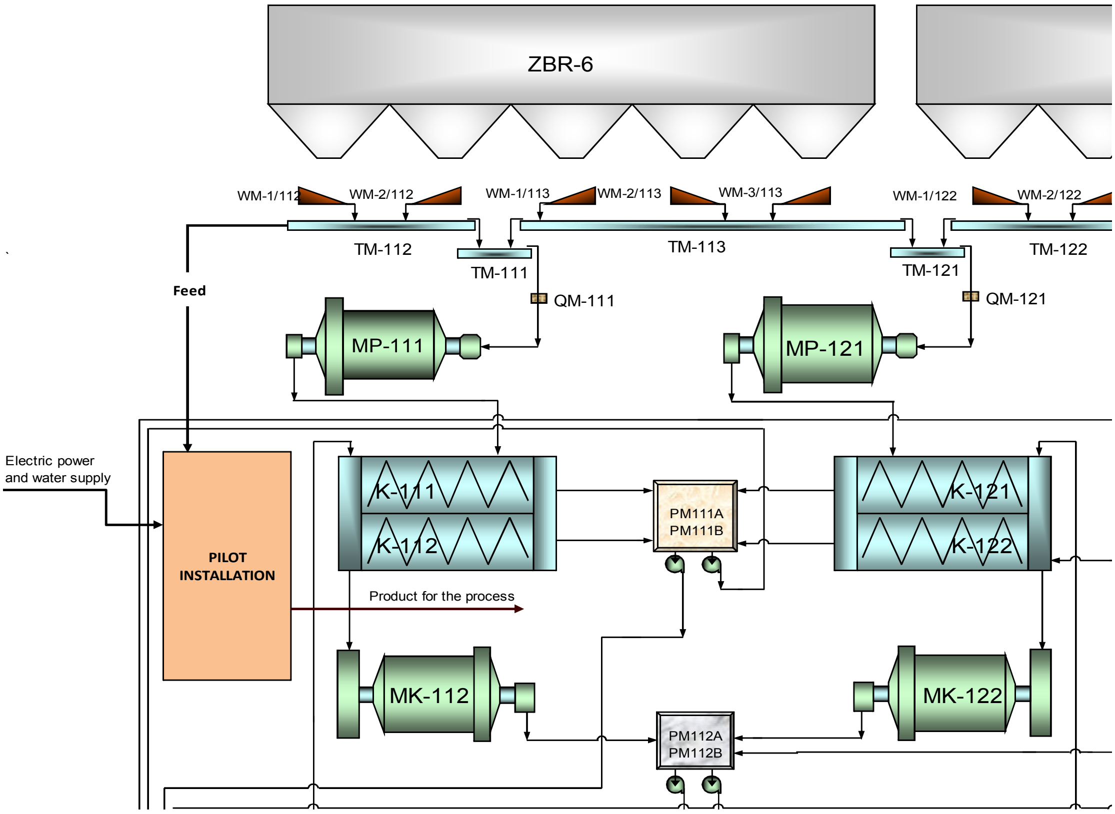

Figure 3. Location of the pilot installation for ore grinding including the beater wheel mill.

Figure 4. View of the pilot installation preparing ore for flotation using the impact comminution technique in Lubin Ore Enrichment Plant.

4. Technological testing of the wheel beater mill

Currently, technological tests of a new high-energy mill in Lubin Area are in progress. Among other things, the following parameters are being determined:

- mill output and energy consumption for grinding,
- grinding product size analysis,
- strength parameters of the mill and material wear of the mill working components.

The mill operating parameters during technological tests:

- motor speed –1630-2600 rpm,
- motor current – 240-280 A,
- motor voltage – 200-400 V,
- motor power – 90-154 kW,
- motor frequency – 33 Hz,
- mill output – 3-7 (max. 8) Mg/h,
- position of classifier flaps 30-60^{o}.

Samples of feed and grinding product are taken during technological tests. Mill feed consists of the product of hammer crushers or a cone crusher.

The continuity of feed delivery to the mill is checked because of gradual adherence of the material to the container walls and resultant breaks in the material stream on the belt conveyor supplying the ore to the mill. A significant impact of the flap in the drawer-type feeder on the installation output has been observed – the opening adjustment is carried out by screwing down a bolt in the proper place on the arm, which is shown in figure 5.

Figure 5. Drawer-type feeder with visible flap opening adjustment.

The maximum installation output has been determined during preliminary tests. The impact of fed material volume on the mill speed has been checked. The output ranging from 4 to 6 Mg/h has been reached for motor speed up to 2600 rpm. Temporary drops in mill speed down to ca. 1650 rpm have been observed, although most of the time at constant loading with feed the speed was between 2180 and 2200 rpm. Increasing preset output above 7 Mg/h caused a drop of the mill beater wheel speed from 1800 to 1600 rpm, which could have resulted in its covering with feed material. At flap maximum opening, the drawer-type feeder was unable to operate in the automatic mode and it was not possible to set the required feed volume. This caused output leaps reaching 10 Mg/h, and instantaneously even 12 Mg/h, which resulted in the mill "choking" and the speed drop to 700-800 rpm. In this case, it was necessary to shut down the feeder and the belt conveyor until the mill was able to process the feed material and return to its high speed.

To sum up, it can be stated that the installation has been working in the most stable way at the output of up to 6 Mg/h in the automatic mode. Above this value, it was necessary to carry out operation in the manual mode, continuously controlling the mill speed so as to prevent its complete stop.

The results of grain size analyses for the feed and grinding product are shown in table 1 and table 2, and their graphical presentation is contained in figure 6.

Table 1. Grain size analysis of the feed – hammer crusher product and high-energy mill product.

Grain class [mm]	Feed of beater wheel mill – product of hammer crusher		Product of grinding: Test 1 Capacity 3.5 Mg/h Rotations 2000 min^{-1}		Product of grinding: Test 2 Capacity 3.5 Mg/h Rotations 1630-2200 min^{-1}	
	γ, %	Σγ, %	γ, %	Σγ, %	γ, %	Σγ, %
+30	21.54	21.54				
30-25	6.92	28.46				
25-15	16.04	44.50				
15-10	8.49	52.99				
10-5	9.91	62.90				
5-3	3.46	66.36				
3-2	2.36	68.72	3.11	3.11	2.92	2.92
2-1	2.36	71.08	2.60	5.71	2.46	5.38
1-0.5	1.73	72.81	3.67	9.38	4.59	9.97
0.5-0.3	0.94	73.75	3.11	12.49	3.07	13.04
0.3-0.2	4.40	78.15	6.33	18.82	5.07	18.11
0.2-0.10	14.94	93.09	30.61	49.43	25.54	43.64
0.10-0.075	0.94	94.03	8.04	57.47	5.91	49.55
0.075-0.045	1.57	95.60	11.02	68.49	13.15	62.70
0.045-0.036	0.31	95.91	2.82	71.31	1.50	64.20
0.036-0	4.09	100.00	28.69	100.00	35.70	100.00
Σ	100.00		100.00		100.00	
d_{80} mm	30.71		0.196		0.193	

Table 2. Grain size analysis of the feed – cone crusher product and high-energy mill product.

Grain class [mm]	Feed of beater wheel mill – product of hammer crusher		Product of grinding: Test 3 Capacity 3-4 Mg/h Rotations 2000^{-1}		Product of grinding: Test 4 Capacity 4-6 Mg/h Rotations 2400^{-1}	
	γ, %	Σγ, %	γ, %	Σγ, %	γ, %	Σγ, %
+30	2.96	2.96				
30-25	2.53	5.49				
25-15	16.03	21.52				
15-10	10.55	32.07				
10-5	14.56	46.63				
5-3	5.70	52.33			0.84	0.84
3-2	5.06	57.39			5.88	6.72
2-1	4.22	61.61	1.88	1.88	7.27	13.99
1-0.5	4.64	66.25	2.62	4.50	7.68	21.67
0.5-0.3	3.59	69.84	2.43	6.93	4.35	26.02
0.3-0.2	12.03	81.87	11.56	18.49	17.37	43.39
0.2-0.10	2.74	84.61	36.06	54.55	36.57	79.96
0.10-0.075	3.16	87.77	5.73	60.28	4.40	84.36
0.075-0.045	2.74	90.51	7.87	68.15	2.92	87.28
0.045-0.036	0.63	91.14	1.23	69.38	0.28	87.56
0.036-0	8.86	100.00	30.62	100.00	12.44	100.00
Σ	100.00		100.00		100.00	
d_{80} mm		15.95	0.196		0.602	

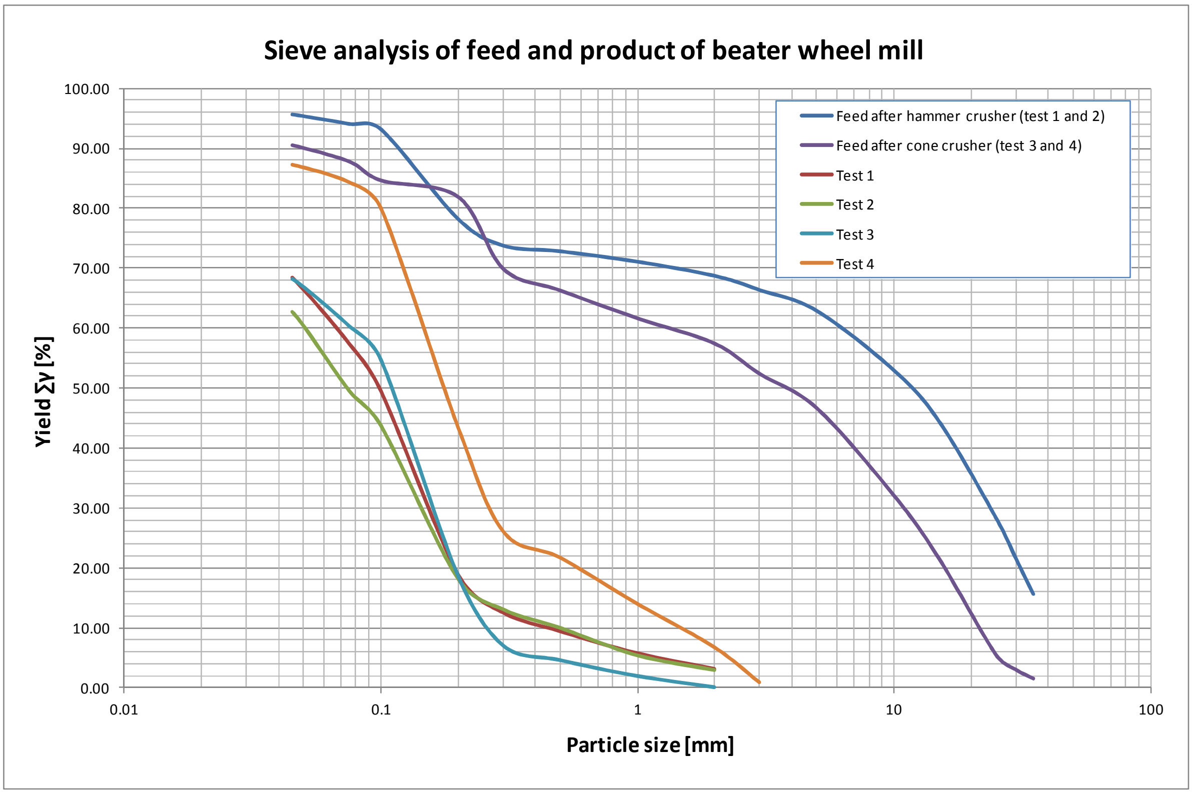

Figure 6. Size analysis of the feed and the product of the beater wheel mill.

The grain size analysis of the grinding product allowed to observe good grinding efficiency of the new mill – the content of the class prepared for flotation range from ca. 40 to 55%. The achieved grinding degrees are very high and range from above 80 to more than 150.

The durability of coating on structural components of the mill, i.e. the beater wheel and the housing reinforcement, is examined simultaneously with conducted technological tests. This gives an opportunity to develop a technology to coat working elements of the mill with modern materials resistant to tribological wear.

5. Summary

As a result of unavoidable deterioration of the quality of mined ores, reduction of enrichment indexes is a natural trend. Therefore, a necessary element of the KGHM activity is to analyse possible actions preventing these disadvantageous trends. Apart from modernisation involving the introduction of new equipment, it is also necessary to make efforts aimed at adjusting flowsheets to changing ore properties.

An important element of this is the technology used to prepare ore for` flotation. The problems of ore crushing and grinding are of particular interest at KGHM. Solutions are being explored which would allow to reduce the number of unit operations connected with multi-stage grinding and classification operations. The research project on grinding in a high-energy mill is an effort aimed at finding these solutions.

Preliminary tests of size reduction in the new mill are positive, although there are still many issues to be clarified with regard to the technology using this type of mill in the conditions of continuous enrichment plant operation.

Nevertheless, the single-stage method of preparation of ore for the flotation process is an advantageous solution, which can be applied on the basis of conventional high-yield systems.

The concept of this technology is shown in figure 7. It includes the following major components:

- the new system to prepare ore for flotation using a high-energy mill,

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- preliminary flotation of raw ore - it is an essential element that prepares the feed for roughing flotation (feed decopperisation) and stabilises the production of the final concentrate, *inter alia* by maintaining reduced organic carbon content in the final concentrate,
- change in middlings processing through grinding in new type mills, e.g. Vertimill®, IsaMill and others, and then separate flotation in an open cycle, including removal of tailings – the second component of final waste,
- implementation of a cleaning circuit in the conventional cleaning circuit,
- changing the method of the final concentrate dehydration by way of conducting the process at a higher temperature, which allows to reduce the water content to ca. 8-9% and to eliminate the drying process.

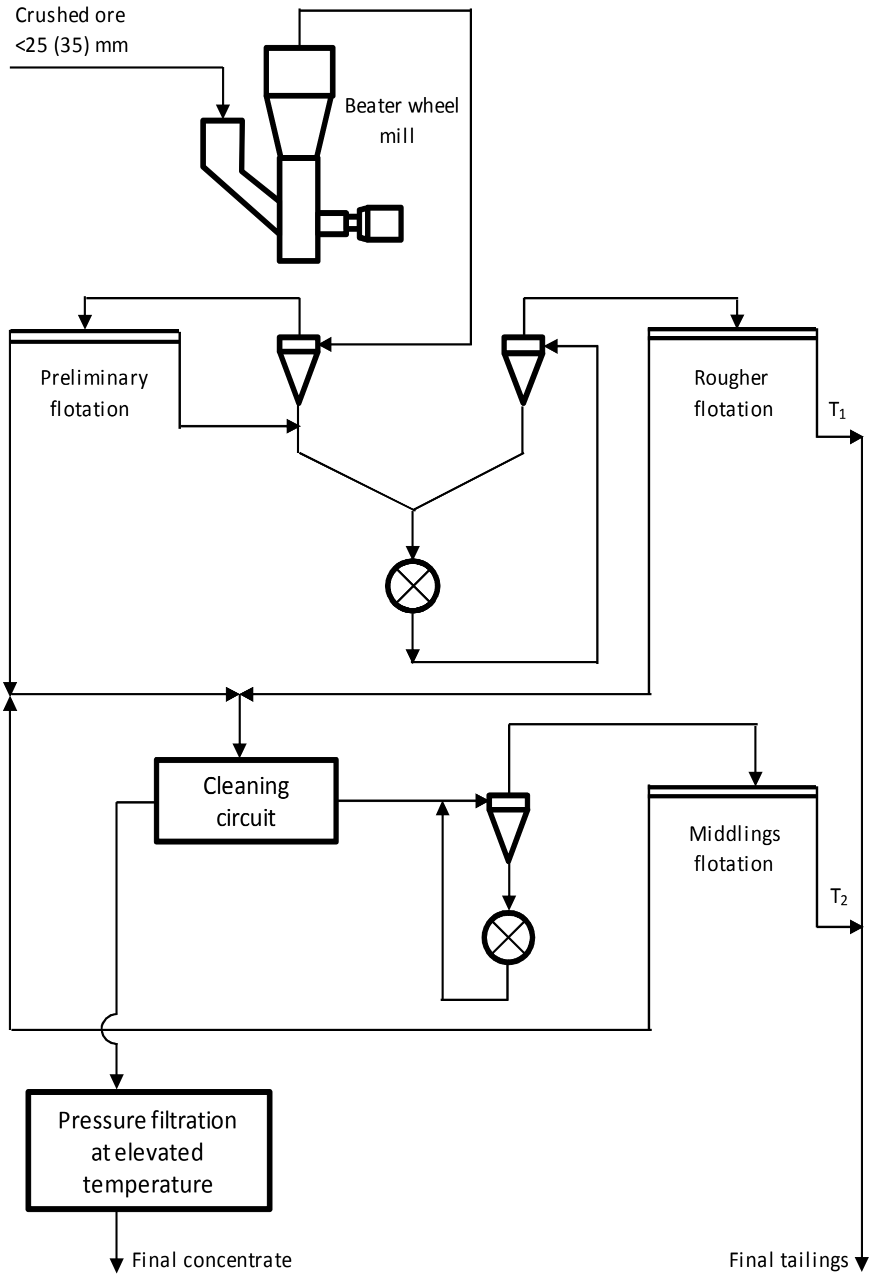

Figure 7. Flowsheet showing the new enrichment technology with a single-stage ore preparation for flotation.

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Modernisation of the system used to prepare ore for flotation, which involves effective grinding, would allow to simplify the enrichment flowsheet, and thus ensure lower ore processing costs. At the same time, the proposed flowsheet is characterised by good technological efficiency in case of low-grade ores and ores which are difficult to enrich.

Research in the scope of grinding in the high-energy mill are continued. This also applies to the study of the flotation process of grinding products in the new mill. Results of flotations will be published.

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