Analysis of impact of HPGR device operation on technological effectiveness of downstream operations of raw materials processing

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Abstract. The aim of the paper was to investigate the impact of HPGR operation on the grinding process effectiveness. A series of laboratory crushing tests, together with tests of grinding in a ball mill, were carried out. There were determined comminution degree values for HPGR and ball mill operation. Results of investigation showed that operational pressing force may determine both effectiveness of HPGR crushing process, as well as the grinding effectiveness. The operating pressing force may influence the dust pollution level, while the noise emission level is not correlated with operational pressure.

1. Introduction – HPGR technology
High pressure technology was invented and introduced in the early 70’s [11] and initially applied mainly to the limestone and cement clinker comminution. Together with development of high-pressure technology, HPGR devices appeared to be useful also in ore processing circuits (iron, copper, gold) and kimberlite crushing (diamonds) [1,3]. Currently, it is one of the most efficient crushing technology in terms of energy-consumption in hard mineral comminution [2]. HPGR device consists of two cylindrical rolls with the same diameter and length, rotating in opposite directions. Each roll is powered by a separate engine of the same power. The rollers are mounted on a solid frame in such a way that one roll is fixed, while the other has the ability to move horizontally due to the hydraulic system acting.

The feed is crushed in the working chamber between two rolls of HPGR device as a result of the pressing forces action. The layer of material is being compacted to a density of approx. 85% of the material original density. Such compression is achieved by applying a high pressure that exceeds the compressive strength of comminuted material [9]. The HPGR product contains a significant yield of fine particles, sometimes compacted in the form of so-called flakes. Commination process in HPGR takes place in two stages. At the beginning, the material is gradually compressed and pre-crushed as a result of narrowing the space between the rotating rolls in the chamber. In the next stage, the pre-crushed material is passing into compacting zone, where the high pressure caused by the force of floating roll pressure acts on the material layer. It acts on all particles passing through the crushing zone primarily by many points of contacts between the individual particles in the layer, which causes a disintegration of most particles. During this process micro-cracks are also created in particles, which reduce the required energy of comminution in downstream operations - grinding in mills. The HPGR products undergo faster disintegration during grinding operation, compared to conventional crushers.
The Bond energy index of HPGR product is decreased, which is one of the main energy-saving factors for roller presses [12].

HPGR usually operates in a closed circuit with material recycle. The device is installed at the crushing stage following cone crushers, jaw crushers or SAG and AG mills. The HPGR product usually goes into a ball mills.

![Diagram of HPGR-based circuit](image)

**Figure 1.** Typical HPGR-based circuit [8]

Generally, the benefits from HPGR application in technological circuits of raw materials processing, can be divided into three groups.

- technological effects – causing increased capacity of entire processing circuit,
- economic benefits – resulting from decreasing the energy consumption of HPGR products. This is caused by micro-cracks and a reduction of the Bond index can be from 10 to 25% [4,5].
- ecological effects – lower noise level, as well as dust and vibrations.

Main aim of the paper was an assessment of economic and ecological effects of HPGR. Economic effects were measured through the course of a downstream grinding process of HPGR products, while ecological effects were investigated through measurements of noise and dust pollution generated by the press device.
2. Materials and methods

Testing programme was carried on a laboratory HPGR device on disposal of AGH University of Science and Technology with the rolls diameter 300 mm, and length 100 mm. Maximum pressing force of the device is 20 kN. HPGR crushing programme included three tests for various operating pressing force: 10, 13 and 16 kN. Each HPGR crushing product was then ground in laboratory ball mill. Three grinding times was used in investigations: 1 minute, 3 minutes and 5 minutes. The limestone rock was the material used in investigations. This type of limestone was with a rather low resistance for comminution, the Bond’s index value $W_i = 9.81$ kWh/Mg. Scheme of investigative programme was presented in Fig. 2.

![Scheme of investigative programme.](image)

**Figure 2.** Scheme of investigative programme.

Particle size analyses were performed for the feed material, for each HPGR crushing products, as well as for each grinding test. The nine grinding products were obtained (three grinding products from each HPGR test), what was presented in Table 1.

**Table 1.** Summary of all crushing and grinding tests.

| HPGP tests | 10 kN | 13 kN | 16 kN |
|------------|-------|-------|-------|
| Number of HPGP crushing products | 1 | 2 | 3 |
| Grinding tests | 1 min | 3 min | 5 min | 1 min | 3 min | 5 min | 1 min | 3 min | 5 min |
| Number of grinding products | 1_1 | 1_2 | 1_3 | 2_1 | 2_2 | 2_3 | 3_1 | 3_2 | 3_3 |

There were calculated comminution degrees for HPGR products as well as for grinding products according to the formula:

$$S_x = \frac{D_x}{d_x}$$  \hspace{1cm} (1)

$D_x$ – characteristic particle of feed [mm]

$d_x$ – characteristic particle of crushing (grinding product), [mm].

The $x$ value denotes the type of characteristic particle, i.e. average – 50% ($d_{50}$ and $D_{50}$), eighty per cent – 80% ($d_{80}$ and $D_{80}$) or ninety-five – 95% ($d_{95}$ and $D_{95}$). For the purpose of article there were determined $S_{50}$ and $S_{80}$ values.
During HPGR tests there were also registering dust emissions [10] (in the form of TSP – Total Suspended Particles) and noise generations [7] (\(L_{AeqT}\) level according to [6]) in order to determine ecological effects of high-pressure grinding. The dust emission level was recorded with using the particle dust analyzer Casella.

Procedures of noise registering and calculations of respective noise indicators are described in the Regulation of the Minister of Environment (2008) [6]. Two main values are calculated most frequently: \(L_{Aeq}\) and \(L_{AeqT}\). The Equivalent Sound Level (\(L_{Aeq}\)) can be determined according to formula (2):

\[
L_{Aeq} = 10 \cdot \log \left( \frac{1}{T} \sum_{i=1}^{n} t_i \cdot 10^{0.1 \cdot L_{AI}} \right) [dB]
\]

where:
- T – total measuring period, [s];
- \(t_i\) – time intervals of T, [s];
- \(L_{AI}\) – registered sound level during the period \(t_i\), [dB].

The value has to be adjusted through suitable corrective filters that adapt the results to the sensitivity range of the human ear. The procedure was described in [6]. For determination the second value, the noise emitted into the environment during the time T (\(L_{AeqT}\)), the following formula should be used:

\[
L_{AeqT} = 10 \cdot \log \left( 10^{0.1 \cdot L_{Aeq}} - 10^{0.1 \cdot L_{AI}} \right) [dB]
\]

\(L_{AI}\) – level of background sound.

3. Analysis of results

The particle size distribution of HPGR feed was presented in Fig.3, together with HPGR crushing products. Feed analysis shows that maximum particle size is finer than 14 mm. About 15% of feed material constitute particles with size below 0.3 mm. Average particle \(D_{50}=6.2\) mm, and \(D_{80}=11.9\) mm. Particle size distributions of HPGR crushing results were also presented in Fig 3.

![Figure 3. Particle size distribution of HPGR feed and HPGR crushing products.](image)

Analysis of the results shows that all HPGR products were finer than 10 mm. Characteristic particles were calculated and presented in Table 2.
Table 2. Characteristic particles calculated for all HPGR tests.

| Characteristic particle | HPGR operating pressing force |
|-------------------------|-------------------------------|
|                         | 10 kN | 13 kN | 16 kN |
| $d_{50}$ [mm]           | 2.8   | 1.9   | 1.4   |
| $d_{80}$ [mm]           | 6.7   | 5.4   | 4.8   |

Results of ball mill grinding were presented in Fig. 4 – 6. Figure 4 presents grinding products for HPGR product crushed at operating pressure 10 kN, while Figs 5 and 6 shows the grinding products for HPGR products treated with the pressing forces 13 and 16 kN, respectively.

Figure 4. Grinding results for HPGR products comminuted at 10 kN.

Figure 5. Grinding results for HPGR products comminuted at 13 kN.
3.1. Characteristics particles and comminution degrees

Characteristic particles calculated for all grinding products are presented in Table 3.

Table 3. Characteristic particles for the grinding products.

| Characteristic particle | HPGR operating pressing force 10 kN | HPGR operating pressing force 13 kN | HPGR operating pressing force 16 kN |
|-------------------------|-------------------------------------|-------------------------------------|-------------------------------------|
|                         | Grindind time                       |                                    |                                    |
|                         | 1 minute                             | 3 minutes                           | 5 minutes                           |
| \(d_{50}\) [mm]         | 2.3                                 | 1.6                                 | 0.9                                 |
| \(d_{80}\) [mm]         | 5.8                                 | 5.3                                 | 4.5                                 |
|                         |                                      |                                    |                                    |
|                         | HPGR operating pressing force 13 kN  |                                    |                                    |
|                         | Grindind time                       |                                    |                                    |
|                         | 1 minute                             | 3 minutes                           | 5 minutes                           |
| \(d_{50}\) [mm]         | 1.7                                 | 1.3                                 | 0.8                                 |
| \(d_{80}\) [mm]         | 5.1                                 | 4.6                                 | 4.1                                 |
|                         |                                      |                                    |                                    |
|                         | HPGR operating pressing force 16 kN  |                                    |                                    |
|                         | Grindind time                       |                                    |                                    |
|                         | 1 minute                             | 3 minutes                           | 5 minutes                           |
| \(d_{50}\) [mm]         | 1.1                                 | 0.7                                 | 0.5                                 |
| \(d_{80}\) [mm]         | 4.4                                 | 3.2                                 | 2.9                                 |

Table 4. Comminution degree for HPGR products.

| Comminution degree | HPGR operating pressing force |
|--------------------|-------------------------------|
|                    | 10 kN | 13 kN | 16 kN  |
| \(S_{50}\) [mm]    | 2.21  | 3.26  | 4.43   |
| \(S_{80}\) [mm]    | 1.78  | 2.20  | 2.48   |
3.2. Dust emission analysis
During the experimental programme also an environmental effect of HPGR was investigated. For each single test a dust emission level was recorded with using the particle dust analyzer Casella. Prior to measurements it was determined a dust emission in the laboratory, when no equipment was operating (so-called background level). The results are presented in Figure 11. It can be seen that average level of dust emission is around 0.1 – 0.2 mg/m$^3$. Values of dust emission for each single test, together with standard deviations, are presented in Table 5.

Table 5. Average values and standard deviations of dust emissions for HPGR tests

| HPGR pressing force, [kN] | Average dust emission [mg/m$^3$] |
|--------------------------|----------------------------------|
| 10                       | 4.8                              |
| 13                       | 5.3                              |
| 16                       | 5.2                              |

Results show that it is rather difficult to clearly indicate if the operating pressure significantly affects the dust emission. Values for pressing force 13 and 16 kN are very similar, what may suggest that differences between individual dust emissions can be insignificant (especially for the two higher values of HPGR pressing force). However, further investigations within this matter are necessary to determine some more clear relationships or models.

3.3. Results of noise pollution
Table 6 presents the results of noise emission level (in dB) of the HPGR device, registered during crushing tests. The values defined by formula (3) were determined and calculated for all HPGR crushing tests.

Table 6. Values of noise and dust emissions obtained for laboratory devices.

| HPGR pressing force, [kN] | Noise level LeqT [dB] |
|---------------------------|-----------------------|
| 10                        | 86.70                 |
| 13                        | 89.04                 |
| 16                        | 87.23                 |
The results presented in Table 6 are similar, regardless the operational pressing force. Differences are insignificant and one may conclude that the level of noise generation during HPGR operation cannot be directly correlated with the operating pressure.

4. Summary and conclusions

The aim of investigations was to verify potential impact of HPGR on the results and effectiveness of downstream grinding operations. Results of investigations showed that various operational conditions of HPGR are effective in different grinding results. There were generally confirmed relationships that can be found in literature that indicate on different effectiveness of downstream crushing and grinding operations, achieved for different values of operational pressure of HPGR device.

Results of investigations carried out indicate that together with increasing operational pressing force comminution degrees of HPGR and grinding products increases too. The more intense growing of average comminution degree can be observed together with increasing of HPGR pressure value. The S80 values also increase, together with increasing of the HGR pressing force, but this growth is significantly lower, comparing the S50 value.

The HPGR operational pressing force – the main operating parameter – is correlated with the dust emission level. Results of investigations show that for higher values of pressure, an increased dust emission level was observed. On the other hand, noise emission of HPGR is regardless the operational pressure.

Results of investigations also confirmed that application of HPGR technology into raw material processing circuits may be effective in lower energy consumption, more environmental friendly as well as achieve more favorable technological effects. The next stage of investigations should be assessment of HPGR operation in ore comminution and processing circuits together with verification of beneficience effectiveness.

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