A method of modeling and control of recycled material to HPGR device in plant scale

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Abstract. The aim of the paper is an analysis and assessment of HPGR device effectiveness in relationship to the volume of recycled material into press. Analysis was carried out in industrial conditions for HPGR device operating in technological circuit of hard ore processing. Data was collected during six months of HPGR operation. There were determined base characteristics of HPGR crushing operations, as well as relationships between operational parameters of the press and feed properties. It was also determined a model that can be helpful in more effective control of HPGR press. Results of investigation show that too low and too extensive pressure volume results in higher mass of the oversize screening product of HPGR recycled to the press. In order to maintain volume of recycled material according to the plant design the operational pressure of the press should be kept within the range that can be calculated from the proposed model.

1. Introduction
Mineral processing operations in technological circuits of ore processing can be divided into two main types:

- operations of size reduction of the feed material, that aim at liberation useful minerals from the gangue. During (usually) several consecutive stages of crushing and grinding the size of final product from that stage is capable of further treatment in beneficiation processes;
- operations of separation, that are treated as primary ones, because here occurs a concentration of useful minerals in one product (concentrate), while the other (waste) contain mostly the material without useful mineral.

The above classification is a very general characteristics of main idea of mineral processing, without detailed description and distinguishing of further operations within each main type, without a variety of supplementary processes, and finally without analysis of arrangement of technological circuits, what significantly influences throughput and effectiveness of mineral processing.

Operations of size reduction are of significant impact on the recovery of useful mineral, because they entirely determine efficiency of separation, through suitable preparation of feed material for beneficiation operations [2,16]. Operations of comminution are very energy consuming and thus they generate a majority of processing costs, it is estimated, that as high as from 30% to 50%, depending the type of mineral and comminution devices applied [4,13]. For example in Polish copper ore processing, energy cost equals around 30% of total processing costs [3,10].
Apart from energy consumption technological effectiveness of comminution, especially in grinding operations might be a concern, mostly due to the relatively low efficiency of tumble mill operations, where a significant amount of grinding media energy is converter into heat or lost [7,8]. Another problem might be inappropriate design of comminution circuit, especially in terms of nominal throughput of individual crushing and grinding devices and volumes of material stream recycles, what causes not optimal operation of the circuit.

Technological development of comminution methods and application of new technologies of crushing and grinding helps in significant reduction of energy costs. In example, HPGR technology is capable of reducing of as high as even 30-40% of grinding energy comparing to tumbling ball and rod mills [1]. New types of grinding, like vibrating mills and electromagnetic mills also shows potentials in improvement of effectiveness of comminution operations in terms of more favourable fineness and energy savings [14,17].

HPGR technology, designed in mid-70’s and developed during next decades [1,11] is regarded as a confirmed method of more efficient comminution of hard ores. Most of concerns concerning the HPGR devices, like increased wear of roll surface, oversize particles, or metal contaminations in HPGR feed, were resolved to some extent. Technological development in rolls production results in constant improvement of the roll’s surface servicing time, while systems of tramp metal detectors help in minimizing the risk of roll’ damage [12]. However the problems might occur in control of HPGR operation, due to a variety of operational factors that need to be controlled in order to maintain high effectiveness of HPGR work.

Plant operational practice often shows that in case of HPGR ore physical and mechanical properties still can be an issue, because they affect the press throughput and the level of comminution degree index. The presented article deals with the problems of volume of HPGR recycle material and their potential impact on press throughput. Some possibilities of control the level of HPGR recycle are also presented.

2. Materials and Methods
Operational pressure of HPGR is a key-parameter that determines the degree of product fineness. However, the operating pressure level should be suitably selected and maintained during the process. Some results of investigations presented in literature [9] show that too low pressing force might result in less intense comminution. Too excessive pressure in turn, may cause that hard flakes (conglomerate of rock) will be formed in HPGR product. These flakes, despite that they consist in fine particles, are returned to HPGR device. They are too coarse to pass to the undersize product in HPGR screening operation, but at the same time these flakes are too hard to comminute themselves on a screen.

The main aim of the paper was to determine a mathematical relationship between operational pressure (P) and volume of recirculating mass of the product (RF). Investigative programme included analysis of operation of HPGR device in plant condition. The HPGR machine with 100 cm roll’s length and nominal throughput (Q) that equalled 100 Mg/h, was crushing the iron ore, and data was collected during 6 months of constant operation. Measurements were performed every 5 minutes. In total more than 50,000 data was obtained. Nominal volume of recycled material was 25%. Figure 1 summarizes a throughput during the analysed time period.
Inspecting the figure it can be noticed that the most frequent throughput was between 95 and 105 Mg/h. However it can be also seen that in nearly 50% of cases there were registered throughput lower than 95 Mg/h, and higher than 105 Mg/h.

Figure 2, in turn, shows a histogram of the recycled material. It can be seen that the most frequent values of percentage recycled material were between 20% and 25%, but outside this range there were more than 50% of cases.

**Figure 1.** Histogram of press throughput volume in analysed period of time.

**Figure 2.** Histogram of the volume of material recycled to HPGR press in analysed period of time.
3. Results of investigations

In the first stage of analysis there were determined linear correlation coefficients between operating pressure and press throughput and recycled material. Results of investigations summarizes Table 1.

| Value of r-Pearson correlation coefficient r [%] | Throughput (Q) | Recycled material (RF) |
|-----------------------------------------------|----------------|-----------------------|
| Operating Pressure (P)                        | 0.033          | 0.019                 |
| Throughput (Q)                                | -              | 0.664                 |

Both coefficient are statistically significant of probability level ($1 - \alpha$) = 0.95. It should be pointed out that considering the huge dataset (over 50,000 cases) presented correlations are significant, however the lowest value of correlation between (P) and (RF) may indicate that there exists the other type of correlation (non-linear).

In the next stage of analysis there were presented values of operating pressure vs. level of recycled material. To do that the values of RF were averaged in each range of operating pressure every 1 bar. Results are presented in Fig. 3.

![Figure 3](image)

**Figure 3.** Relationship between operating pressure (P) and volume of recycled material (RF) in the analysed case of HPGR operation.

4. Discussion

Analysis of the Fig. 3 shows that the content of the recycled material in HPGR feed increases together with increasing the operational pressure. On the other hand, too low pressure also causes an increased content of RF in HPGR feed. This case is logical and easy for explanation. When operating pressure (P) is too low, a degree of comminution in HPGR is also lower, because relatively weaker forces act on the material bed in working chamber between the rolls of HPGR press. The HPGR product is coarser, therefore there are more of an oversize particles on the HPGR screen, that are recycled to the press for re-crushing. The case with too excessive pressure can be explained too, but this also depends on the susceptibility of material for conglomeration and forming so-called “flakes”. Flakes are a kind
of compacted structures of HPGR product that can be formed when very high forces act on the material being comminuted in the press. When the flakes are too hard, to de-agglomerate themselves on the screen, then such structures are recycled to the press. Both cases, described above, are of a negative impact of comminution effectiveness and HPGR capacity. There are also some other factors influencing formation of flakes (i.e. material moisture), but their analysis is not within the scope of this article.

Results of analysis also show that it is possible to determine a range value of operating pressure for which the HPGR device will be working according to nominal (designed) operational parameters, and thus content of recycled material will not be too high. The model describing the volume of recycled material as a value dependent on operating pressure, can be described as follow:

\[ RF = 0.007 \times P^2 - 1.481 \times P + 99.758 \]  

(1)

where:
RF – volume of HPGR product recycled to the press, [%],
P – operational pressure, [bar].

Formula (1) has relatively high value of determination coefficient \( R^2 \) that equals 0.716. It means that nearly 60% of the phenomenon under analysis (i.e. volume of RF) can be described by means of this model. Considering a huge database (over 50,000 cases) this result can be regarded as very accurate.

Assuming that the maximum content of RF in HPGR feed is known, it is possible to determine such range of operating pressure, for which the RF level will not be exceeded. Calculations can be performed also in opposite way, i.e. what values of operating pressure should be accepted in order to maintain a given value of RF.

5. Summary and conclusions
The presented paper concerned the relationship between operational pressure and volume of recycled HPGR product. The research programme confirmed that it is possible to determine a relationship between operational pressing force (P) and HPGR recycled material (RF). The polynomial shape of this curve indicate that both too low and too excessive pressure results in higher content of recycled HPGR product into HPGR feed. This also lead to decreased HPGR efficiency in terms of throughput and achieved comminution degree. It is worth to mention that even though the fineness of crushing products are generally higher together with increasing of operational pressure, it is true within a certain range. Further increases of (P) cause relatively lower increases of comminution degree \( S_x \) and a significant content of flakes in HPGR product is becoming a problem with even higher pressure volume.

Results of investigations also show that it is possible to calculate such an operating pressure that maximizes technological effect in terms of the level of recirculated material. The determined functional relationship is true for the investigated type of ore, but it is also possible to adjust the model for the other types of material. That may indicate, that a range of optimal value of pressure that maximizes technological (fineness, recycled material) and economical (energy consumption) effects of the press operation, can be determined.

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