Verification of the Modernized Technological Process Through TPM Indicators

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Storage of zinc wastes is associated with a high risk of environmental pollution. The way to manage the problem is using the waste materials in the transition process, the final product of which is the zinc oxide concentrate. Transition process is technologically complex and every failure to the discipline results in a large number of unscheduled stops. Such an issue was encountered by B. Recycling. An update of environmental regulations has forced a comprehensive modernization of the technology lines used. The implementation of new solutions brought the necessity of examination and evaluation of the effectiveness of the process. In the paper the analysis conducted for this purpose are described. The elements of TPM method were selected as the test method. The OEE, MTBF and MTTR values for the individual process lines and additionally for the most problematic subassemblies were determined basing on the research and collected data.

Keywords: Total Productive Maintenance, OEE, MTTR, MTBF.

1. INTRODUCTION

The process of poor zinc content ore enrichment is realized in two stages: processing of ore in roll down furnaces and agglomeration of crude zinc oxide. Change of some environmental regulations, especially the strict requirements of Sulphur dioxide emission level in waste gases, forced the company to make some investments. It resulted in separating new company – B. Recycling which business area is the management of zinc-bearing waste out of scattered sources. One part of the implemented changes was the modernization of technological lines for zinc recovery, that were used in the facility before the modification of the previously used technology, and equipping the installation with the system for absorption of Sulphur dioxide were supposed to limit level of dangerous substances in emitted gases to the level allowed by the regulations.

It was also necessary to ensure the supply continuity, which forced the activation of a mechanism stimulating supply system with waste from different producers. The last condition of the company effective functioning was creating efficient enough technology based. Another goal of modernization was increasing the indicators of process efficiency and effectiveness to the European level.

The final product on the process managed in the facility is the zinc oxide concentrated dust that can also be granulated. The roll-down furnaces are charged with the continuous flow batch materials.

The analysis was conducted after one year period, during which work and functioning of lines no 1, 2, and 6 (Fig. 1) was observed and described.

The mentioned technological process is in fact complex and requires strict discipline and even minor negligence may cause a number of unplanned stoppages of the system resulting in the failures or discontinuity in the supplies. This is a major problem for the company, because every brake in the way lines work significantly influences production effectiveness. The necessity of depicting the quantitative description of the current state and defining the effects of the implementation of new solutions has appeared. Certain TPM indicators were chosen as a test method the most suitable for this case. [1, 3, 9].

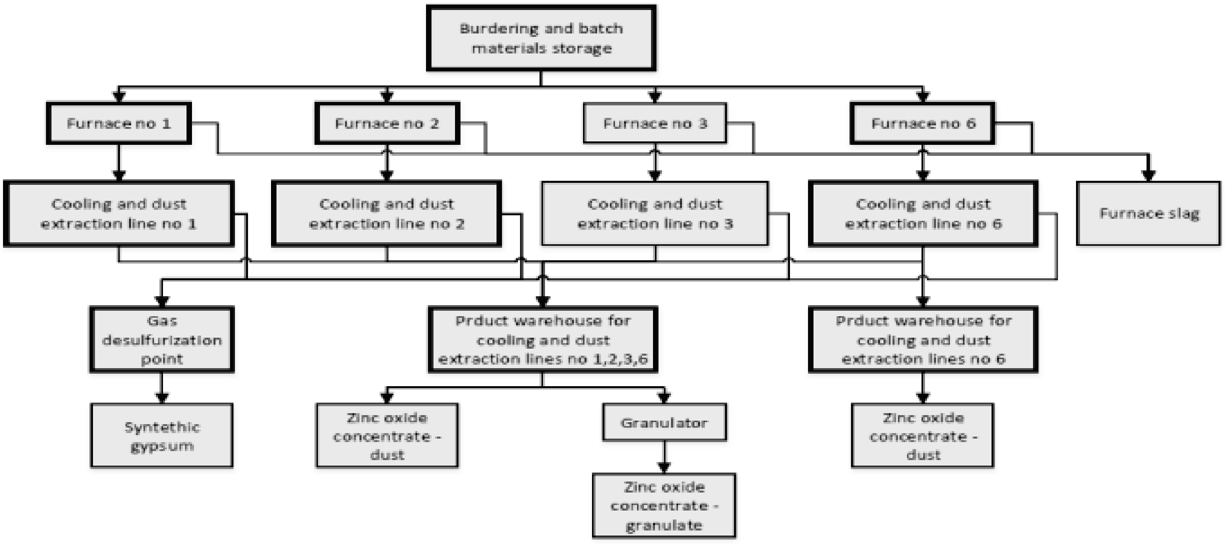

Fig. 1. Diagram of technological lines in B. Recycling Sp. z o. o. after the modernization.

2. THE ANALYSIS OF PLANNED STOPPAGES AND MACHINES BREAKDOWNS

During the modernization, some technological lines were liquidated. Line no 3 was left in the previous state (Fig. 1). In the paper, the analysis of three modernized lines used for zinc oxide concentrate production is described.

Those are lines no 1 and 6 – adapted for processing both the steel fly ashes and zinc-bearing sludge, and line no 2 that is intended for sledges from the zinc electrolysis department of "Bolesław" Mining and Metallurgy Plant.

Figure 1 shows the diagram of technological lines after implementation of changes. The analysis focused on the breakdowns and planned stoppages of the equipment included in the installation of zinc oxide concentrate production. Basing on the data collected in the facility, the tables, diagrams and graphics describing the results were developed.

During the TPM (Total Productive Maintenance) analysis, the basic characteristics were calculated [2]:

- OEE – Overall Equipment Effectiveness
- MTTR – Mean Time To Repair
- MTBF – Mean Time Between Failures

2.1. CALCULATION OF OEE INDICATOR FOR EACH TECHNOLOGY LINE

Basing on the data gained during one year observation period of the system exploitation, the detailed statistical analysis was conducted, which included: times of proper work of technological lines and roll down furnaces, times of breakdowns, failures and micro stoppages of the lines and the equipment included.

The histograms were developed, that were describing the amount of time of downtimes, taking into account the cause of the stoppage (planned/ breakdown). Because of the diversity of the failures causes, those were divided for several groups, depending on the place of occurrence (installation of slug reception, roll-down furnaces, dust settling chambers, cooling towers, filters, pneumatic product transportation system, and ventilator).

While planning the modernization it was assumed, that one of the effects would be the increase of production process effectiveness indicators. To estimate how effective the resources used after implementing the changes are, for each of three lines analyzed, the OEE indicator was calculated (using formula 1). Its value describes the percentage of theoretical maximum possible effectiveness is currently used.

$$\mathrm{OEE} = \mathrm{A} \cdot \mathrm{P} \cdot \mathrm{Q} \cdot 100\% \qquad (1)$$

- A – availability rate[%],
- P – performance rate[%],
- Q –quality rate [%].

Calculating the availability rate:

$$\mathrm{A_i} = \frac{\mathrm{A_{i2}}}{\mathrm{A_{i1}}} \cdot 100[\%] \qquad (2)$$

- A_{i1} – net operating time [h],

- A_{i2} – processing time (net operating time – planned stoppages) [h],
- i – technology line number.

The character of work of each analyzed line is similar. It allows to generalize at some points, i.e. the causes of planned stoppages are the same (extinguishing / firing,(build-ups) removing – preparation for refit, dodder forging, twisting off the rubble, brickworks, firing).

Calculating the performance rate

Two ways of calculating Pi for described case were proposed [9]. The first one is to consider, that if the furnace unit works with its designed performance and during the modernization all the machines and equipment of the line were designed to manage the maximum capacity of roll down furnace, than the performance rate for the line may be assumed to be equal Pi=100%.

On the other hand, considering the complexity of technological process, the difficulties in keeping the technological discipline and the variety of the batch material quality, it may seem unreasonable to assume, that the performance rate will be kept on the highest level without any disturbances. It may be decreased i.e. by gradual accumulation of build-ups. Because the furnaces process continuously, it is difficult to point the exact values of performance at the time. Though, basing on the experience, it may be assumed, that the main decrease of capacity during the reference period is no greater than 5%. In that case, the performance rate equals Pi=95%.

To compare those cases, OEE was calculated twice, for both Pi values.

Calculating the quality rate

Products quality is calculated basing on the amount of batch material, the amount of zinc oxide concentrate manufactured out of it and content of pure zinc in both. Qi quality rate was calculated using formula 3.

$$Q_i = \frac{Q_{i2}}{Q_{i1}} \cdot 100[\%] \qquad (3)$$

- Q_{11} – Zn content in batch material [Mg],
- Q_{12} – Zn Cotentin product [Mg].

2.1.1. Calculating availability rate for each technology line

Due to the character of furnaces processing, all the technological lines work seven days/week, for 24 hours, in four – grader system. Table 1 contains data used for availability rate.

Table 1. Data used for calculating the availability rates for technology lines.

	Line no 1	Line no 2	Line no 6
t_{ppi}[h]	1,999.5	996	797
t_{aw1} [h]	1,126.5	509.5	1,331.5
r_{oi}	88%	---	88%

- t_{ppi} – time of planned stoppages duration for technology line [h],
- t_{awi} – breakdowns time of technology line [h],
- r_{oi} – the rate of annual workload, that considers the discontinuity of batch materials (dust) supplies.

Availability rate for technology line no 1.

Calculating net operating time

$$A_{11}= (365 \text{ days} \cdot 24 \text{ hours} - t_{pp1}) \cdot r_{o1}=5{,}949.24\text{h} \qquad (4)$$

Calculating the processing time

$$A_{12} = 365\text{days} \cdot 24 \text{ hours} - t_{pp1} - t_{aw1}=5{,}634\text{h} \qquad (5)$$

Calculating the availability rate

$$A_1 = \frac{A_{12}}{A_{11}} \cdot 100\% = \frac{5{,}634}{5{,}949.24} \cdot 100\% = 94.70\ \%$$

The same procedure was used while calculating the availability rate for other lines:

Availability rate for technology line no 2.

Calculating the operating time

$$A_{21} = 365 \text{ days} \cdot 24 \text{ hours} - t_{pp2}=7764\text{h} \qquad (6)$$

Calculating the processing time

$$A_{22} = 365\text{days} \cdot 24 \text{ hours} - t_{pp2} - t_{aw2}=7254.5\text{h} \qquad (7)$$

Calculating the availability rate

$$A_2 = \frac{A_{22}}{A_{21}} \cdot 100\% = \frac{7{,}254.5}{7{,}764} \cdot 100\% = 93.44\ \%$$

Availability rate for technology line no 6

Calculating the operating time

$$A_{61} = (365\ \text{days} \cdot 24\ \text{hours} - t_{pp6}) \cdot r_{o6} = 7{,}007.44\text{h} \quad (8)$$

Calculating the processing time

$$A_{62} = 365\text{days} \cdot 24\ \text{hours} - t_{pp6} - t_{aw6} = 6{,}631.5\text{h} \quad (9)$$

Calculating the availability rate

$$A_6 = \frac{A_{62}}{A_{61}} \cdot 100\% = \frac{6{,}631.5}{7{,}007.44} \cdot 100\% = 94.64\ \%$$

2.1.2. Calculating the quality rate

Products quality is calculated basing on the amount of batch material, the amount of zinc oxide concentrate manufactured out of it and content of pure zinc in both (table 2).

$$Q_i = \frac{Q_{i2}}{Q_{i1}} \cdot 100[\%] \quad (10)$$

- Q_{i1} – Zn content in batch material [Mg],
- Q_{i2} – Zn content in the final product [Mg].

Table 2. Zinc content in batch material and in final product.

Line		amount [Mg]	Zn content [%]	Zn amount [Mg]
Line no 1	Batch material	54,518.385	27.52	15,003.46
	Product	22,360.037	59.44	13,290.81
	Q_1	**88.58** %		
Line no 2	Batch material	58,839.159	17.52	10,308.621
	Product	19,039.309	45.55	8,672.405
	Q_2	**84.13** %		
Line no 6	Batch material	54,518.385	27.52	15,003.46
	Product	22,360.037	59.44	13,290.81
	Q_6	**84.13** %		

2.1.3. OEE values for particular technology lines

Table 3. Calculated OEE values for particular technology lines.

	Line no 1	Line no 2	Line no 6
Availability (A_i)	94.70%	93.44%	94.64%
Performance (P_i)	95%/100%	95%/100%	95%/100%
Quality (Q_i)	88.58%	84.13%	88.58%
OEE (P_i=100%)	**83.88%**	**78.61%**	**83.83%**
OEE (P_i=95%)	**79.68%**	**74.68%**	**79.63%**

Table 3 contains the collective summary of calculated indicators for lines 1, 2 and 6(with consideration of two assumed values of Pi).

2.2. CALCULATING THE MTBF AND MTTR INDICATORS FOR PARTICULAR TECHNOLOGICAL LINES

The MTBF indicator was calculated using formula (11)

$$MTBF_i = \frac{t_{ppri}}{n_{ppi}} \quad (11)$$

- t_{ppri}– the sum of proper work duration times for technological line "i"[h],
- n_{ppi} – number of proper work occurrence for technology line "i".

The MTTR indicator was calculated using formula (12)

$$MTTR_i = \frac{t_{awi}}{n_{ni}} \quad (12)$$

- t_{awi}– sum of repairs duration for technological line "i" [h],
- n_{ni} – number of technological line "i" repairs [h].

MTBF and MTTR indicators for technological line no 1

Figure 2 shows the percentage of particular types of breakdowns on occurring on technological line no 1.

MTBF indicator for technological line no 1.

$$\mathrm{MTBF_1} = \frac{\mathrm{t_{ppr1}}}{\mathrm{n_{pp1}}} = \frac{5{,}634}{45} = 125.2\ \mathrm{h/year}$$

$$\mathrm{MTBF_1} = 125.2\ \mathrm{h/year}$$

$$\mathrm{MTTR_6} = \frac{\mathrm{t_{aw6}}}{\mathrm{n_{n6}}} = \frac{1{,}331.5}{51} = 26.11\ \mathrm{h/year}$$

$$\mathrm{MTTR_6} = 26.11\ \mathrm{h/year}$$

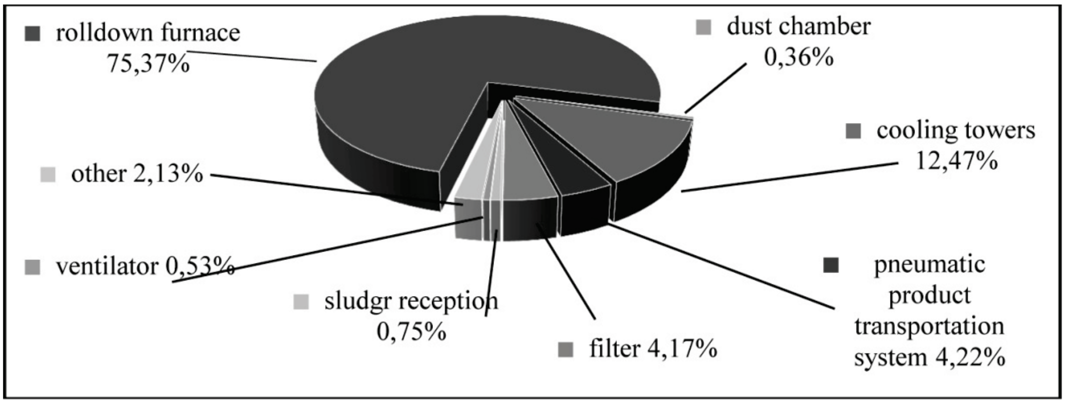

Fig. 2. The percentage of particular type of breakdowns occurring on technological line no 1.

MTTR indicator for technological line no 1.

$$\mathrm{MTTR_1} = \frac{\mathrm{t_{aw1}}}{\mathrm{n_{n1}}} = \frac{1{,}126.5}{53} = 21.25\ \mathrm{h/year}$$

$$\mathrm{MTTR_1} = 21.25\ \mathrm{h/year}$$

The same procedure was used while calculating those indicators for other lines:

MTBF indicator for technological line no 2.

$$\mathrm{MTBF_2} = \frac{\mathrm{t_{ppr2}}}{\mathrm{n_{pp2}}} = \frac{7{,}254.5}{38} = 190.9\ \mathrm{h/year}$$

$$\mathrm{MTBF_2} = 190.9\ \mathrm{h/year}$$

MTTR indicator for technological line no 2.

$$\mathrm{MTTR_2} = \frac{\mathrm{t_{aw2}}}{\mathrm{n_{n2}}} = \frac{509.5}{49} = 10.38\ \mathrm{h/year}$$

$$\mathrm{MTTR_2} = 10.38\ \mathrm{h/year}$$

MTBF indicator for technological line no 6.

$$\mathrm{MTBF_6} = \frac{\mathrm{t_{ppr6}}}{\mathrm{n_{pp6}}} = \frac{6{,}631.5}{44} = 150.72\ \mathrm{h/year}$$

$$\mathrm{MTBF_6} = 150.72\ \mathrm{h/year}$$

MTTR indicator for technological line no 6.

Due to the fact, that significant number of breakdowns concerns the roll-down furnaces, the MTTR indicator was also calculated for this equipment in lines 1, 2 and 6.

3. FINAL ANALYSIS

An analysis of collected data and values of calculated indicators allows to point the unplanned stoppages as an area generating the biggest loses of effectiveness in the production process.

Table 4. The analysis results for technological lines no 1, 2 and 6.

	Line no 1	Line no 2	Line no 6
Breakdowns time [h/year]	1,126.5	509.5	1,331.5
Breakdowns time [%]	12.86	5.82	15.20
Planned stoppages time [h/year]	1,999.5	996	797
Planned stoppages time [%]	22.83	11.37	9.10
Proper work time [h/year]	5,634	7,254.5	6,631.5
Proper work time [%]	64.31	82.81	75.70
OEE [%]	83.88	78.61	83.83
MTBF [h/year]	125.2	190.9	150.72
MTTR [h/year]	21.25	10.38	26.11

Considering the problem from the perspective of the results obtained during calculating the OEE indicator, the quality is the area with the biggest improvement potential. Though in this case, products quality depends strictly on the used technology, in which further interferences could be impossible or generate costs too big for company to manage [10]. Due to these facts, the actions focused on improving the availability of the equipment should be prioritized [6, 7]. Table 5 contains the times of processing and stoppages for modernized lines. Table 4 contains detailed data concerning times of lines stoppages with special attention for breakdowns of roll down furnaces.

The most time-consuming are actions taken for equipment recovery after the failures caused by accommodation of the build-ups inside the furnace. In such situation it is necessary to cool down the machinery, remove the build-ups and heat up. The resulting stoppage may last even several dozen hours.

4. CONCLUSIONS

Conducting the analysis of amount and causes of technological lines stoppages allowed to establish the enterprises resources utilization rate, and to point to the areas of the biggest improvement potential. One of the conclusions is the necessity of improving the availability of machines.

Time of breakdowns duration varies, and is significantly longer for lines 1 and 6 than for line no 2. Those three lines are adjusted for processing different batch materials (Line no 2 - for sludge from the zinc electrolysis, lines no 1 and 6 - steel fly ashes and zinc-bearing sludge). Different physicochemical properties of charge and the process influence i.e. the speed of build-ups accommodation. The conducted analysis showed that this is the most common cause of furnaces failures.

Assigning that the amount and duration of the specific equipment has allowed to point the roll-down furnaces as the most problematic subassemblies, if the unplanned stoppages are considered. Its breakdowns are about 72.83% of all failures of each line. The most time – consuming part is the machines recovery after removing the build-ups. Mean value of MTTR indicator for furnaces is 23.31 hours per year. It is though necessary to seek for technical solutions that may shorten the time of those operations. One of the options is using the Winchester industrial cannon.

One of the effects of the modernization was supposed to be the improvement of the process effectiveness indicator values to the European level. As the measurement of realization of this goal, the OEE value calculated for each line was taken. Depending on assumed performance of the equipment, the results varied from 74.68% to 83.88%. The lowest value of this indicator was calculated for line no 2. The cause of those differences may be the technology used in the lines, as mentioned before. In this case, the OEE is influenced by lowest content of zinc in the product manufactured on line no 2 comparing to other. However, calculated values are not much different from the worldwide level. Considering the complexity of the process, this result may be considered to be satisfactory. It may be said, that the modernization was necessary and effective, but it also has to be mentioned, that there is still quite big improvement potential in the process.

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ACKNOWLEDGEMENTS

This work was supported/founded by research project AGH University of Science and Technology 15.11.130.422.

Date submitted: 2017-11-22
Date accepted for publishing: 2018-02-12

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