ISSN 2347 - 3983
Volume 8. No. 3, March 2020
International Journal of Emerging Trends in Engineering Research
Available Online at http://www.warse.org/IJETER/static/pdf/file/ijeter16832020.pdf
https://doi.org/10.30534/ijeter/2020/16832020

Quality and Energy Indicators of Grain Crusher as a Function of Screen Wear

Vladimir Shirobokov, Oleg Fedorov, Alexey Ipatov, Sergei Shmykov, Liliia Novikova
Federal state budgetary educational institution of higher education "Izhevsk State agricultural Academy", Russia

ABSTRACT

Closed-circuit crushers are the most common units upon grain crushing for farm livestock. Each kind of animals requires for specific size of crushed grains. The simplest approach to adjust grain fineness modulus is application of separating screens. In closed-circuit crushers separating screen is located in crushing chamber, which results mainly in intensive wear of screen as well as leads to higher wear of crushing hammers. Modification of separating screen geometry during operation deteriorates the quality of crushed grain and increases energy consumption. Operation lifetime of screen can be improved by thermal strengthening of separating hole edges.
The studies performed at the premises of OAO Put Ilicha, Udmurtia, revealed deterioration of quality of crushed grain and decreased energy indicators depending on crusher yield. Operation results of screen with strengthened hole edges have been compared with those of screen with nonstrengthened hole edges. It has been demonstrated that the effective surface area of screen increases more intensively with nonstrengthened hole edges; with the increase in the yield, the quality indicators of crusher deteriorate nonlinearly, idle capacity decreases, and useful capacity consumption increases.

Key words: crusher, screen, holes, wear, indicators, surface area, strengthening, capacity, efficiency.

1. INTRODUCTION

In Russian agribusiness industry there is an increase in the number of farms which, aiming at reduction of prime costs of production, should use their own grain forage for preparation of combined feed while buying only commercial additives.
The lines of combined feed production include machines for preliminary preparation of combined feed ingredients, dosage, and blending.
The most energy-intensive procedure in the feed production process is crushing. Grain for farm livestock is crushed mainly by closed-circuit units with suction of initial material and discharging of final product. In comparison with open-circuit crushers, these units are characterized by lower compliance with the requirements of standards and zootechnology in terms of quality indicators [1-5]. Screen installed in crushing chamber (Fig. 1) leads to closing of screen holes with coarser particles which in their turn close output for crushed particles after reaching the required sizes, this is the reason of significant deterioration of quality indicators of crushed grain and crusher energy properties [3, 4].

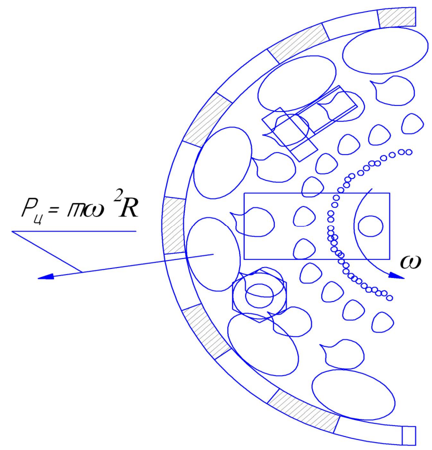

Figure 1: Schematic view of grain crushing in chamber of closed-circuit crushers

Herewith, first of all the screen hole edges are worn (Fig. 2). The worn edges promote impingement of particles, reaching the required fineness modulus, back to the crushing chamber leading to grain excessive crushing and increase in process energy intensity.

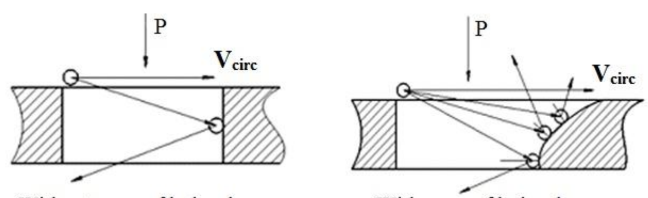

Figure 2: Particle paths: V_{circ} - circular speed of particles; P - resultant force

1.1 Formulation of The Problem

This work is aimed at increase in operation efficiency of grain closed-circuit crusher by increasing operation lifetime of separating screens.
In order to achieve the formulated target, it is required to solve the following problems: to analyze quality and energy indicators of closed-circuit crusher as a function of yield with

thermally strengthened and nonstrengthened separating screens.

2. METHODS

The screen hole edges were thermally strengthened in accordance with the recommendations discussed in [4, 6]. Only moderate segment of metal around screen hole was thermally strengthened (Fig. 3) by laser radiation. The arrows indicate at the places of hole edges strengthening (Fig. 4).

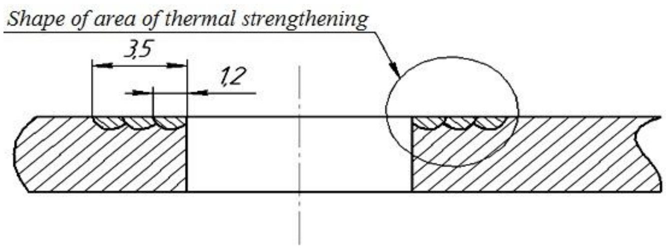

Figure 3: Area of thermal impact

The thermal strengthening was performed using LRS Automatic laser unit, (OKB Bulat) [7].
Geometrical parameters of the treatment have been selected on the basis of mathematical simulation of heat and mass transfer upon high speed laser treatment [6]. The modes of laser strengthening were based on necessity to perform quenching with fusion of initial material [8, 9].

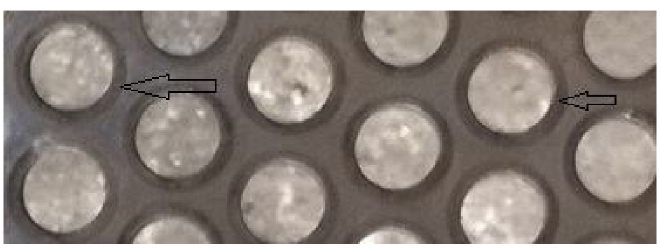

Figure 4: Thermally strengthened screen.

The strengthened screens were tested at OAO Put Ilicha farm, Zavyalovsky district, Udmurtia.
The wear rates of screen strengthened hole were analyzed by metallography methods determining wear patterns and variations of wear rates. The analysis was carried out using a Neophot-72 metallographic microscope in light field with magnification of 100×.
The screen wear rates were determined using a MMI-2 small instrumental microscope with scale of 0.005 mm: sizes and elongation of holes; an IKV 640143 vertical optimeter with the accuracy of 0.001 mm: screen wear rate; a Ts4505 clump meter, accuracy class 2.5: current and voltage. Screen analysis was performed in accordance with the standard [10].

3. RESULTS AND DISCUSSION

The studies performed at OAO Put Ilicha farm, Udmurtia, revealed deterioration of quality of crushed grain as a function of screen wear of DKR-5M crusher [5]. Herewith, the screen holes are elongated due to intensive abrasive wear, mainly in the middle portion, and the surface area of holes increases (Fig. 5).

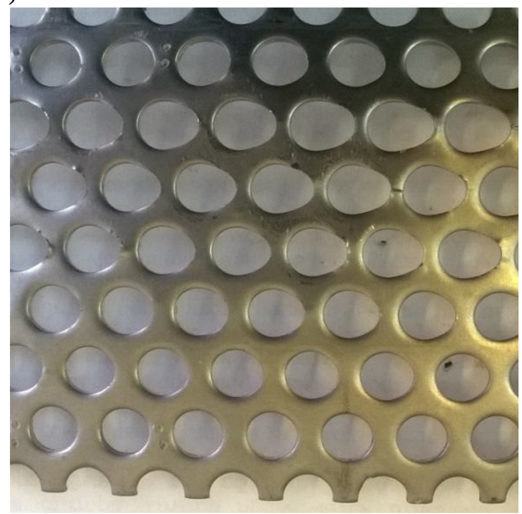

Figure 5: Fragment of worn separating screen of DKR-5M crusher

During wearing of screen hole edges, in the area of thermal strengthening the wedge is formed, which is stipulated by gradient pattern of the structure. The gradient pattern is determined by local laser radiation leading to strengthening of moderate surface thickness of separating screen. Figure 6 illustrates peculiar surface wear patterns of strengthened hole edges as a function of yield. In the case of yield of 50 t, the hole edge wear is nearly not detectable, it does not affect properties of crushed grain.

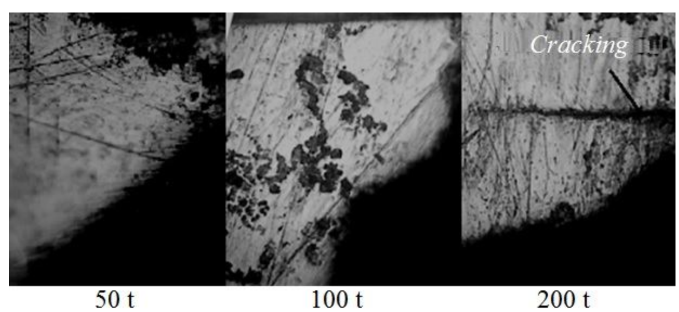

Figure 6: Variation of screen hole edge profile as a function of yield

In the case of yield of 100 t, a wedge is formed with characteristic enlargement in the area of thermal strengthening, herewith, the grain quality is deteriorated, energy consumption increases. This situation is observed upon further operation of hammer crusher. When the yield exceeds 200 t, the operation properties are deteriorated significantly (Table 2), the strengthened cutting edge is completely worn and destroyed (Fig. 6, c: cracking at the interface of material fusion and area of thermal impact).

Increase in hardness of screen hole edges leads to decrease in wear. The wear regularities were analyzed by micrometric studies, significant decrease in wear rate as a function of yield was determined (Fig. 7).

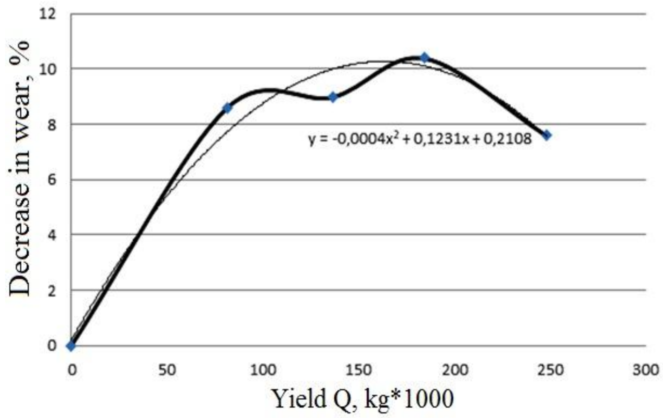

Figure 7: Decrease in wear of strengthened holes

The presented plot demonstrates decrease in wear intensity of strengthened screen holes. The maximum wear resistance is observed before the yield of 200 t, upon further operation, the strengthened holes are characterized by increased wear intensity, which is confirmed by wear pattern (Figs. 3, 6). The preliminary studies [6] demonstrated that the operation efficiency of hammer crusher with strengthened screen increased by 22%. In addition, it is known that the main parameter effecting separation is the efficient surface area of screen, hence, it is necessary to determine surface area of screen holes as a function of crusher yield.

During wearing the screen holes become egg-shaped (Fig. 8), this surface area can be determined as the sum of surface areas of semicircle So and semi-ellipse Se.

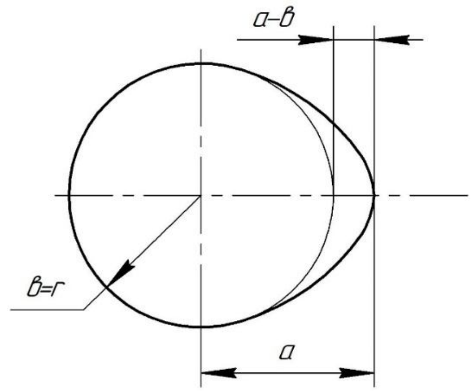

Figure 8: Calculation of surface area: a - semimajor axis, b - semiminor axis, r - hole radius

$$S = \pi \cdot b \cdot (b + 0.5 \cdot \delta), \qquad (1)$$

where: $\delta = a - b$ is the mean arithmetic screen wear along the semimajor axis of ellipse, m.

In the case of the screen of DKR-5M crusher with the hole diameter of 0.01 m, the effective surface area of the screen is determined as follows:

$$S = 7.85 \cdot (1 + 0.1 \cdot \delta) \cdot 10^{-5} \qquad (2)$$

The effective surface area is determined as the product of mean arithmetic surface area of one hole by the number of holes of crusher screen.

Table 1 and Fig. 9 summarize the results of screen wear and predictions of effective surface area of separating screen (Eq. 2) as a function of yield of DKR-5M crusher.

Table 1: Field tests of screen wear and predictions of effective surface area

No.	Crusher yield Q, kg 10^3	Screen wear, $m \cdot 10^{-3}$		Screen effective surface area, S_{eff}, $m^2 \cdot 10^{-3}$	
		nonstrengthened, $\boldsymbol{\delta_{ns}}$	strengthened, $\boldsymbol{\delta_s}$	nonstrengthened	strengthened
1.	0	0.00	0.00	66.72	66.72
2.	81.30	0.73	0.34	71.6	68.99
3.	136.69	1.01	0.56	73.46	70.46
4.	184.85	1.30	0.69	75.40	71.33
5.	248.59	1.41	1.11	76.13	74.13

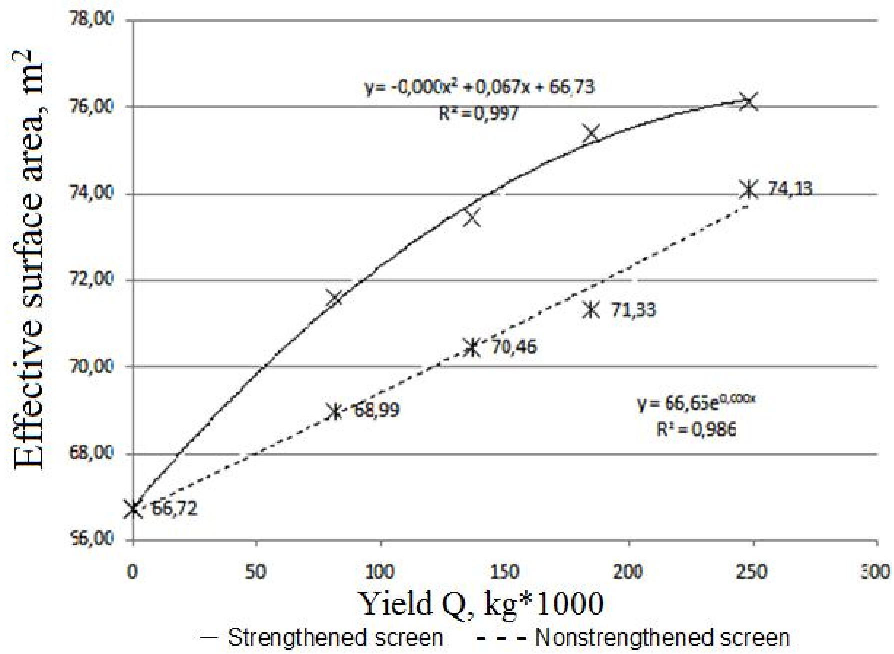

Figure 9: Effective surface area as a function of crusher yield

It is shown that the increase in the effective surface area of screen is more intensive for nonstrengthened holes.

Moreover, the wear of strengthened hole edges at the yield of $249 \cdot 10^3$ kg is 0.063 mm, and that of nonstrengthened edges is 0.173 mm. That is, the wear resistance of strengthened screen hole edges is higher more than by 2.75 times than that of nonstrengthened edges.

In addition, the contents of whole grains in crushed product and fineness modulus, as well as idle capacity and useful capacity were studied as a function of yield, the results are summarized in Table 2 and Figs. 10 and 11.

Table 2: Analysis of quality and energy indicators of grain crusher

Yield Q, $kg \cdot 10^3$	Content of whole grains P_{wg}, %;	Fineness modulus d_{avg}, $m \cdot 10^{-3}$	Idle capacity N_{idle}, W	Useful capacity N_{use}, W
0.00	1.295	1.376	6120.00	16320.00
81.30	1.69	1.412	5957.00	19584.00
136.69	2.648	1.56	5875.00	23360.00
184.85	2.925	1.913	5752.00	24360.00

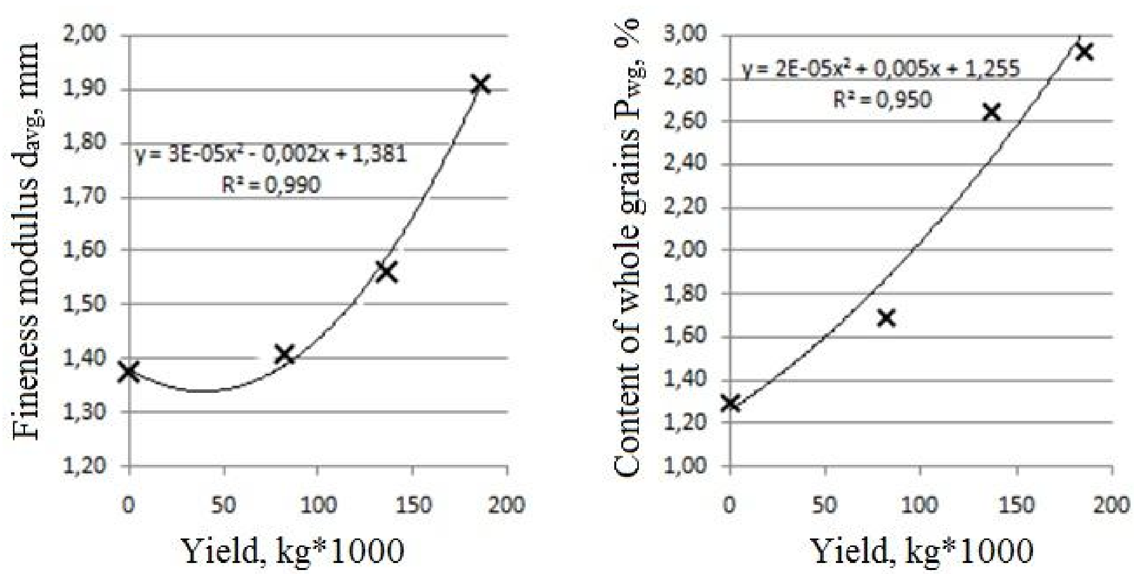

Figure 10: Content of whole grains Pwg and fineness modulus davg as a function of crusher yield Q

The experimental results demonstrate that with the increase in the yield, the quality indicators of crusher operation decrease nonlinearly. Herewith, the content of whole grains does not comply with the standard requirements [11], it is higher than 0.3% by several times. While solving the approximation equation with regard to the fineness modulus d_{avg}, it becomes obvious that at the yield in excess of $155 \cdot 10^3$ kg, the fineness modulus exceeds the allowable value of $1.8 \cdot 10^{-3}$ m predetermined for young beef cattle [11]. Hence, after reaching the yield of more than $155 \cdot 10^3$ kg, the crushed grain is suitable only for adult livestock.

Analysis of energy indicators of crusher operation (Table 2 and Fig. 11) demonstrates that with the increase in the yield, the idle capacity decreases and consumption of useful capacity increases. The decrease in idle capacity can be attributed to increased size of screen holes (Fig. 5) and improved streamlining of crusher hammers due to wear of their edges. Herewith, the increase in the effective surface area of screen by 13% resulted in decrease in idle capacity by 6.4% and increase in useful capacity by 49% (at the yield of $184 \cdot 10^3$ kg). The dependence of idle capacity can be applied for screen state diagnostics and timely replacement of screen by measuring voltage and current intensity.

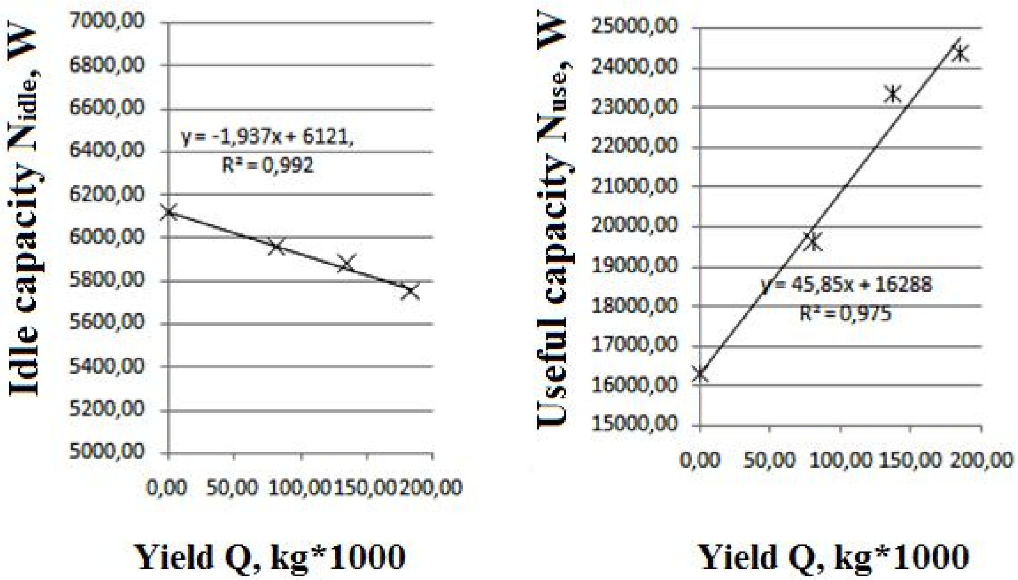

Figure 11: Idle capacity Pidle and useful capacity Puse as a function of crusher yield Q

Significant increase in power consumption for useful work is related with intensive wear of hole edges of crusher screen (Fig. 5). Herewith, major portion of crushed grains after reaching a preset fineness modulus are reflected to crushing chamber, crushed additionally, and consume energy (Fig. 2). That is, the wear of screen hole edges deteriorates separation conditions of particles of preset fineness.

4. CONCLUSION

Quality and energy indicators of grain crusher operation significantly vary with the increase in effective surface area of screen as a consequence of wear.

Increase in effective surface area of screen holes as a consequence of hole wear results in increase in energy consumption by 49% and increase in fineness modulus more than by 39%, which exceeds the allowable level for young beef cattle.

Thermal strengthening of hole edges of separating screen allows to increase operation lifetime by 2.7 times.

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