Technical exploitation parameters of grinding rolls work in flour mill

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Abstract

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The proposed research paper analyses power consumption in grinding rolls of a flour mill. The observed mill has 15 grinding passages. The hourly efficiency of grinding roll on the first passage is 3,006.72 kg/h. The specific power consumption of individual grinding rolls ranges from 4.955 to 24.26 kWh/t. The thesis also contains results of research of grinding effects on grist. The greatest effect on grist was observed on the first grinding passage, where particle size after grinding was only 12% of the original grain size, as determined by sieve analysis. On the second through fifth passage, it was 85–96% (or 78–85% with shelling) of the original size. It was discovered during scouring that, in some cases, the sieve size of particles after grinding increased from 101 to 104% of the original size. This is due to shear force causing trituration of grist.

Keywords: milling; machines; performance; energy consumption

Milling grain in flour mills is an important first step in producing such products as breads and cakes. The key machine in a flour mill is the grinding roll. Its function is to separate as much endosperm from the grain as possible. Because of this, the effect of grinding rolls on grist, as well as efficiency and power consumption are of permanent interest to grinding roll designers. The stimulus for development in the flour milling process is the flour miller's requirement to produce the highest quality products at minimum cost. In the past, this was achieved through investment in new technologies and strategies (Owens 2001).

The aim of this research was to analyse the efficiency and power consumption on individual grinding passages, including the effect on grist, in the process of grinding of wheat by grinding rolls. The subject of research was the process of semolina and flour production as a whole on all grinding passages of the observed mill.

The importance of measuring the grist dispersity is necessary to assess the final disintegration processes quality in relevant processing equipment and to detect individual properties of the mixtures produced (Smejtková et al. 2011). Particle size was assessed as one of the most important physical properties which affect the flowability of wheat flours. (Kuakpetoon et al. 2001).

Grain milling technologies involve size reduction procedures in which grain kernels are broken into pieces of various sizes by the machinery. One of the estimations of the efficiency of the milling process is based on energy required to create new surfaces. Size reduction is one of the least energy-efficient one of all the unit operations and the cost of power is a major expense in crushing and grinding, so the factors that control this cost are important (McCabe et al. 2005).

MATERIAL AND METHODS

The observed flour mill consists of five scrapping, two shellings, one transitional and seven scouring

Table 1. Technical parameters of grinding rolls

Passage	Grinding rolls					Drive of rolls		
	length (mm)	number of grooves/cm	position	grooves inclination (%)	facet width (mm)	revolutions (min^{-1})	gearing	power capacity (kW)
1S	1,250	3.2	CH-CH	6	0.2	620	1:2.5	45
2S	1,250	4.8	CH-CH	6	0.2	620	1:2.5	30
3S	1,250	6.4	CH-CH	8	0.1	560	1:2.5	22
4Sf	1,000	8.9	O-O	10	0.1	500	1:2.5	15
4Sc	1,000	10.2	O-O	10	0.1	500	1:2.5	11
5S	1,000	11.5	O-O	12	0.11	500	1:2.5	11
1L(a)	1,250	11.5	CH-CH	10	0.1	560	1:1.23	15
1L(b)	1,000	–	–	–	–	560	1:1.23	11
2L(a)[1]	1,000	–	–	–	–	560	1:1.23	15
2L(b)[1]	1,000	–	–	–	–	560	1:1.23	15
Pr	1,000	–	–	–	–	500	1:1.23	15
1V	1,000	–	–	–	–	500	1:1.23	15
2V	1,250	–	–	–	–	470	1:1.23	15
3V	1,000	–	–	–	–	470	1:1.23	11
4V	1,000	–	–	–	–	470	1:1.23	11
5V	1,000	–	–	–	–	440	1:1.23	11
6V	1,000	–	–	–	–	440	1:1.23	7.5
7V	1,000	12.7	O-O	12	0.1	440	1:2.5	7.5

[1] grinding rolls with joint inlet and outlet openings, set so that the first one processes 45% and the second 55% of the material

passages. Grinding is done by nine doubled grinding rolls, two entoleters and four triturators. Technical parameters of grinding rolls and auxiliary machines are listed in Table 1.

Processed wheat was analysed in the mill laboratory. Wheat was of standard quality with a density of 790 kg/m and moisture of 14%. It was moistened to 16.5% before grinding.

Real efficiency determination. Measurements were done on all grinding rolls during operation. The real efficiency of all grinding rolls Q_s was calculated from the measured weight of grist samples and the time of their sampling using the equation:

$$Q_s = \frac{m}{t}\,3{,}600 \qquad \text{(kg/h)} \qquad (1)$$

where:

m – average weight of grist sample (kg)

t – average time of sampling (s)

Specific power consumption determination. Digital electrometer DIZ W1E4 (Schrack Technik, s.r.o., Czech Republic) was used to measure the power consumption of grinding rolls drive.

The specific power consumption of grinding rolls (A_m) was calculated according to the equation:

$$A_m = \frac{A}{m_s}\,3{,}600 \qquad \text{(kWh/t)} \qquad (2)$$

where

A – electric work of grinding roll (kWh)

m_s – weight of grist at time t (h)

$$m_s = \frac{Q_s \times t}{1{,}000}(t) \qquad \text{(kWh/t)} \qquad (3)$$

where:

Q_s – real efficiency of grinding roll (kg/h)

t – work time of grinding roll (h)

Degree of grist disintegration determination. Samples of grist were taken on both sides of the observed grinding machine. Samples were sifted using a laboratory sifter with a mesh size of 850, 500, 355, 250, 160, 125 μm (Fig. 1). The material captured in sieves was weighed and results recorded. From these results, the weight of throughs was determined.

For determination of grist disintegration degree by individual grinding rolls, weight values of throughs of individual sieves of the sifter were used.

The weight of through of the sieve f, labelled m_{xf}, was measured. Through of other sieves were calculated according to the following equations:

through of sieve *e* $m_{xe} = m_{xf} + m_{pf}$ (4)
through of sieve *d* $m_{xd} = m_{xe} + m_{pe}$ (5)
through of sieve *c* $m_{xc} = m_{xd} + m_{pd}$ (6)
through of sieve *b* $m_{xb} = m_{xc} + m_{pc}$ (7)
through of sieve *a* $m_{xa} = m_{xb} + m_{pb}$ (8)

where:
$m_{x(a \text{ to } f)}$ – weight of through of sieve *a* to *f* (g)

The weighted average of particle size $\bar{x}$ was calculated from values of throughs of individual sieves of the laboratory sifter:

$$\bar{x} = \frac{m_{xa} \times r_a + m_{xb} \times r_b + m_{xc} \times r_c + m_{xd} \times r_d + m_{xe} \times r_e + m_{xf} \times r_f}{m_{xa} + m_{xb} + m_{xc} + m_{xd} + m_{xe} + m_{xf}} \quad (\mu\text{m}) \quad (9)$$

where:
$r_{a \text{ to } f}$ – mesh size (μm)

The degree of grist disintegration is a non-dimensional number, calculated using the formula:

$$S = \frac{\bar{x}_p}{\bar{x}_N} \quad (10)$$

where:
$\bar{x}_p$ – average particle size after grinding (μm)
$\bar{x}_N$ – average particle size before grinding (μm)

RESULTS AND DISCUSSION

Measurements were done under usual working conditions in the flour mill, which was put into service in 2002.

Real efficiency determination

Results of the real efficiency of individual grinding rolls are listed in Table 2. The efficiency of the mill stated by the manufacturer is 80 tons per day. Its real efficiency during the research was 3,006.72 kg/h, which means that it only treated 72.16 t of wheat in 24 hours. This means that the operator only used 90.2% of the mill's capacity and could treat 7.84 more tons of wheat per day.

The hourly efficiency of grinding rolls on grinding passages spanned from 3,006.72 to 1,113.92 kg/h. The only exception is the fourth grinding passage, which is divided into two passages, one of which, labelled 4Sc, treats the coarse fraction of grist, and the other, labelled 4Sf, treats finer grist. Because of this, the grinding roll on passage 4Sh had relatively low efficiency of 539.64 kg/h.

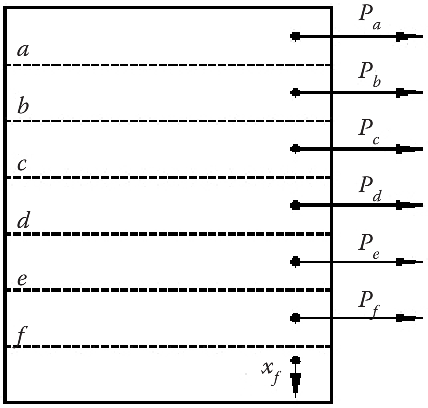

Fig. 1. Schema of laboratory sifter

a to *f* – sieves; p_a to p_f – material retained in sieve; x_f – through of sieve *f*

The grinding roll efficiency of 1,553.76 kg/h was determined on the first shelling passage. Other shelling passages had lower efficiency, spanning from 990.36 to 801.72 kg/h. The efficiency of transitional passage was 493.2 kg/h.

Grinding rolls on scouring passages had efficiency spanning from 725.40 kg/h on passage 1V to 200.52 kg/h on passage 5V.

The percentage of weight of wheat treated by individual grinding rolls can also be gathered from the results of the research. If the grinding roll on passage 1S treats 100% of ground wheat, then the second most loaded grinding roll is the one on passage 2S, treating 79.86% of all wheat. The third most loaded grinding roll is on passage 1L(a), which shells 51.68% of all treated material. The smallest amount of wheat goes through the grinding roll on passage 5V, which scours only 6.67% of treated wheat.

Specific power consumption determination

Measured and calculated values characterizing the power consumption of grinding rolls in grinding of wheat are listed in Table 3.

It can be seen from the results that the power consumption of grinding rolls individual electromotor on all passages was even. The results also show that the motor with a performance of 11 kW on the fifth grinding passage was permanently overloaded, while motors on other passages were overloaded, meaning that the usage of their performance capacities is low.

Table 2. Efficiency of grinding rolls measurement

Passage	Average sample weight (kg)	Average time of sampling (s)	Grinding roll efficiency (kg/h)	Processed wheat percentage (%)
1S	11.4	13.65	3,006.72	100.00
2S	12.2	18.29	2,401.20	79.86
3S	4.9	15.57	1,113.92	37.05
4Sc	3.4	22.68	539.64	17.95
4Sf	7.6	21.51	1,271.88	42.30
5S	11.1	27.67	1,444.32	48.04
1L(a)	12.3	28.50	1,553.76	51.68
1L(b)	6.2	22.54	990.36	32.94
2L(a)	7.3	32.78	801.72	26.66
2L(b)	9.0	32.78	988.56	32.88
Pr	3.8	27.73	493.20	16.40
1V	6.2	30.77	725.40	24.13
2V	5.6	31.41	641.88	21.35
3V	2.5	32.00	281.16	9.35
4V	2.3	31.14	266.04	8.85
5V	1.6	28.70	200.52	6.67
6V	2.0	29.35	245.16	8.15
7V	5.7	40.2	510.48	16.98

Specific power consumption on individual passages under conditions of observation varied from 4.955 to 24.26 kWh/t.

For comparison, results of the research done by Opáth et al. (2004) were used. Their research showed the lowest specific power consumption

Table 3. Specific power consumption measurement

Passage	Effective power (kW)	Utilization (%)	Power consumption (kWh)	Grist weight (t)	Specific power consumption (kWh/t)
1S	36.17	80.4	36.17	3.007	12.029
2S	23.56	78.5	23.56	2.401	9.813
3S	20.11	91.4	20.11	1.133	17.749
4Sf	9.60	64.0	9.60	0.540	17.778
4Sc	9.35	85.0	9.35	1.272	7.351
5S	12.31	111.9	12.31	1.444	8.525
1L(a)	7.70	51.3	7.70	1.554	4.955
1L(b)	7.57	68.9	7.57	0.990	7.646
2L(a)	7.32	48.8	7.32	0.802	9.127
2L(b)	8.68	57.9	8.68	0.989	8.777
T	11.96	79.7	11.96	0.493	24.260
1V	5.51	36.7	5.51	0.725	7.621
2V	5.59	37.3	5.59	0.642	8.707
3V	3.45	31.4	3.45	0.281	12.278
4V	5.68	51.6	5.68	0.266	21.353
5V	3.70	33.6	3.7	0.201	18.41
6V	4.27	56.9	4.27	0.245	17.429
7V	3.93	52.5	3.93	0.511	7.691

Table 4. Size of particles before and after grinding and the degree of grist disintegration

Passage	Size of grist particles (μm)		Degree of grist disintegration
	before grinding	after grinding	
1S	4,750	579	0.12
2S	651	554	0.85
3S	608	582	0.95
4Sf	685	621	0.91
4Sc	779	645	0.83
5S	673	645	0.96
1L	677	528	0.78
2L	531	435	0.85
1V	458	452	0.99
2V	443	456	1.03
2V entoleter 1	457	432	0.95
3V	448	446	0.99
3V entoleter 2	446	416	0.93
4V	487	494	1.01
4V triturator 1	494	480	0.97
5V	502	525	1.04
6V	467	482	1.03
6V triturator 2	488	481	0.98
7V	491	497	1.01
7V triturator 3	498	487	0.89
T	584	505	0.86
T triturator 4	503	478	0.95

(3.31 kWh/t) on the third and fifth grinding passage and the highest specific power consumption (7.27 kWh/t) on the fifth and sixth scouring passage of the mill on which the research was conducted.

Achieved results are also comparable with the results of Carlsson-Kanyama and Faist (2010), who stated that energy consumption ranges from 0.32 to 2.58 MJ per kg of wheat flour.

Degree of grist disintegration determination

Results of disintegration of grist measurements (Table 4) show that the degree of disintegration on the first grinding passage was 0.12, which means that the average particle size after grinding was only 12% of the original size of wheat grain. This passage had the greatest grinding effect. This result is comparable with results of research done by Kažimírová and Opáth (2007), with the degree of disintegration of 0.13 on passage 1S in the mill observed by them. The lowest degree of disintegration was found on scouring passages using smooth rolls. This is also comparable with the results gathered by Kažimírová and Opáth (2007).

On the second through fifth grinding passages of the observed mill, the degree of disintegration spanned from 0.85 to 0.96.

The degree of disintegration of 0.78 was found on the first shelling passage. On the second shelling passage, it was 0.85, the same as on the second grinding passage.

During the second, fourth, fifth, sixth and seventh scouring, the degree of disintegration varied from 1.01 to 1.04, which means that particles increased their size transition through the grinding machine. This was caused by the use of smooth rolls, their advance and greater pressure. This was also the case on passage 7V, where rolls with fine grooves were used. Under these conditions, shear force causing trituration of grist also has a greater effect. The integrity of endosperm was disrupted, but individual grist particles were immediately pressed together and agglutinated into larger particles. This issue was dealt with by the installation of an auxiliary grinding machine on passage 5V. A greater amount of fine flour was created in grinding.

CONCLUSION

The mill was only used at 90.2% of its full capacity. Results show that the work of grinding rolls was even, and observed properties did not change significantly during the research period. The efficiency of grinding rolls on grinding passages varied from 539.64 to 3,006.72 kg/h. The lowest value was found on passage 4Sh, which treated more robust grist brought to the fourth grinding passage. The efficiency of grinding rolls on shelling passages gradually declined, which is considered optimal. The efficiency of the grinding roll on shelling passage 1L was 1,553.76 kg/h. The efficiency of the second shelling passage was 988.56 kg/h. The efficiency of scouring passages was the lowest, varying from 725.40 kg/h on passage 1V to 200.52 kg/h on passage 5V. This means that the efficiency of all grinding machines on grinding passages was greater than the efficiency of machines on other passages of the observed mill.

Specific power consumption for the same degree of grist disintegration was not the same on individual passages. Only a portion of electromotor capacity was used on most of the passages of the observed mill. The only exception was the electromotor on passage 5S, which was permanently overloaded.

Over-equipped electromotors increase investment costs unnecessarily and require more effective compensation of mill's power factor. Based on this, it is recommended to take the expected efficiency of grinding rolls into account when designing flour mills and propose more adequate performance of the installed electromotor. Power consumption in grinding was even. This is caused by the steadiness and evenness of material flow onto individual passages.

The analysis of degree of grist disintegration showed that the mill produces very fine flour, with a min. gradual decrease of individual particle size. The only exception was the first grinding passage, where the size of ground material was only 12% of the original grain size. The degree of decomposition observed on the second, fourth, fifth, sixth and seventh scouring passage was higher than 1.0, which means that the size of ground particles increased. Smooth grinding rolls are used on these passages, with an exception of passage 7V, where rolls with fine grooves are used. The increase of particle size, discovered by sieve analysis, was caused by increased shear and pressure forces and lack or sharp decrease of cutting force on ground grist particles.

Presented results can be used as groundwork for designers and for optimization of parameters of grinding rolls and technical systems of flour mills as a whole. In practice, the results gathered are usable for adjustment of exploitation parameters of grinding and sifting machines, allowing for more exact division of final products on individual mill passages and power savings.

References

Carlsson-Kanyama A., Faist M., 2010. Energy use in the food sector: 1–36. Available at: www.comuv.com

Kažimírová V., Opáth R., Tóth P., 2003. Analýza spotreby elektrickej energie na výrobu pšeničnej múky. [Analysis of energy consumption in the production of wheaten.] In: Proceedings Progresívna technika v živočíšnej, potravinárskej výrobe a v odpadovom hospodárstve, September 10–11, 2003. Nitra,: 39–43.

Kažimírová V., Opáth R., 2007. Technické aspekty výroby pšeničnej múky. [Technical Aspect of Wheat Flour Production.] Nitra, SUA in Nitra: 110.

Kuakpetoon D., Flores R.A., Milliken G.A., 2001. Dry mixing of wheat flours: Effect of particle properties and blending ratio. Lebensmittel-Wissenschaft & Technologie, *34*: 183–193.

McCabe W.L, Smith J.C., Harriott P., 2005. Unit Operations of Chemical Engineering. 7th Ed. New York, McGraw-Hill International: 984–1000.

Opáth R., Kažimírová V., 1998. Analýza spotreby energie na mletie pšenice. [Analysis of energy consumption for grinding of wheat.] Acta Technologica Agriculturae, *1*: 24–27.

Opáth R., Kažimírová V., Tóth P., 2004. Energetická náročnosť procesu mletia pšenice. [Energy consumption during the milling process of wheat grain.] Acta Technologica Agriculturae, *7*: 106–108.

Owens G., 2001. Cereals Processing Technology. Cambridge, Woodhead Publishing: 248.

Smejtková A., Vaculík P., Passian L., 2011. Stanovení disperzity meliva pšenice, ječmene a ječmenného sladu. [Determination grist dispersity – wheat, barley and barley malt.] Agritech Science, *3*: 1–4.

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