Petroleum and Coal

Article **Open Access**

Influence of the Degree of Mixing on the Quality of Preparation of Coal Batches

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Received November 6, 2022; Accepted May 26, 2023

Abstract

The degree of mixing all indicators of coal batch for 98 – 99%, which ensure a stabilization of the properties of coke in conditions multi-basin coking raw material base is one of the most important problem of the coal preparation technology for coking Based on the results of the research in terms of coke production of PJSC "ArcelorMittal Kryvyi Rih" found that the large quantity of components in the mixture, the variability of their physicochemical parameters are cause of low degree of mixing the batch. Organized mixing of the coal batch using mixing machines was recommended to implement.

***Keywords**: Coal; Coal batch; Organized mixing; Homogeneity of the technological properties; Multi-basin coking; Raw material base.*

1. Introduction

The requirements for the coal that is submitted for processing are determined by the capabilities of the layer coking process. They boil down, first of all, to ensuring the stable specified properties of the coal batch (moisture content, sulfur, ash content, release of volatile substances, bulk density, particle size composition, stickiness, cokeness) in quantities that correspond to one loading of the coke chamber and in each small its volume, in order to obtain coke that meets the requirements of modern blast furnace smelting [1-2].

The homogeneity of the technological properties of the coal batch is an important parameter. Thus, a well-mixed coal batch by volume provides the same parameters of the plastic zone as it moves in the coal load, affects the flow of shrinkage phenomena during the formation of semi-coke, coke, and determines the same properties of coke in the volume of each lump.

The homogeneity of the composition and properties of the coal batch, which determines the homogeneity of the coke and its behavior during secondary heating in the blast furnace, presupposes obtaining the same values of its parameters in samples taken from any point of the loading volume. In this regard, the approach to the state of homogeneity of the batch is a function of the degree of mixing of its components [3].

Therefore, another important aspect improving the technology preparation of coal batch for coking in order to improve coke quality is to ensure a high degree mixing of coal concentrates that make up the batch for coking, as this determines the possibility of obtaining homogeneous structure of coke.

For optimal conditions of sintering and coke formation, it is necessary to ensure close contact between coal grains and uniform distribution of low-sintering coal in the total mass, which is achieved by mixing the components of the coal batch with its appropriate granulometric composition [1,4-6]. In this regard, during the preparation of the coal batch for coking, it is necessary to pay special attention to the high-quality mixing of its components and to ensure the homogeneity the composition of the coal batch. Thus, increasing the uniformity of coal quality indicators will improve the operating conditions of coke batteries, stabilize coke quality indicators, and increase blast furnace coke output by increasing its strength.

2. Results and discussions

Considering that for the coke-chemical industries of Ukraine, the trend of forming a multi-basin coking raw material base is maintained, in addition to averaging the batch before feeding it to coking, which ensures stabilization its properties, increasing the degree homogeneity of coal loading in the volume of the coking chamber becomes important.

Coal concentrates from about 15 suppliers were delivered to the silos of the closed warehouse at the coke plant of PJSC ArcelorMittal Kryvyi Rih. In coal preparation shop the batch was composed constantly of 9-12 components, what are illustrated by the histogram data (Fig. 1).

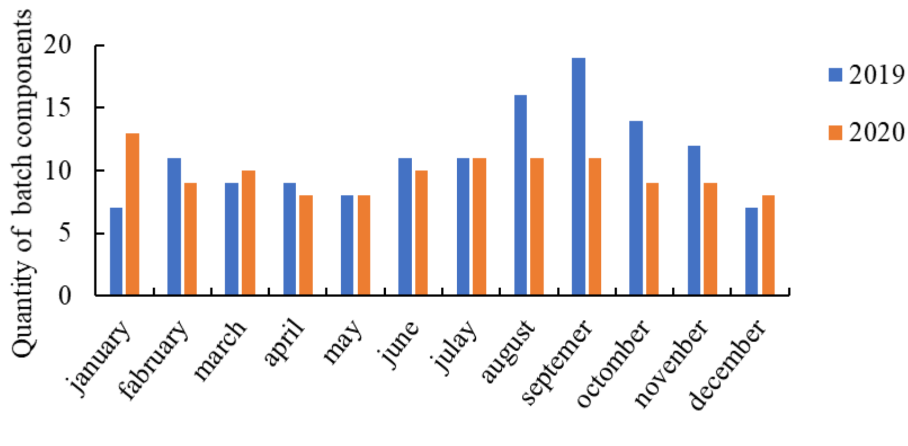

Fig. 1. The number of components in the coal batch coke plant of PJSC «ArcelorMittal Kryvyi Rih» for the period 2019 – 2020

At many coke-chemical enterprises abroad, the maximum number of coal concentrates that make up the batches does not exceed 2-3. The quality coke is primarily determined by the optimal composition and amount of coal concentrates. Irregularity in the supply of such a large number of coal grades and fluctuations in their physical and chemical parameters reduce the quality of coke and the stability of its indicators. It is quite difficult to ensure the high quality of coke and the stability of its physical and mechanical properties in the conditions of coke chemical enterprises when using a large number of coal concentrates in the batch.

To obtain coke of stable quality, it is necessary to solve the problem of effective mixing of the coal batch going to coking [1-2].

Sampling of coal concentrates and coal batch was carried out manually from the surface of the stopped conveyor using a device (frame). A frame was installed on the conveyor belt, which is two parallel walls, vertically located at a distance that is at least two sizes of the maximum piece. The frame was immersed in the coal raw material to the transport surface perpendicular to the flow direction. The selected sample was delivered to the coal testing room for further preparation for the test.

Preparation included successive operations of grinding, reduction and separation of the sample. Equipment and tools for sample preparation met the requirements of State Standard of Ukraine 4096-2002 «Brown coal, lignites, anthracite, combustible shale and coal briquettes. Methods of selection and preparation of samples for laboratory tests» (ISO 5069/1:1983 Brown coals and lignites) [4].

The indicators of technical, plastometric and petrographic analyzes of coal concentrates and coal batches are given in the Table. 1-3.

Continuing the research [2,7], after analyzing and summarizing the data on the quality indicators of coal raw materials, it was established that the degree of mixing of the batch in the coal preparation shop, calculated according to the method [8] on the yield of volatile substances, varied from 84 to 88.3%, which it is far from the optimal, economically justified degree of its mixing of 97-98%.

Table1. Change of technical and plastometric quality indicators of coal concentrates

Supplier	Rank of coal	Content in the batch, %	Technical analysis, %				Plastometric indicators, mm	
			W_t^r	A^d	S^d_t	V^{daf}	x	y
Integrity CS USA	Zh	9-12	5.5-8	7.4-9.3	0.8-1	29.8-37.5	29-46	18-22
Eagle Blend USA	Zh	10-22	6.1-8	7.6-8.2	0.85-0.95	34.7-35.2	34-44	17-20
Pechorska	2Zh	16-27	4.9-13.3	8.1-9.3	0.51-0.68	30.7-32.4	26-36	16-22
Integrity CS USA	Zh	10-16	5.4-8	8.4-8.8	0.82-1.04	29.0-34.0	28-38	18-23
Ukrkoks	Zh	4-9	9.4-11.2	7.2-10.5	1.68-2.26	32.3-32.5	23-27	19-24
Kievskaya	Zh	7-13	10.2-13.4	7.0-8.1	1.91-2.35	30.4-32.4	2-12	23-28
Pivnichna	K	20-27	7.5-14	7.6-9.3	0.38-0.47	23-24.2	35-42	14-17
Vdala	K	4-10	7.7-11.8	8.1-8.9	0.74-0.76	28.4-29.5	16-21	14-15
Ukrkoks	K	4-6	8.3-12.2	7.2-8.4	1.79-2.18	24.1-29.3	19-30	13-20
Uzlovs'ka	K	3-10	9.2-12.7	5.7-6.8	1.78-1.95	22-24.4	18-21	14-15

Table 2. Change in petrographic quality indicators of coal concentrates

Su*	M**	Petrographic composition (with-out mineral impurities), %					Distribution of vitrinite reflection coefficient, %							
		Vt	L	Sv	I	ΣFC	< 0.5	0.5-0.65	0.66-0.89	0.9-1.19	1.20-1.39	1.40-1.69	1.70-2.59	> 2.6
1	0.89-1.16	79-82	3-5		15-16	15-16		0.3-1.7	12.0-54.7	32.1-85.3	0.3-22.6	0-19.2	0-3.1	
2	0.95-0.98	72-77	4-7		18-24	18-24		3.7	19.3	87				
3	0.97-1	69-80	0-2		19-29	19-29		0.6-1	8.0-14	84.4-91	0.3-3.6	0.3-1		
4	0.99-1.15	77-82	3-4	0-4	14-19	14-19		0-0.3	9.6-24.4	36.4-88.4	0.6-19.8	0.0-15.7	0.0-3.7	
5	1.03-1.07	89-91	2-3		6-9	6-9		2.4-2.6	0.3-20.3	69-99.4	0.3-11.7	0.6		
6	1.09-1.1	88-93	1		6-11	6-11			0-0.3	94.7-96	4.0-5			
7	1.12-1.16	43-52	0-5	1-5	47-52	48-55			0.3-0.7	74.1-87.7	12.3-25.6	0.3-1.7		
8	1.16-1.18	86-89	1-2		9-12	9-12			0-0.3	62.0-66.0				
9	1.18-1.4	87-92	1-3	0-1	6-12	6-12	0-0.7	0.3-3.7	0.3-19.6	26.6-64.6	6.8-30	0.3-49.4	2.9-13	1-11.3
10	1.43-1.49	92			8	8			0.7-1.6	0.6-10.5	33.7-43.7	37.7-55.8	8.9-9.3	0.3-1

Su Suplier: 1-Integrity CS USA; 2-Eagle Blend USA;3- Pechorska; 4-Integrity CS USA; 5-Ukrkoks; 6-Kievskaya; 7-Pivnichna; 8-Vdala; 9-Ukrkoks; 10-Uzlovs'ka
*M**-Mean vitrinite reflection coefficient. Ro, %*

Table 3. Quality indicators of selected batch samples

S*	T**	Technical analysis, %				Packing density, t/m^3	Content (%) in class (mm)				
		Wtr	Ad	Sdt	Vdaf		+6 mm	6-3 mm	3-0,5 mm	-0,5 mm	0-3 mm
1	17	10.9	9.7	0.97	28.9	0.800	4.83	9.52	43.03	42.62	85.65
2	18	10.5	8.9	0.90	28.3	0.777	5.98	8.52	38.68	46.82	85.50
3	16	11.4	9.1	0.91	28.7	0.774	4.39	8.54	51.29	35.78	87.07
4	16	11.4	8.9	0.93	28.5	0.783	5.83	8.38	39.72	46.07	85.79
5	17	10.8	9.2	0.97	29.1	0.795	5.07	10.19	51.67	33.07	84.74
6	15	10.5	8.7	0.95	28.3	0.786	4.11	10.41	47.39	38.09	85.48

S- sample, T**- Thickness of plastometric layer, y, mm*

Table 3. Quality indicators of selected batch samples, continuation

S*	M**	Petrographic composition (without mineral impurities), %					Distribution of vitrinite reflection coefficient, %							
		Vt	L	Sv	I	ΣFC	< 0.5	0.5-0.65	0.66-0.89	0.9-1.19	1.20-1.39	1.40-1.69	1.70-2.59	> 2.6
1	1.09	70	2	1	27	28			10	69	16	3	2	
2	1.09	68	1	2	29	31		1	10	72	11	6	1	1
3	1.10	63	2	1	34	35		1	8	70	14	5	2	
4	1.10	65	3		32	32			9	70	13	6	2	
5	1.09	67	2		31	31			12	71	11	4	2	
6	1.09	66	3	1	30	31			12	65	17	4	2	

S- sample, M**- Mean vitrinite reflection coefficient, Ro, %*

The degree of mixing of the batch, which was determined by the fluctuation its humidity, was in the range of 74.2-77.8%, which is undesirable, considering the significant influence of moisture on the bulk density of the batch and the quality of coke.

Thus, according to research [9-11], humidity fluctuations lead to a decrease in mechanical strength, an increase in coke consumption, and a decrease in blast furnace productivity.

The range of ash content was 43-47%, the degree of mixing according to the sulfur content index was high - 92.3-96%, which is explained by slight fluctuations sulfur content in the coal batch. A low degree of mixing of the batch - 19.3-22% was obtained for the «lean» class of 0-0.5 mm. This is due to the content of the specified class in the coal batches coal preparation shop in the range of 40-46%, which is much higher than the optimal value.

The indicator the degree mixing of the batch according to the change in the plastic layer thickness samples is 67-70%, and the bulk density of the batch is 68-72.4%, which also does not contribute to obtaining high-quality coke.

The degree mixing of the batch according to the indicators of its petrographic composition for vitrinite and the sum of fusinized components was 87.7-91.5 and 86-90.2%, respectively, which is not enough for an optimal, economically justified degree of mixing.

Analyzing the obtained results the degree of mixing of the batch, it can be stated that this batch needs additional mixing before feeding it into the coke chamber.

Experimental box coking was carried out to study the influence of the degree of uniformity the coal batch on the physical and mechanical coke properties. Samples of the production coal batch with the established degree of mixing (base batch) and samples after additional mixing were coked.

The quantitative assessment the degree of mixing was taken amount of mixing «on cone». It was established that the increase in the homogeneity of the batch leads to an increase in crushability according to the M_{25} indicator by 2-4%, while the abrasion resistance according to M_{10} decreased by 0.5% (the obtained results are illustrated by the diagrams in Figure 2).

At coke plant at different times were used plate, blade, bull, screw, disintegrator machines and machines for organized mixing of the batch.

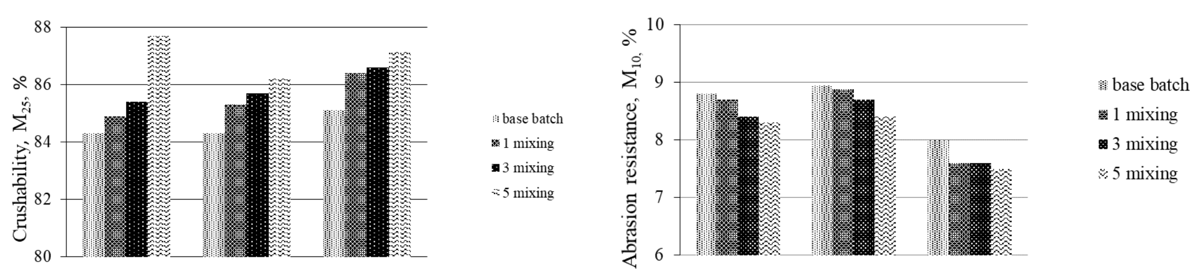

Fig. 2. Change crushability and abrasion resistance as a function of dependence from the degree of homogeneity of the batch

Using rotary type mixers is suggested for to achieve effective mixing of the batch components in production conditions. The design mixer is shown in Figures 3 and 4. The mixer is mounted above a conveyer belt, so that its rotors fit within the cross sections formed by the ribbed conveyer belt, with a gap between the plane of the belt and the rotor blades.

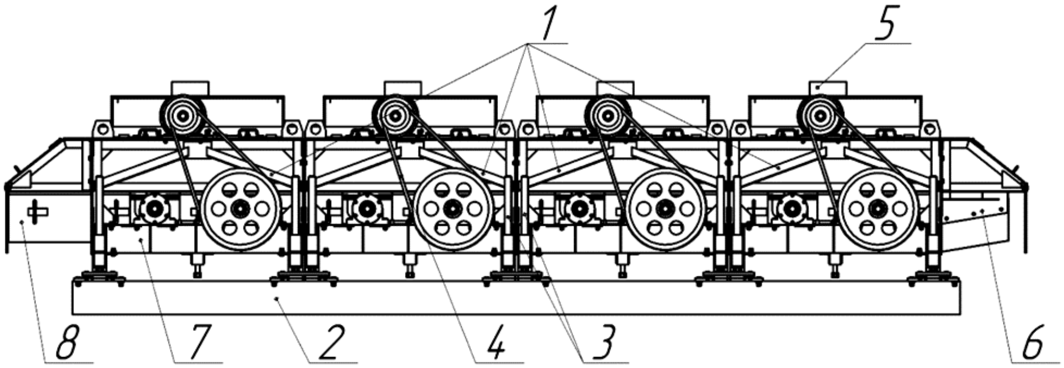

Fig. 3. Four section rotary mixer: (*1*) mixer section; (*2*) support; (*3*) adjustable screws; (*4*) belt transmission; (*5*) electric motor; (*6*, *8*) shielded input and output sections; (*7*) seal

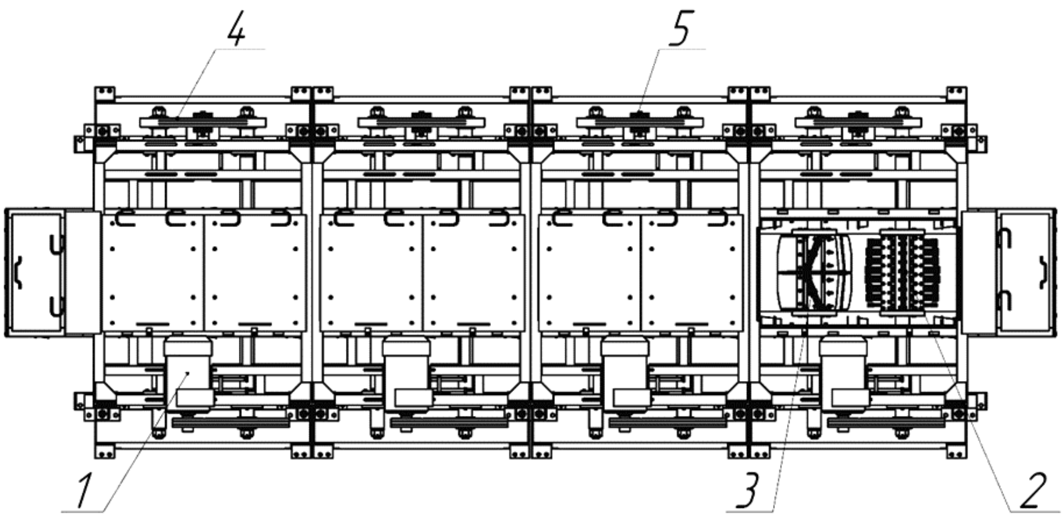

Fig.4. Four section rotary mixer (top view): (*1*) electric motor; (*2*) cable rotor; (*3*) blade rotor; (*4*) belt transmission; (*5*) tension roller

The rotors (Figs. 5 and 6) are responsible for the mixing. Each section of the mixer contains two types of rotors: one with regular blades and one with cable elements. The rotors turn in the same direction as the coal batch moves through the mixer.

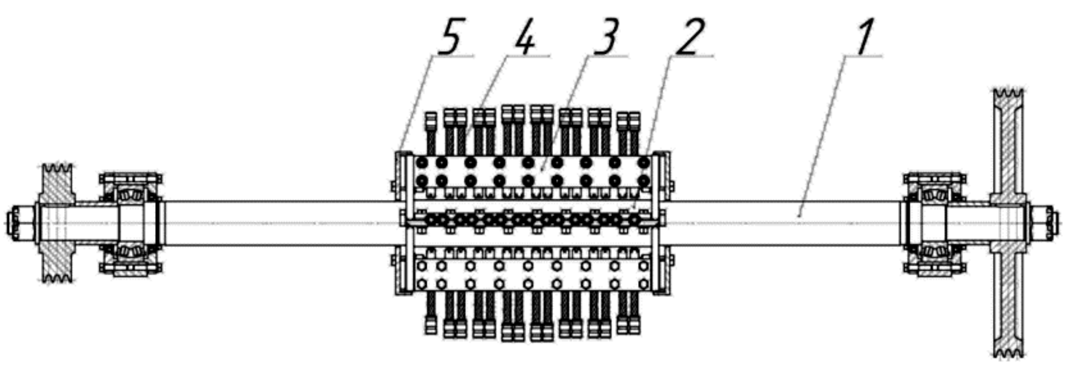

Fig.5. Cable rotor of mixer: (*1*) shaft; (*2*) drum; (*3*) removable blades; (*4*) cable elements; (*5*) lock

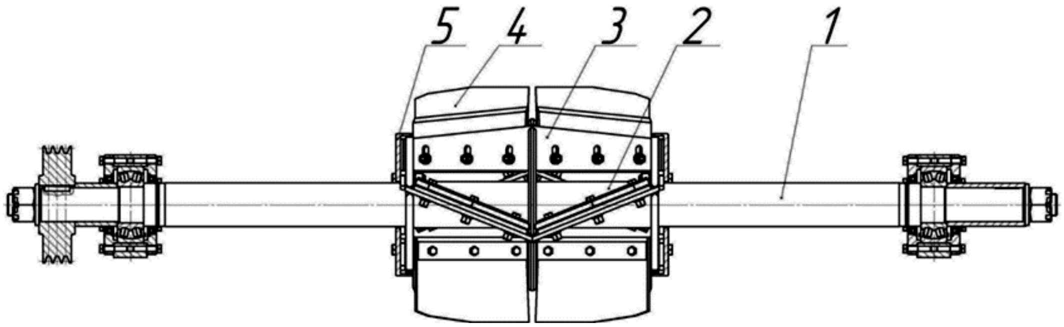

Fig.6. Blade rotor of mixer: (*1*) shaft; (*2*) drum; (*3*) removable blades; (*4*) flexible blade elements; (*5*) lock

As the coal batch moves over the belt, it is acted on by the rotor blades and mixed with the protective additives. The characteristics of the SR2520×1.0 mixer are as follows in the Table 4.

Table 4. Characteristics of the SR2520×1.0 mixer

Width of conveyer belt, mm	1000
Number of sections	2
Rotor diameter, mm	520
Rotor speed, rpm	250
Length of rollers in horizontal support, mm	410
Conveyer slope, deg	0
Rated power, kW	15
Power of a single electric motor, kW	7.5
Number of motors	2

According to the results of studies of the mixer, it was established that its use ensures a mixing degree of 98% in terms of all quality indicators of the coal batch (technical analysis, granulometric composition, bulk density and petrographic indicators). The given design of the mixer can also be used for the uniform distribution of magnesium chloride additive during the preventive treatment of coal raw materials to preserve its fluidity during the winter period during transportation [12].

As can be seen from the data in Table 5, when using a mixer for additional homogenization of the coal batch, the stability of its quality indicators increases.

Table 5. Coefficients of uniformity of quality indicators of experimental batches

Sample	Without mixer				With the mixer running			
	W, %	A^d, %	S^d_t, %	V^{daf},%	W, %	A^d, %	S^d_t, %	V^{daf},%
1	10.9	8.9	1.45	31.8	10.8	9.2	0.97	28.9
2	10.5	8.7	1.50	31.5	10.6	8.9	0.9	28.3
3	11.4	8.6	1.41	30.5	10.8	9.1	0.92	28.5
4	11.4	8.1	1.30	30.8	10.9	8.9	0.93	28.3
5	10.8	8.0	1.26	29.9	10.8	9.2	0.96	28.9
6	10.5	9.1	1.51	31.7	10.6	8.9	0.96	283.
Average value	10.9	9.1	0.94	28.63	10.7	9.0	0.94	28.53
Dispersion	0.166	0.1227	0.0009	0.1067	0.015	0.0227	0.00082	0.0867
Mean square deviation	0.407	0.349	0.03	0.326	0.122	0.15	0.028	0.294

3. Conclusions

The low degree of mixing is due to the large quantity of components in the of the batch, irregular supply of coal concentrates, fluctuations in their physical and chemical parameters. Research results indicate that increasing the homogeneity of the coal batch through the introduction of organized mixing will improve the physical and mechanical properties of coke.

It should be noted that the smallest effect from the use of mixing units is achieved with the batch preparation scheme, which involves grinding all its components in one crushing unit. At the same time, the use one crusher instead two or four makes it possible to achieve a high degree of homogeneity of the batch [8].

In the final grinding schemes, which provide for group or differentiated grinding the components of batch is required to use mixing machines. To ensure the efficiency mixing the components of the coal batch, it is desirable to install mixers in the transfer nodes, on the transfer of the batch from the conveyor to the conveyor or on top of the coal tower, in this case the segregation of the batch is reduced to a minimum [13].

Symbols

$W^r{}_t$	*water content in coal, as received state, %;*
A^d	*ash content of coal in the dry state, %;*
V^{daf}	*volatile matter in the dry ash-free state, %;*
$S_t{}^d$	*sulphur of coal in the dry state, %;*
R_0	*mean vitrinite reflection coefficient, %;*
Vt	*vitrinite, %;*
Sv	*semivitrinite, %;*
I	*inertinite, %;*
L	*liptinite, %;*
∑FC	*sum of fusinized components, %;*
y	*thickness of the plastic layer, mm.*

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