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THE EFFECT OF CLIMATOLOGICAL AND HYDROLOGICAL PARAMETERS ON THE PERFORMANCE OF MINING WORKS IN A FUNCTION OF PROVIDING THE ENERGY FUEL FOR STABLE OPERATION OF THE THERMAL POWER PLANT GACKO

Abstract

This paper presents the climatological and hydrological effects on the calorific value of coal as an energy fuel for the Thermal Power Plant Gacko. Since the average annual rainfall is approximately 1,700 l/m^2, and that groundwater levels are quite "high" even in the dry season, humidity is a parameter that significantly affects the reduction of coal calorific value of coal in operating conditions. Previous experiences in coal production, as well as the laboratory tests, have shown that the humidity in coal is increasing, due to the increased rainfall and flooding of floors due to the increased groundwater levels. Also, in the dry period, under the effect of wind and solar radiation, coal on the landfills of the Thermal Power Plant quickly loses moisture thus increasing the heat value and also the production power of generator and achieve greater production and economic effects [7].

Keywords: *humidity, climatology, hydrology, energy fuel, lower calorific value*

INTRODUCTION

The main subject of coal exploitation at the open pit "Gacko" is to provide the sufficient quantities of coal for the needs of the Thermal Power Plant "Gacko", the required quality with minimum operating costs. As the conditions of coal exploitation in certain parts of deposit of the return zone will constantly deteriorate (greater stratification, greater change in coal quality, etc.), and the requirements of the Thermal Power Plant Gacko are becoming more stringent, it is necessary to manage the coal quality in operational conditions maintaining the exploitation quality of coal within the set (required) limits [7]. The negative impact of increased moisture content, on reducing the calorific value of coal, in the period of rain and snowfall, occurs in the entire technological process, i.e. from the coal exploitation in the deposit, transport of coal to the crusher, at the landfill of crusher, transport of coal from the crusher to the landfill of the Thermal Power Plant and at the landfill of the Thermal Power Plant itself. Coal as a pure carbonaceous substance partially absorbs moisture, but waste layers (clays and marls) are porous and absorb moisture, which significantly reduces the calorific value and grindability of coal.

1 CLIMATE CHARACTERISTICS OF THE GACKO ENERGY BASIN

The climatic type that prevails on the plateau of the Gacko Filed (subalpine climate - under valley climate according to

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the Köppen classification of climate which is unsurpassed and current to this day) directly affects the intensity, quality and scope of mining works during the year, especially during the two spring and autumn precipitation maximums because this is the climate type, which has a Mediterranean fluviometric regime (the highest amount of precipitation occurs in the winter half of the year 72%.). The annual distribution during the year clearly shows that in the summer half of the year only 10 to 15% of the total amount is excreted annually. The annual course and distribution of precipitation is extremely unfavorable and uneven during the year, which has always been a basic feature of the Mediterranean precipitation regime. The mine achieves the best results in the summer part of the year when there is a small amount of precipitation, low humidity and when the machinery can work smoothly and gives maximum effect during working hours.

During the autumn and spring, the climate of the Gacko Basin is crucially influenced by the Mediterranean cyclones (Genoese and Cypriot depressions and smaller cyclones that form in the Adriatic Sea) which cause precipitation because their trajectories are mainly directed towards the Dinaric Mountain system where the Gacko mining energetic basin is situated.

Snow, as a type of solid precipitation has a very significant impact on the mine work, both in its height and the amount of water that melts on sunny days and at low temperatures when it turns into snow ice, ice and glaze. In that way, the work and transport of mining material on the roads on which mining machines move becomes more difficult. The average number of days with snow cover of more than one centimeter is 75. The average number of days with snow is 44 days. In recent years, due to the climate changes, which are on the scene for a long time, the number of days with snow and its height, as well as the number of days with snow cover, has been decreasing. The maximum height of the snow cover measured in the last 25 years was 115 cm, and it was measured on March 4, 2005.

Rain, as a type of liquid precipitation has a very bad effect on radar works, especially when a larger amount appears for a short period of time. Then the torrential flows are created leading to a sudden penetration of water into the mine, both by surface and underground. A huge amount of water flows into the existing water reservoirs and the pumping capacities are maximally loaded because they have to discharge a huge amount of water, via pipelines to the rivers Mušnica and Gračanica.

As for the hydrological situation, during the year it is most favorable in the summer period of the year, when the precipitation is minimum (small amount of precipitation and low humidity) and the mechanization of the mine can work smoothly and easily. At the time of two precipitation maxima which are one in early spring and one in late autumn, the hydrological situation is much more difficult, due to the large amount of precipitation and greater penetration of groundwater and surface water into the mine.

The value of daily amounts (24 hours) of precipitation is sometimes extremely high to exceed the monthly amount. The absolute daily amount of precipitation (24 hours) was measured on October 13, 1975 and amounted to 198.4 l/m^2, which exceeds the maximum value of the daily amount of precipitation for a return period of 100 years.

The maximum daily amount of precipitation (24 hours) that occurs once in 50 years is 174.0 l/m^2. The number of days with precipitation during the year is 136, which means that the precipitation occurs every two to three days. The annual number of rainy days has been declining in recent years due to the large impact of climate changes, which have been intensified, especially in the last ten years.

Diagram 1 shows the spatial distribution and average amount of precipitation for the return reference period of over 70 years [3]. Table 1 shows the amount of precipitation for the return reference period of over 70 years.

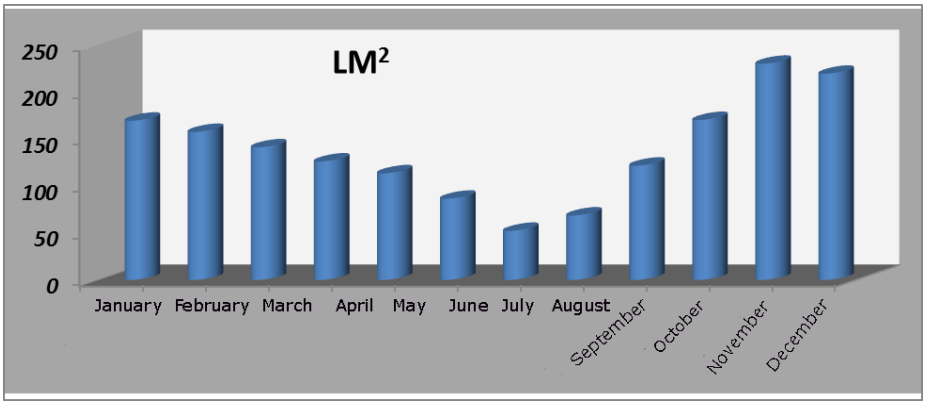

Diagram 1 *Spatial distribution and average amount of precipitation for the return reference period of over 70 years*
(Source: Meteorological Station of the Mine and TPP Gacko)

Table 1 *The amount of precipitation for the return reference period of over 70 years*

Month	**Amount of precipitation l/m^2**
January	169.3
February	157.4
March	141.0
April	126.0
May	113.4
June	86.36
July	52.19
August	68.57
September	121.5
October	170.0
November	229.9
December	219.24
Total	**1654.80**

Relative humidity is as an important climatic element, which affects the work in the spring in many ways. During the hot summer months, the relative humidity is very low, especially in the afternoon (20% even less) when it is accompanied by very high tropical temperatures and, in addition, there are huge whirlwinds of marly-

coal dust, which further complicates the human work in the mine since the normal human biorhythm requires a humidity of 45 to 65%.

In the winter months, the relative humidity is very high (90% even higher) followed by a large amount of snowfall and ice, which also further complicates the work in the mine and reduces the calorific value of coal.

Diagram 2 shows the mean monthly and mean annual air humidity (%). Table 2 shows the values of average monthly and average annual air humidity [3].

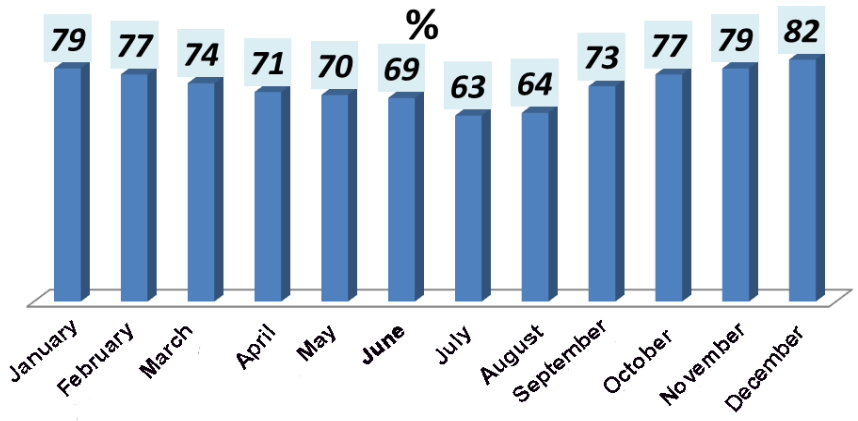

Diagram 2 *Mean monthly and mean annual air humidity (%)*
(Source: Meteorological Station of the Mine and TPP Gacko)

Table 2 *The values of average monthly and average annual air humidity* [3]

Month	**Amount of precipitation l/m^2**
January	79
February	77
March	74
April	71
May	70
June	69
July	63
August	64
September	73
October	77
November	79
December	82
Medium annual	**73**

Wind, as a very important climatic factor, has multiple effects on the mine operation and its facilities. Due to the high strength of wind, especially the north wind, which is the most common in the wind roses, which can exceed speeds over 100km/h, delaying and receiving arrows due to high vibrations and wear and movement, must stop working, according to the design constraints. The wind rose is given in the diagram for 2021, where the representation of certain directions during the year can be seen and it is less, more similar to the previous years.

During the summer half of the year, during long dry periods, due to wind gusts from the floor and mining machine, the large whirlwinds are created, sand and dust, which further complicate operation in the mine and mining machines, because then the huge concentration of solid pollutants in the air and relative air humidity at the annual minimum.

Diagram 3 shows the direction, frequency and strength of wind for 2021 (%) [3].

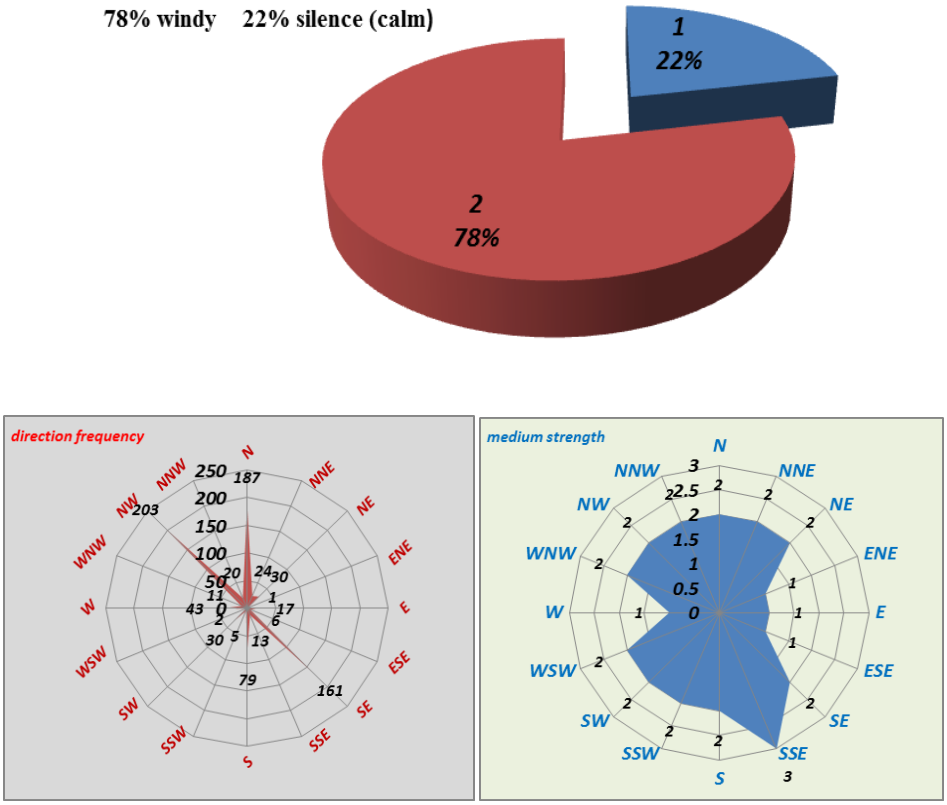

Diagram 3 *Wind direction, frequency and strength for 2021*
(Source: Meteorological Station of the Mine and TPP Gacko)

Table 3 shows the values of wind direction, frequency and strength for 2021 [3].

Table 3 *The values of wind direction, frequency and strength for 2021*

Direction	Direction frequency	Wing strength	Medium strength
S	230	0	0
N	187	465	2
NNE	24	60	2
NE	30	51	2
ENE	1	1	1
E	17	24	1
ESE	6	8	1
SE	161	342	2
SSE	13	37	3
S	79	177	2
SSW	5	10	2
SW	30	56	2
WSW	2	3	2
W	43	65	1
WNW	11	18	2
NW	203	349	2
NNW	20	45	2
Total	**1062**	**1711**	

High summer temperature, low relative humidity in the summer half of the year as well as winter high relative humidity and a large amount of precipitation directly affect the combustible coal matter deposited in the landfills of the thermal power plant, i.e. on qualitative characteristics, which are manifested by variations in the calorific value of energy fuel. High tropical temperatures, especially in the last ten years, are constantly increasing as well as the number of tropical days during the summer. During 2021, there were 34 tropical days on the territory of Gacko, which has never been recorded so far. In some earlier climatic periods, the number of tropical days was 5 to 7. Tropical days previously appeared only in July and August, and in recent years occur in June and September, which further aggravates the situation and leads to increasing warming, lower relative humidity and less precipitation during the summer half of the year. This climate type negatively affects the coal landfills, almost all year round. In the winter part of the year, since the landfill is in the open, the landfill is saturated, under the effect of a huge amount of precipitation, which reduces the calorific value of combustible coal, especially in its surface part, which is exposed to the direct rainfall. In the summer part of the year, when the precipitation is minimum (there are no raindrops for days), the relative humidity is very low (20% in the afternoon and even lower), high tropical daily temperature (over 30^0C), the landfill self-ignites and the coal heat decreases.

Diagram 4 shows the average monthly absolute minimum and maximum air temperatures for 2021. Table 4 shows the values of average monthly absolute minimum and maximum air temperatures for 2021, as well as the spatial distribution and annual course of air temperatures [3].

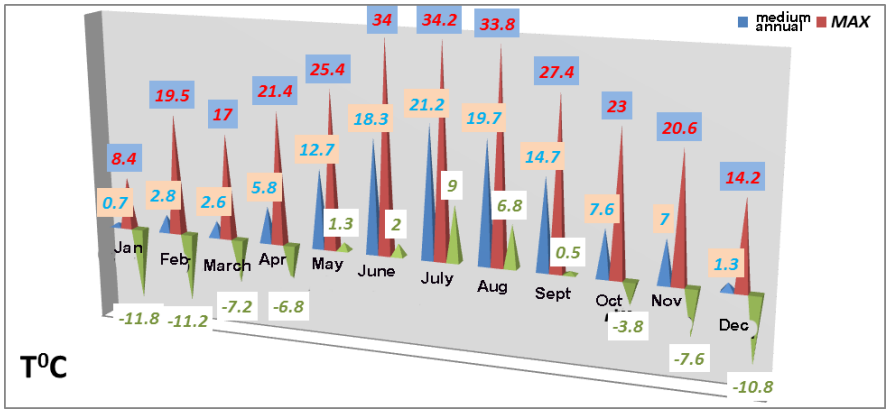

Diagram 4 *Mean monthly absolute minimum and maximum air temperatures for 2021 (Source: Meteorological Station of the Mine and TPP Gacko)*

Table 4 *The values of average monthly absolute minimum and maximum air temperatures for 2021 as well as the spatial distribution and annual course of air temperatures.*

	January	Febr.	March	April	May	June	July	August	Sept.	Octo.	Novem.	Decem.	Medium annual
Medium	0.7	2.8	2.6	5.8	12.7	18.3	21.2	19.7	14.7	7.6	7.0	1.3	**9.5**
Max	8.4	19.5	17.0	21.4	25.4	34.0	34.2	33.8	27.4	23.0	20.6	14.2	**23.2**
Min	-11.8	-11.2	-7.2	-6.8	1.3	2.0	9.0	6.8	0.5	-3.8	-7.6	-10.8	**12.0**

2 HYDROLOGICAL CHARACTERISTICS OF THE GACKO ENERGY BASIN

Hydrology of the Gatačko field is very similar to the other karst fields, the general direction of movement of both surface and groundwater is from the north and northeast to the south and southwest.

The current state of hydrology is somewhat different. The river Mušnica was moved by a new canal through the Gacko field and introduced into its bed near the village of Bašić. The current open pit "Gacko" is well secured from water of the river Musnica, both surface and underground, considering that it is the main recipient of all the waterof the Gacko field. Previously, the river Mušnica flowed directly along the final slope of the mine, on its southern and southwestern side, so that the water penetrations into the mine, whether surface or underground, were very present and unpredictable, especially during the periods of heavy rainfall.

The river Gračanica was moved to a new regulatory riverbed with impermeable foils, directed to the west and introduced into the abandoned riverbed of the river Mušnica, and through the Srdjevski klanac near the village of Bašić it was reintroduced into the river Mušnica. With this relocation, the current open pit is quite well secured, both from the surface and groundwater of

the river Gračanica. The mine has uninterrupted production of coal and waste, unlike the previous period, when the surface mine existed in the western exploitation field and had to have a defense system on its northern and northeastern side the PERIPHERAL CHANNEL - PS1-PS2-PS3-DIAPHRAGM - INJECTION CURTAIN to protect against surface and groundwater from the north and northeast [6]. Such a defense system was very complex, economically unfavorable and, regardless of the complexity of maintenance, it was necessary.

The current situation of the mine in terms of surface and groundwater is far more favorable regardless of its depth (120 m) and the development of open pit towards the central parts of the Gacko field, due to this reason such a complicated hydrological defense system is not needed. Evacuation of water from the mine is being done successfully using a system of submersible pumps in water reservoirs and pipelines from water reservoirs in the riverbeds of the rivers Mušnica and Gračanica.

Surface and groundwater are collected in water reservoirs and from that aspect the open pit has solved the problem of drainage, but the negative impact of flooding of coal and waste remains. Since the Mušnica River has been relocated to a new surface bed, the groundwater flowing through the alluvium of the Musnica River remains present in the waste excavation zone. The final southern slope reached the designed excavation elevation, which almost coincides with the route of the old bed of the river Musnica [5]. Groundwater problems are constantly present in both rainy and dry periods. All the water that gravitates from the south are directed towards the reservoir, but they also pass through the coal floors, so there is a frequent occurrence of flooding the energy fuel that is transported to the landfill of the thermal power plant.

Coal flooding is a frequent occurrence of exploited coal from the local "coal zone", especially in the period of increased rainfall, when clay as an insulator captures all groundwater and surface water, which passes through the permeable parts of the coal seam. Clay interlayers, which appear in the coal seams of the roof series, represent a balance both as inorganic matter and raw material that carries moisture and which, due to its small thickness in the layer, is delivered together with pure coal substance to thermal power plant landfills.

3 IMPACT OF HUMIDITY ON QUALITATIVE CHARACTERISTICS OF ENERGY FUEL

The essence of technological problems related to the water content (moisture) is in a difficult control of this parameter, and thus all other quality parameters.

Difficult control is due to the high variability of the content of (coarse) mine moisture, which represents the largest part of the total moisture. The change in the content of water (moisture) in the deposit is conditioned by changes in the hydrological and hydrogeological situation. Thus, the humidity is highest at the time of melting snow and heavy rains. The excavated coal quickly moistens in case of precipitation, especially if there are clay-marl impurities [1].

Parameter that is directly related to the water absorption in coal is porosity, which is expressed through the effective porosity. Effective porosity is the ratio of volume of interconnected pores to the total volume [2]. The properties of coal as a collector of groundwater and surface water depend on the effective porosity. Effective porosity in terms of water absorption refers primarily to brown coal and lignite (the Gacko coal).

In the case of tests with a low percentage of moisture (below the usual norms), the thermal value was corrected via an appropriate diagram (diagram 5) constructed according to the laboratory tests.

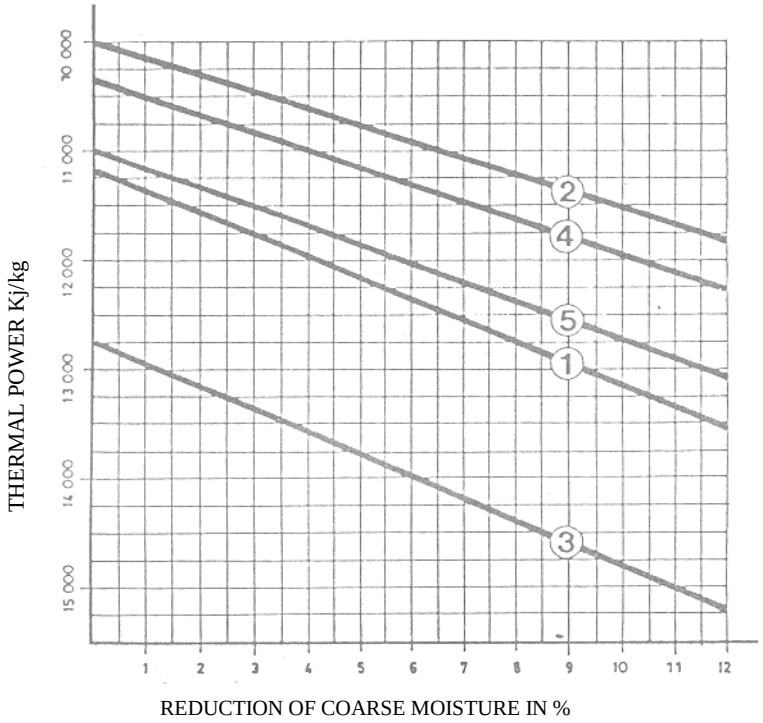

Diagram 5 *Diagram of the effect of coarse moisture reduction on the calorific value of coal in samples from drillhole 292*

Laboratory tests have shown that by reducing the coarse humidity by 1%, the calorific value of coal increases by about 200-250 kJ/kg [4].

FINAL CONSIDERATIONS

The qualitative characteristics of energy fuel that is burned in the boiler of the Gacko Thermal Power Plant largely depend on the climatological and hydrological conditions in which the coal is mined at the OP "Gacko". The complexity of climatological conditions and their impact on the quality of combustible coal is reflected in the large number of days with precipitation (rain and snow) during the year, which leads to the increased humidity and thus reduced the lower calorific value of coal. Moisture is a parameter that, in addition to the participation of waste layer with the presence of the carbonate component, mostly reduces the calorific value of coal, and thus the negative effects, in the energy production power of the Gacko Thermal Power Plant block.

In the period of increased precipitation, the water content of coal increases, which creates problems in reaching the required granulation in the mills of the thermal power plant, as the initial phase in the preparation of energy fuel for combus-

tion in the boiler of the thermal power plant. By reducing the production capacity of the thermal power plant block, lower economic profit is achieved, which means that increased moisture in coal in the entire economic system of mines and thermal power plants, significantly affects the negative economic effects. Also, the complex hydrological conditions, which are manifested in the appearance of a large number of springs, which gravitate towards the coal floors to a certain extent (slightly less than climatic conditions), affect the coal flooding and increase moisture content in the period without precipitation. In the coming period, a special attention should be paid to the problems of reducing the negative impact of moisture caused by the unfavorable climatological and hydrological conditions through study analyzes and research, in order to reduce the negative economic effects caused by this parameter of energy fuel quality.

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