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Evaluation of the Moisture Content of a Coking Coal for the Heat Consumption During Carbonization

by Dr. rer. nat. K. G. Beck,
Dr. rer. nat. R. Beckmann
and Dr. Ing. W. Weskamp

of Steinkohlenbergbauverein,
Essen, Germany

On an invitation by the American Institute of Mining, Metallurgical, and Petroleum Engineers three years ago, we had the opportunity to present to the Blast Furnace, Coke Oven, and Raw Materials Conference in Philadelphia a report on carbonization tests, which specifically dealt with the more essential coke characteristics and how they are affected by carbonization conditions[1]. The results of these tests had been obtained in a semi-industrial scale coke oven with a charging volume of 11.1 cu. ft.. Such test ovens are used with good success both in Europe and the USA for the determination of coke characteristics[2]. However, it is not possible to carry out thermo-technological investigations with such ovens, because the considerable surface and waste gas losses prevent an exact evaluation of the underfiring heat, which can be related to practical operation. Such thermo-technological investigations, however, are of particular significance for the West-German coke oven plants, since the expenses for underfiring constitute by far the largest factor of all costs which can be influenced by the mode of operation. Steinkohlenbergbauverein, thus, decided to build a test plant to be erected on a large coke oven plant in commercial operation. The test plant consists of an oven block with five industrial-scale semi-divided flow controlled coke ovens of underjet design. A bricked-up bulkhead of 59.1 in. width connects the test ovens (Fig. 1) with the adjoining oven group. On the other side there is a buttress of the usual type, with bricked cooling duct and concrete end. The dimensions of the ovens in cold condition and the hot dimensions determined during operation are shown in the following table (Fig. 2). In order to be able to heat all oven walls uniformly, "quantometers" and needle valves have been incorporated in each set of heating flues on the coke and ram side. The heat for underfiring the central oven can be measured individually. This separate gas feeder and measuring system proved necessary, because a comparison of the heat consumption ascertained

[1] Size Distribution, Strength and Reactivity of Coke and how they are affected by the Coking Process
H. Echterhoff, K.G. Beck and W. Peters, 1961

[2] Doherty, J.D., R.J. Hodder, L.N. Anthony
Some Effects of Moisture in Coking Coal,
Blast Furnace and Steel Plant 1962, pages 3/16

from the five test ovens with the heat consumption of newly constructed larger oven groups revealed great differences. This is in agreement with the results obtained by the British Coke Research Association at their test plant at Wingerworth. From the report by D.A. Hall, W.J. Pater, and F.K. Warford[3] on "The effect of drying coal charge and filter cake on coke oven performance and the yield and properties of the products" it can be seen that even an industrial-scale coke oven of 10 t. capacity, which is operated separately from a coke oven battery, has a thermal efficiency of only 50%, as compared with the usual 70-80% efficiency of coke ovens arranged in batteries.

The coke is classified in a special screening plant (Fig. 3) and tested for its strength. A condensation plant (Fig. 4) serves to determine the amount and composition of the raw gas. This plant is designed in such a way that both the gas evolved from the five ovens, and the yield of by-products can be followed over the carbonization time of one oven. All measured data are centrally registered in a control station to monitor the operation.

From among the various serial tests so far carried out to ascertain the effects of heating flue temperature and moisture in the coking coal, the influence of the moisture content of the coal on high-temperature carbonization will be illustrated in the following.

Similarly to the method adopted by Brisse and Price[4], who used a wooden chamber, the distribution of the bulk densities as dependent on the moisture content of the coal was investigated in a test chamber of steel, prior to the commencement of carbonization tests (Fig. 5). Altogether 37 sampling points were arranged at three different levels. The coal used had a volatile content of 25.3% (free of water and ash), a size consists of 72% under 0.08 in. and 34% under 0.02 in., its ash content was 7.1% (free of water). Fig. 6 shows the distribution of bulk densities at moisture contents of 10%, 8%, and 6% at the three measuring levels. Due to the effect of dropping, the bulk density below the charging holes is always substantially above the bulk density between the charging holes. Naturally, this difference is reduced with the height of dropping. In the upper section of the

[3] Hall, D.A., W.J. Pater, F.K. Warford
Journal of the Inst. of Fuel (1963), pages 3/11

[4] Brisse, A.H., J.G. Price
Explorations in coke making research with a full scale coke oven model
Blast Furnace and Steel Plant 1959, pages 1285/90

Hock, H., M. Paschke
Archiv Eisenhütten 3 (1929), pages 99/102

Koppers, H., A. Jenkner
Glückauf 66 (1930), pages 834/38

Eisenberg, G.A.,
Glückauf 68 (1932), pages 445/61

Ejdelman, A.B., F.Z. Elenkij, G.D. Butuzov
Coke and Chemistry (USSR) 1961, pages 3/6

chamber there is also a more uniform distribution due to levelling. The following Fig. 7 shows the distribution of bulk densities under charging hole 1 and between charging holes 1 and 2. The hatched area is a measure of the inequality of the bulk densities. It illustrates the difficulty of heating an oven chamber with coal of high moisture content in such a way that the same carbonization rate is attained throughout the chamber. The results show how important it is for coke oven plants to lower the moisture content of the coking coal and, thus, to bring about an equalization of the bulk densities in the oven chamber in order to warrant a uniform carbonization of the chamber contents resulting in coke of homogeneous structure and strength.

After charging, the bulk density of the coke does not at all remain constant, but it changes during carbonization. Immediately after charging the coal, it starts shrinking. This shrinking phenomenon continues for 2 hours. It is caused by an intrinsic oiling effect inherent with coal. During the distillation, part of the gas evolves through uncarbonized coal. This gas, let us call it internal gas, carries with it about 122 gr./cu.ft. compounds from the plastic zone which are solid or liquid under normal conditions. They are partially precipitated as an oily film on the surface of the coals. To initiate the first shrinkage it only requires a stimulus which is created by the gases and vapours passing through the coal.

The second shrinkage does not begin until after the formation of the first semi-coke. It should be due to the relaxation of tensions in the structure of the coke, and subsidence of the coke, caused by cracks.

Fig. 8 shows the duplication of the shrinkage effect between 10 and 6% moisture, its reduction at 4% to a value lower than at 10%, and the almost complete disappearance of shrinkage at 2% moisture content. If the bulk density is calculated after the initial shrinkage, it turns out to be the same between 10% and 4% moisture content. Thus, the first shrinkage is effective until the same bulk density (wf) is reached. In the case of coals with swelling properties a reduction in the moisture content will not have any influence on the mode of operating the ovens. At 2% moisture content, the bulk density (wf) of the coal is so high that the coal grains cannot, of their own weight, become more compacted. The second shrinkage of the coal tested was not large enough to regain the initial coal volume. The coal struck to the wall, and pushing the coke was difficult.

There are generally two possibilities of investigating the effect of the moisture content of the coal on heat consumption. Either the heating flue temperature is kept constant for all tests and the influence of differences in the moisture content is balanced by modifying the carbonization time, or the tests are made at equal carbonization times, while a change in the heating flue temperature will compensate for differences in the moisture content.

The first mode of operation was chosen for our investigations, i.e. at a heating flue temperature of 2280°F. the carbonization time according to the respective moisture content of the coal was determined in preliminary tests. The serial tests comprised 6 tests in which the water content of the coal was changed in steps of 2% between 2 and 12%. A new test with modified moisture content was not commenced until the battery was surely at an equilibrium. The duration of the test, at each moisture content, was at least 5 times 24 hours.

The coking coal, in a thermal drier, was adjusted to the desired moisture content. No larger deviations than 0.1% from the desired moisture content of the coal were determined in the larry car.

Fig. 9 illustrates the bulk densities, carbonization times and throughputs in their dependency of the moisture content. The bulk density (moist) has a minimum at 4 to 6% moisture content of the coal. This minimum, in the curve of the bulk density (wf) is shifted towards the higher moisture content. The curve of the carbonization time has about the same tendency as the curve of the bulk density (moist). The negligible differences can be accounted for by modifications in the carbonization conditions owing to the influence of the moisture content of the coal. In this case, it is particularly the great dependency of the heat conductivity on the water content which makes itself felt. The dependency of bulk density and carbonization time on the moisture content of the coal are also reflected in the throughput. The hatched area between the curves for moist and water-free throughput is a measure for the amount of water which must be processed as a ballast during carbonization. Referred to the coke yielded wf/wf an increase in the throughput of 18% will result, when the moisture content of the coal is reduced from 12 to 2%.

In discussions about the heat consumption for carbonization, as dependent on the moisture content of the coal, the question is always raised how much energy is required for expelling the moisture of the coal in the oven and if under certain circumstances it may be more economical to reduce the moisture content of the coal in a special drying process[5]. The heat consumption figures measured in our test ovens with the coal described above have been illustrated in Fig. 10. They change from 832 Btu/lb. at 2% moisture content of the coal (moist) by 70 Btu/lb. to 902 Btu/lb. at 12% moisture content of the coal (moist). As the illustration further reveals, the differences in the heat consumption figures are by no means equal for each 2% change in the moisture content. At higher moisture contents they are essentially larger than at lower ones, although the changes in the amounts of moisture and coal at 0.02 lb. are the same.

Before following up the reasons for the non-linearity of the course of the heat consumption curve, the calculated heat consumption figures likewise illustrated in Fig. 10 should be mentioned which result from operating the ovens at equal carbonization time and at a heating flue temperature as modified in correspondence with the moisture content of the coal. The data necessary for the re-calculation have been taken from an earlier investigation into the effect of the heating flue temperature on high temperature carbonization[6]. The carbonization time of 20 hours which results from coking a coal with 10% moisture at a heating flue temperature of 2280°F. has

[5] Wollenweber, W., Glückauf 57 (1921), pages 987/92

Koppers, H., Koppers-Mitteilungen 14 (1932), pages 3/8

Baum, K., Glückauf 68 (1932), pages 1/8, 40/45

Litterscheid, W., Brennstoff-Chemie 13 (1932), pages 386/91

Hofmeister, B., Glückauf 88 (1952), pages 367/70

[6] Weskamp, W., W. Dressler, E. Schierholz, Glückauf 98 (1962), pages 567/77

been taken as the basis. The heat consumption differences for any 2% change in the moisture content are larger than they are at constant heating flue temperature. Table 2 (Fig. 11) compares the results of the two modes of operation. When reducing the moisture content of the coal from 12 to 6% a saving averaging 14.4 Btu is attainable for each 1% reduction in the moisture content at constant carbonization time, while an average of only 9.0 Btu could be determined at constant heating flue temperature.

On the other hand, when operating at constant heating flue temperature, a larger increase in the throughput of the coke ovens can be achieved by changing the carbonization time.

The question about the real heat requirement for the evaporation of the moisture led us to further investigations and observations regarding the heat economy of a coke oven and how it is influenced by differences in the moisture content. In carrying out these further investigations it appeared expedient to extensively break up the individual thermo-technological mechanisms in a coke oven. By means of a section through a coke oven (Fig. 12), an explanation of the individual items should be given initially. The underfiring heat Q_1 fed through the heating flue is only partially utilized for carbonization. Items Q_2 and Q_3 represent the total losses. Item Q_2 collects the waste gas and surface losses of the lower part of the oven up to the coal line. Item Q_3 includes the surface losses above the coal line. The heat amount Q_1 minus Q_2 is largely transferred to the chamber charge (Q_{10}). Only a negligible portion, through heat transfer, flows into the area above the coal line Q_4. This heat, depending on the temperature condition prevailing in the gas collecting space, can be transferred to the gas or is lost as surface loss. During carbonization, together with external Q_6 and internal Q_7 gas, a substantial amount of heat reaches the gas collecting space and leaves it again with the developed mixed gas Q_5. Item Q_8 is constituted of the evaporation heat of the water, the tar and the light oil at 32°F. and the gas formation energy (Gasarbeit) of the gaseous distillation products at 32°F. At the time of pushing, the coke possesses the sensible heat, item Q_9. The chemical processes occurring during the carbonization have an overall heat inherence which is considered under Item Q_{11}. A sensible heat Q_{12} is brought into the coke oven by the feed coal, the underfiring gas and the combustion air.

During the tests, all temperatures for the calculation of the sensible heats have been measured excepting the temperature of the external gas and internal gas when entering into the gas collecting space. For these measurements special suction pyrometers had to be designed because it is very important not to disturb the flow conditions prevailing in the measured range during measurements. The suction pyrometer to measure the temperature of the external gas was equipped with a narrow hood which on the one hand keeps off the radiation of the wall and on the other offers a screen against the internal gas. The hot must at least have the width of one piece of coke in order to be independent of the geometry of the coke lumps. Suction must be so dimensioned that the same velocity will prevail inside and outside the hood. When the suction is too strong, the temperature will drop immediately which indicates that gas from other sources is simultaneously sucked in which can only be colder in any case.

A similar procedure was adopted for measuring the temperature of the internal gas. In a pipe with a diameter of 3.94 in. a second pipe with a diameter of 1.97 in. is inserted to screen off the heat influx from the gas collecting space. The space in between the two pipes is filled with asbestos and a gas inlet is created by a conical shell. The distance of the thermocouple from the coal surface can be changed at random by using an adjusting screw.

Since the internal gas will surely have a temperature exceeding a 212°F., the system was heated above 212°F. to avoid condensation of steam. Approximately 1 minute after the commencement of measuring, a temperature of approximately 392°F. was reached; 6 to 8 minutes later, the temperature continues to raise further. By this time, the asbestos, heated up by the gas from the gas collecting space has attained a temperature higher than 392°F. and superheats the internal gas.

Further measurements revealed that the internal gas has a temperature of 212°F. immediately after charging. After one hour, the temperature has risen to 302°F., to remain constant at 392°F. from the 2nd to the 7th hour of carbonization. With these temperatures, all variables required for the establishment of a detailed heat balance are known.

At a temperature of 59°F. of the coal input, 1210 Btu/lb. water is required for heating up, evaporation and superheating to 392°F. At an efficiency of the underfiring system of 80%, 1510 Btu will be required in terms of underfiring heat per lb. moisture. The further heating up of the steam is effected almost exclusively by heat exchange with the hotter external gas.

This value of 1510 Btu/lb. water now serves to calculate the heat consumption for dry coal. This turns out to be approximately 810 Btu/lb. for the coal used, at a constant heating flue temperature of 2280°F. At a moisture content of 6% it is lowest and raises by 12.6 Btu towards coals with 2% and 12% moisture content.

If an attempt is made at calculating the heat consumption at a change in the moisture content by 2%, it must be taken into consideration that in case of moist coal as used in practical operation, a change in the moisture content is automatically connected with a modification in the amount of coal, for the carbonization of which additional heat is required. The savings in terms of underfiring heat for the reduced moisture of 0.02 lb. can be calculated at 30.2 Btu if the above two pyrometers are taken into consideration. On the other hand, an additional heat consumption of 16.2 Btu is required for the additional 0.02 lb. dry coal. From the difference of these 2 values of 30.2 - 16.2 results a constant reduction in consumption of 14 Btu/lb. for each 2% reduction in the moisture content.

If this calculated value of 14 Btu is compared with the measured differences in heat consumption illustrated in Fig. 10 it can be shown that the calculated and the measured differences agree when reducing the moisture content from 8 to 6%. Below 6%, the measured difference is smaller, below 8% larger than 14 Btu. Now, what are the reasons for these deviations from the calculated figures?

A quantitative treatment of these phenomena would become too complex at this point. Therefore, our report will be confined to an explanation of the results. In a balance in which all items stated in Fig. 12 have been considered it can be shown that the curve of the sensible heat of the total gas is responsible for the tendency of the underfiring curve. This heat results from the sensible heat of the external and internal gas and from a portion absorbed by heat exchange from the vault of the gas collecting space. The curve of the sensible heat of the total gas runs through a minimum at 6% moisture content of the coal. Its rise towards higher, and lower moisture contents has different reasons.

At 6% moisture content of the coal the sum of the sensible heat of the external and internal gases is equal to the sensible heat of the total gas. Thus, in the wall, there flows only such heat as is lost as a surface loss. Since in this range there is no heat exchange in the vault of the gas collecting space, the heat consumption difference calculated from changes in the amounts of moisture and coal is equal to the measured difference.

At higher moisture contents, the mean wall temperature in the area of the charge drops, and with it the sensible heat of the external gas. As the amount of steam in the internal gas, moreover, has a rising tendency, the temperature of the total gas decreases. By convection and radiation, heat from the vault of the gas collecting space is transferred to the total gas, which, through heat conduction in the wall is transferred from the area of the charge into the area of the gas collecting space and must, therefore, be fed as underfiring heat.

Below 6% moisture content of the coal, the reasons for the rise of the sensible heat of the total gas are of different nature. With the reduction in the moisture content there is an increase in the average chamber wall temperature and, thus, in the sensible heat of the external gas. However, since the internal gas, owing to the decreasing amount of moisture, demands less heat for superheating, a high temperature of the total gas is attained. The lower the moisture content the earlier the time when the total gas has a higher temperature than the vault of the gas collecting space, and thus yields heat. The temperature gradient between the wall in the area of the charge and above the charge is now very much smaller and hence less heat flows as item Q_4 into the area of the gas collecting space. The heat determined as surface loss below 6% moisture content of the coal is, thus, partially supplied by external gas. This heat need no longer be fed via Q_4 through underfiring, and so the measured heat consumption difference becomes smaller than the calculated one.

Let us briefly survey the results of these investigations:

The steam evolved from the moisture of the coal reaches the gas collecting space at a temperature of 392°F. This required 1510 Btu underfiring heat per lb. water at a thermal efficiency of the coke oven of 80%. The heat for further superheating of the steam is supplied by the hotter external gas. With the aid of this value, a detailed heat balance of the coke oven can be established permitting to critically observe the measured heat consumption and to scrutinize the correctness of the chosen carbonization time at constant heating flue temperature. Besides, the non-linear course of the heat consumption curve has been interpreted.

The economic significance of reducing the moisture content will be different according to the conditions of coke oven operation and can only be seen within the total economy of a mining company. If potential savings by reducing the moisture content of the coal are not referred to coal with a coal ready to be charged but to a dry coal amount of 0.9 lb. which corresponds to a coking coal with 10% moisture and which constitutes the figure used in economic calculations by German coke oven operators, savings in the heat consumption averaging 17 Btu, for each 1% reduction in the moisture content of the coal are revealed in the range of 10 to 6% moisture content which is the range of primary technical interest. For expelling 1 lb. moisture, in the range of 10 to 6% moisture content at an efficiency of 80%, an average of 1530 Btu or, at an efficiency of 70%, an average of 1840 Btu will have to be expended. For a modern drier one likewise calculates with a heat expenditure of 1710 Btu/lb. moisture, if a flotation concentrate is for instance dried from 22% moisture content to 6% moisture content. The savings in heat consumption are thus absorbed or even surpassed by the expenses for previous drying. However, the reduction of the water content brings about other advantages which are apt to exert a favourable influence on the economy of a coke oven plant. The question of drying can gain vital significance if the basis of raw materials can thus be extended considerably, as it happed in the case of the Lorraine coking plants after the process using dried coal had been successfully developed at the Marienau test plant and proved in practical operation at the Hagendingen coke oven plant[7]. An effect which cannot be underestimated will be the influence of a lower moisture content of the coal on the life of a battery. An essential advantage is a possible increase in the throughput which permits savings in the capital service and a reduction in other overheads.

There is a substantial difference between the conditions prevailing in USA and in Germany which must be considered in judging the importance of the moisture content of the coking coal for the economy of coke oven plant operation.

In the Federal Republic of Germany more than 80% of the total coke outputs is produced at coking plants located in the immediate vicinity of collieries supplying coking coal. Our investigations confirmed that in terms of thermal economy there is no advantage in reducing the moisture content of a coking coal in a thermal drying unit prior to its carbonization. Accordingly, the average moisture content of the feed coal used in German coking plants located at collieries is at 9 to 10%. However, if the coking coal has to be transported to the coking plant over long distances, as it happens in many cases in the USA, there will be freight savings which can be significantly higher than the expenditure for thermal drying[8]. Thus, it is understandable that, as a rule, American coking coals have a lower moisture content.

7) Loison, R., P. Foch
Revue de l'industrie minerale (1961), pages 593/618

8) Doherty, I.D., J. Griffen
Blast Furnace, Coke Oven, and Raw Materials
Conference, 1960, pages 117/37

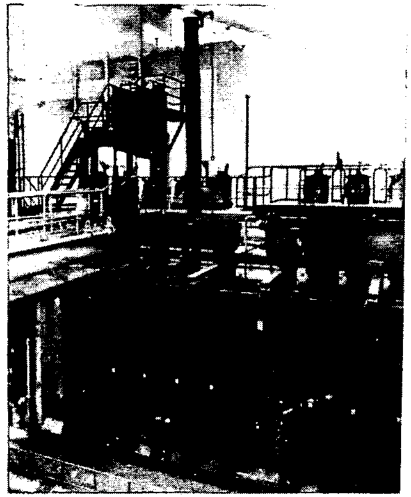


Fig. 1

	Cold Dimensions In.	Hot Dimensions In.
Length between buckstays	500	509
Length between door plugs	468	477
Height of chamber	164	167
Charging height (Coal line)	152	-
Width of chamber (Machine side)	16.5	16.2
Width of chamber (Coke side)	18.9	18.5
Mean chamber width	17.7	17.3
Thickness of oven roof	39.4	-
Pitch	45.3	-
Capacity of oven Cu.ft.	729	

BWV 1964	Oven Dimensions	VK 150

Fig. 2

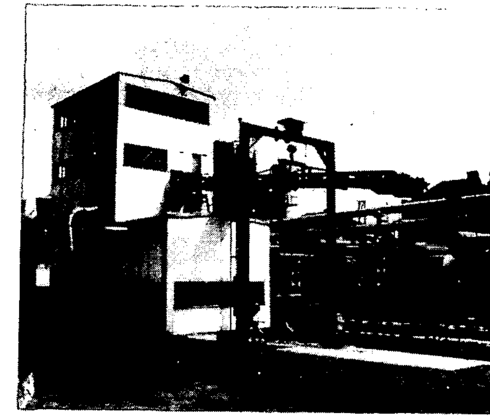
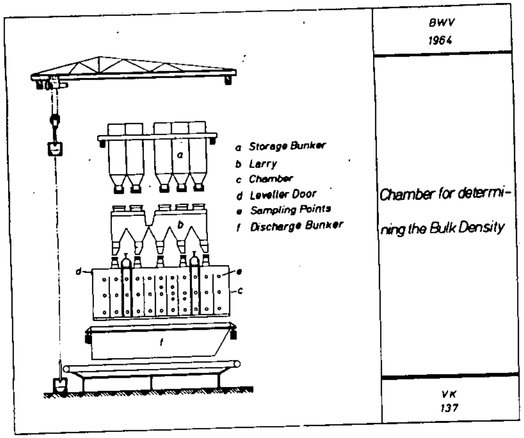


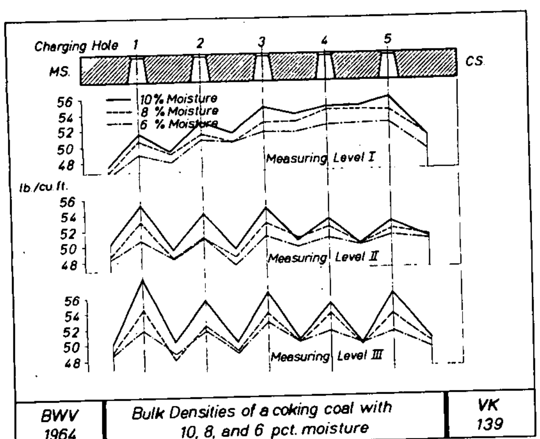
Fig. 3

Fig. 4



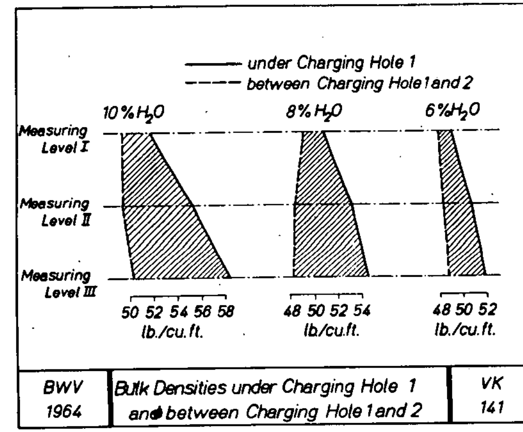
BWV 1964 | Chamber for determining the Bulk Density | VK 137

Fig. 5



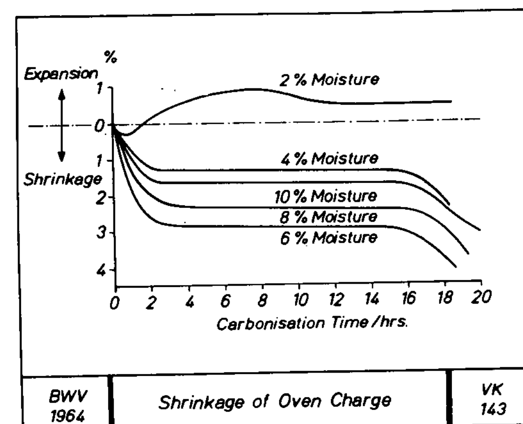
BWV 1964 | Bulk Densities of a coking coal with 10, 8, and 6 pct. moisture | VK 139

Fig. 6



BWV 1964 | Bulk Densities under Charging Hole 1 and between Charging Hole 1 and 2 | VK 141

Fig. 7



BWV 1964 | Shrinkage of Oven Charge | VK 143

Fig. 8

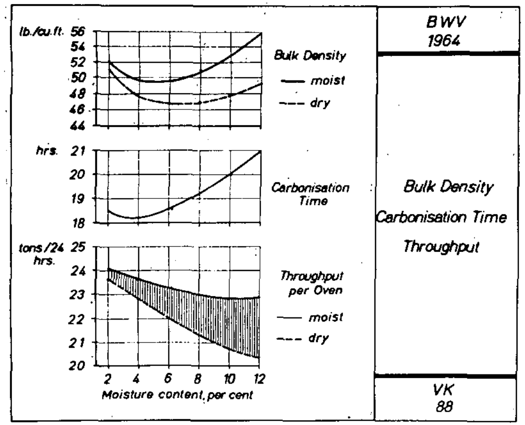


Fig. 9

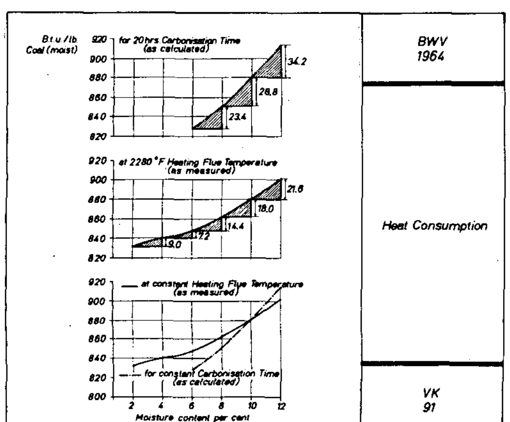


Fig. 10

Mode of Operation	1 per cent reduction in the moisture content of the coking coal in the range of 12-6 % H_2O results in:	
	a change in Throughput i. e.	reduction in Heat Consumption referred to 1 lb. coal, moist (efficiency of oven = 80 %)
Constant Carbonisation Time	- 0.9 % by a change of Bulk Density	14.4 Btu.
Constant Heating Flue Temperature	+ 1.5 % by a change of Bulk Density and Carbonisation Time	9.0 Btu.

BWV 1964 | Moisture Content of Coal Throughput, Heat Consumption | VK 151

Fig. 11

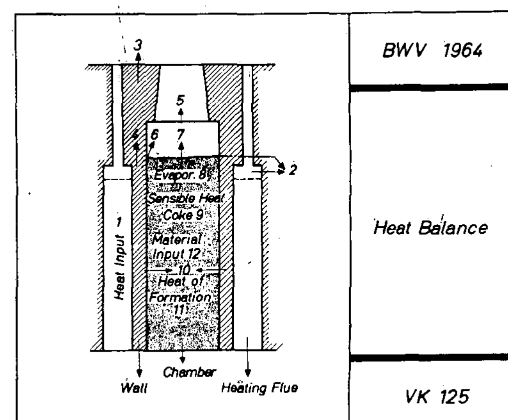


Fig. 12