

PAUL WEIR COMPANY

FOR: CHICAGO SECTION: AIME, FEBRUARY 2, 1977

WHAT IS COKING COAL?

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As consultants to the coal industry and to customers of the coal industry, the Paul Weir Company gets involved in all its phases and varifications, not the least of which is trying to determine the quality of coal for its intended use and the degree of beneficiation required to meet its end use.

This may involve coal for steam generation, chemical use, or for carbonization. My particular subject tonight is to discuss some of the various tests required to determine the coking characteristics of coals. In this respect we get involved in analyses of coals from most of the world and find that different parts of the world will frequently have different standards and tests by which they evaluate the quality of coking coals they require.

I deal, for instance, to a great extent with coals used in the Japanese or European markets. The Japanese have their JIS standards (referring to the Japanese Institute of Steel). The British have British Standards and the various European countries will have their own particular specifications, with the

latter generally using ISO, an international system developed by the International Office for Standardization. In North America, ASTM standards are most often used, although the latter is frequently referred to by other countries in addition to their own.

We will often end up by using for a particular coal all the standards combined, or parts of one and parts of another. Sometimes it can get confusing!

Coal is a heterogeneous, carbonaceous, fossilized material of almost infinite variations in consist, varying from low grade lignite to graphitic like metaanthracite. Among its many properties is the ability of some types of coal to form coke when heated in ovens or retorts.

Coking coals are by definition, coals that when heated to sufficiently high temperature pass through a transient plastic stage in which they successively soften, swell and resolidify into a coherent cellular coke. The purpose of coke is to supply carbon in a reducing atmosphere to reduce the ore to a relatively pure metal.

Obviously the higher fixed carbon that the coke has, the more effective it will be as a reducing agent. This means that the coke should have a minimum of ash and volatile matter. Since certain impurities in the coke also get into the hot metal produced, (such as sulfur and phosphorous) these impurities also are

required to be minimized. In fact, definite limits are placed on those impurities.

The physical properties of the coke produced are largely determined by the quality of coal. Its cellular structure must be such as to permit the gases to pass through and consume the coke efficiently and at the same time, particularly in a blast furnace it must be strong enough to withstand the blast furnace charge of ore and flux.

Since coke is manufactured from coal, it is obvious, then, that the quality of the coal is very important, not only as to its volatiles and mineral analyses but as to its ability to make coke of the desired physical structure.

What are the tests used to determine these parameters? They are seemingly almost endless. Some tests that were popular some years ago are now seldom used. Others, including the exotic petrographic analysis, are quite popular.

And, frankly, quite often, after spending a great deal of time - and money, collecting all our fancy test data the user will insist upon actual coke tests, sometimes settling for a 500 lb. test oven, and, in case of an utterly strange coal, will require real full size coke oven charges, for final proof!

Basically, of course, a complete chemical analysis of the coal must be made. This would include the standard analyses, which means: Proximate analysis on a dry basis, the total and inherent moisture; the (gross) calorific value, and sulfur.

In addition: ultimate analysis; ash fusions, and the mineral analyses of the ash. There is no particular need this evening to go into the methods of these analyses. They are all written up in the ASTM standards.

One might, however, mention some of the nonacceptable limits:

Obviously, they wish as low an ash in the coal as possible. It should certainly not be over 12 percent and is generally 4.5 to 8%. Total sulfur in the coal should also be as low as possible, with the standard of 1.0 percent generally being the upper preferred limit, although in some cases they will accept higher sulfurs, if they are blending lower sulfur coals with it. Most contracts are written with penalties and covers clauses for being over certain ash and sulfur levels.

Phosphorous also is an important element to be considered 0.08 percent phosphorous in the coal is considered to be the upper limit for iron making. However, this will depend also on the phosphorous in the particular ore being used as well as the quality of the other coals used in the final coal blend. There are other detrimental elements such as alkalies and salts. Fortunately most Appalachian coals are well within the required limits, although some of our Western coals could give some problems.

Speaking of blending coals to provide a proper mix to make good coke, the Japanese are masters in the art of blending coals received from all over the world. I have watched them blend as many as 12 different varieties of coal, all scientifically blended by a computerized system. And they have one of the lowest coke rates per NTHM. The ultimate criterion of coke quality is the coke rate required to produce a unit of hot metal. This varies from country to country and recently has been between 1,000 and 1,500 lbs./NTHM. The new furnaces are doing better than that.

One can have all of the above mentioned suitable chemical properties in a coal, but if the coal does not coke, or does not make a suitable physical coke structure, or if in the process of making coke it has the property of expanding in the coke ovens thus ruining the oven walls it is not an acceptable coking coal.

To pinpoint what is an acceptable coking coal, aside from its chemical properties, one must go into various other types of analyses. For example, we know that coals of certain ranks can be ruled out as a coking coal. The rank of coals are common knowledge, and they are classified from low grade lignites or brown coal to high grade anthracites. The ASTM uses a common classification for these ranks. For review I am showing them in:

SLIDE I

(ASTM Classification of Coal Rank)

Of all the various ranks of coal, the coking coals are in the categories of High Volatile A, with some in B and C, and in the medium and low volatile ranks. All others are noncoking.

I mentioned previously the ISO Standards, used commonly in Europe. They delineate in greater detail than ASTM and use a numbering system.

SLIDE II

(ISO Standard Coal Classification Chart)

They divide coals into Hard and Soft coals, the latter being coals of a gross heating value of less than 10,260 Btu on a MAF basis. The slide shows only the classification of coals above this value, namely, hard coals.

A three-figure code number is used to express classification of a coal. The first figure is "Class," the second indicates "Group," and the third, "Sub-Group." Example 634 refers to a coal of Class 6, Group 3, Sub-Group 4. Which, specifically, is a strongly coking coal. The class is based upon VM, the group is based upon free swelling index or the Roga Index. Group 3 and up has an FSI of over 4. The sub-group refers to its maximum dilatation the Gray King Coke type - a British coke test.

Having defined coals by rank and thus narrowing a coal's acceptability for coking one goes further into various physical tests, generally, of an empirical nature. The first, and usually performed along with the proximate analyses is the FSI or free-swelling index. Here a standard one gram, minus 60-mesh coal sample is heated to 820 to 950 C in a special translucent silica crucible, all described in ASTM procedures.

If the coal will coke a coke button is formed and its height and shape is measured in accordance with a standard size and shape chart, and are given numbers in order of size of coke button from 0 to 9.

The f.s.i. is a good field test to determine whether a coal has coking potential or not, and certainly the higher numbers indicate a strong coking potential, but it is not good enough to tell what type of coke you are going to get. This requires further testing procedures.

Coking coals, when heated to sufficiently high temperatures pass through a transient plastic stage in which it successively softens, swells, as it gives off volatile matter, and then resolidifies into a cellular coke. The degree of plasticity is one of the measures of coking characteristics. This plasticity characteristic as the coal becomes fluid or semifluid acts similar to "cement" in concrete, in that it cements the noncoking or inert material in the coal similarly, as aggregate is cemented in concrete.

To illustrate, the next slide shows the general characteristic stages of a coking coal when subject to heating.

SLIDE III

(Coal Temperature - Plasticity Chart)

A measure of this fluidity is important and although

there are different methods to do this, one of the most acceptable is the Gieseler Plastometer method, an ASTM procedure.

This plastometer shows the temperature and time of a given sample going through the plastic range. These points are significant when blending coals. The plastometer also gives a measure of the viscosity or fluidity of the coal in that it contains a stirrer in which the RPM is measured. The more fluid the coal the more rapid the R.P.M. This is called D.D.P.M. and is considered a very important number in evaluating the coking quality of the coal.

A test somewhat similar to the Gieseler is the Audibest-Arm dilatometer used in Europe along with the Ruhr Dilatometer used by the Germans. The Audibert-Arm dilatometer is an ISO test. It attempts to measure the coking properties. A pencil made of powdered coal is inserted in a calibrated narrow tube topped by a steel rod which slides in the base of the tube. It is heated at a constant controlled rate.

By making regular readings of the displacement of the piston as a function of temperature and expressing the displacement in percentages of the original length of the pencil, a curve is produced as shown in:

SLIDE IV

(Chart Showing Dilatometer Curve)

One reports not only the temperatures but the dilatation in percent and the contraction in percent.



One should also mention the Gray-King Test developed in England as a method for determining the coking properties of coal. It is also an ISO standard. In this test a small sample is carbonized at 600° C and is classified by a series of coke types grading from A to G and to G-8 for strongly coking coals. Anything below G grade is not considered coking coal.

Poland has developed the Roga test, which is also another test of the coking power of coal. It is an ISO standard. This test is similar to the U.S.B.M. agglutinating test, only they mix the sample with a standard anthracite instead of silicon carbide. The carbonized sample is then rotated in a drum, giving the material a tumbler test for hardness or stability factors.

The measures for the strength of coke to determine its hardness, friability, or stability is determined by various rotary drum tests or by a drop or shatter test. In this latter a sample of the coke produced is dropped on a steel plate and the products sized to determine its friability.

Generally, testing laboratories will confine themselves to the drum tests as being more indicative of what would happen in a blast furnace. In this respect the ASTM tumbler test is most prominent. The term "stability factor" is applied to the percentage retained on a 1-inch screen. The plus 1/4-inch screen percentage is designated as the hardness factor.

All countries are familiar with the ASTM Tumbler Test. However, as usual, there is a desire to modify it for their own usage. In Europe, the ISO has adopted the Micum Tumbler test. In Japan they use the JIS Tumbler Test. Each one uses a different drum diameter and number of r.p.m.s. but they are all a measure of stability and hardness of coke. Fortunately there are charts which give us the comparative results of each of these tests.

One other test which must be mentioned is one measuring the expansion of coke in a coke oven. This is quite important as although a coal may make excellent coke, if it expands in the oven it can ruin the oven and in fact cannot be pushed from it. For this reason low volatile coals cannot be used by themselves because of their expansion properties. High volatile coals on the other hand shrink, and if too high in volatile will result in low coke tonnage as well as making too soft a coke. This can be and is corrected by adding LV coals. Certain MY coals can be used without blending.

The tests for expansion is made in a "movable wall" test oven in which the actual pressure is recorded. There is also a sole heated oven for small samples developed by Commercial Testing and Engineering for this measure of expansion.

So far I have spent my time in discussing certain chemical and physical tests to determine the coking characteristics of coals. I will now discuss a method of coal analysis which according to some enthusiasts, can give you the complete answer. I am referring to petrographic analyses by the oil reflectance method.

It has been known for many years that the coking characteristics of a coal is related to its petrographic constituents. investigations of the Illinois Geological Survey, U.S. Steel, Penn State University among many others who have pioneered this method, have now shown, and it is being used on a worldwide scale, that it is practical to determine the coking properties of a coal by examining the petrographic constituents under a microscope. It is now accepted as one of the tools in classifying not only whether a coal will coke, but it is even possible to determine the quality of coke it can produce.

Coal is made up of the organic remains of plant life and some extraneous minerals. By use of a microscope, it is found that coal consists of entities, or macerals of various types. There are the vitrinites, or vitrinoids, exinoids, resinoids, fusinoids, micrinoids, semi-fusinoids, and of course, some minerals such as pyrite and silica, etc.

Some of these macerals are "reactive" in that they will melt or become plastic on exposure to heat; other entities will not be relatively affected by heat and are called "inerts." Obviously, the ratio of these reactives versus inerts is quite important. It is also found that there are various degrees of reactivity among the reactive macerals. Some are more reactive than others, and certain types of reactives combined with a proper ratio of inerts make a stronger coke than others.

These entities or macerals are measured by established procedures by the oil reflectance method, using special microscopic equipment, light, and measuring devices. By measuring the degree of reflectance of incident light from polished coal specimens of suitably prepared samples of coal, a quantitative method has been developed by which the types of reactive entities and inert entities can be determined. The kinds of macerals themselves are identified and counted by the point-count system. This equipment is frequently computerized to speed up the determination.

It is not the purpose of this discussion to describe all the technical details of the methodology involved. It obviously takes skill to make the determination and one of the difficulties in not being able to use the method more generally is the lack of coal petrologists who can do the work. But it is becoming more widespread each year, and possibly will soon be standard procedures in most large coal laboratories.

In the oil reflectance method, the rank of the various entities is determined by measuring the light reflectance. The percentage of light reflectance is determined for the specimen tested and this will give the rank of coal in terms of high, medium or low volatile and even anthracite.

The percentage of light reflected from vitrinoids varies over a relatively wide range depending upon the rank of the coal. Arbitrary reflectance classes are set up from 0 to 80, to cover the entire reflectance range. The lower range of reflectance covers the high volatiles and as the reflectance increases, it could include anthracite. These classes are also called types.

The reactive vitrinoids are classes from 0 to 20. Illinois No. 5 high volatile, for example, has basically type 5 to 8, with predominance in type 6.

An example of the relationship between Reflectance and volatile matter is shown in:

SLIDE V

(Reflectance vs. Volatile Matter)

It is also possible to make up charts comparing Reflectance values with heating values, Fsi, and even Gieseler flindites and dilatometer readings. In fact, the Japanese strongly lean towards comparing fluidities and/or volatile matter with reflectance values.

After many experiments and comparison with laboratory coke-oven tests, it has become possible to develop curves which can predict coke stability by first determining the reflectance class or types of reactives, which when combined with the inert macerals in the coal, will give an inert ratio and strength index.

Where it is deficient in inerts, they can tell how much should be added to obtain optimum results.

The basic chart is shown in:

SLIDE VI

The inert index is called the Composition-Balance Index. A numerical value is placed on the coordinate which is the ratio of what there is in the coal to what there should be. If the coal is in balance the index is 1.0; if it is deficient, it is below 1.0; and, if it has excess, it is above 1.0. The theory then is to blend various types of coals to arrive at a balance index.

The strength index on the vertical scale is calculated and expressed in arbitrary units, the range for coking coals being from 2.0 to 7.0. This is produced by blending various percentages of inerts with each vitrinite reflectance class and gives the strength index for each particular mixture of reactives and inerts.

It is, of course, a complicated procedure, and the data must be set up in a computer to get any speedy results.

The next slide:

SLIDE VII

gives in general the coke characteristics that can be arrived at from being able to plot your coal balance and strength point on the Composition-Balance Index chart.

Since few coals fall into the ideal Composition in themselves, the art of blending particular coals together to arrive at the optimum coke characteristics can be calculated using the basic petrographic data of the various coals. An example is shown in

SLIDE VIII

Another example of a particular blend is shown in:

SLIDE IX

The next three slides illustrate how the Japanese, which as previously stated, are required to use coals from all over the world, classify coking coals by these methods.

SLIDE X

This slide shows the Balance Index-Strength Index plotted against the JIS Tumbler Index instead of ASTM coke stability.

The gray area shown centered around the 1.0 balance index and a strength index of 4.0 is the ideal range for good blast furnace coke.

SLIDE XI

This slide shows the relationship of fluidity and mean reflectance values. The gray area indicates the ideal area. Practically all their coals must be blended in their proper proportions to get into this area.

And, finally the last slide:

SLIDE XII

Gives another relationship used by the Japanese by plotting V.M. against total expansion using the Arnu Dilatometer instead of Gieseler Fluidity.



CONCLUSION

I have tried this evening to briefly review the various methods of evaluating the coking properties of coals.

As you can see, it is a complicated subject, and one which requires a variety of analyses before one can arrive at a coal's coking characteristics.

If you are confused with all the various testing methods - "Join the club!" as most of us are often confused, also. Our practice is to run all analyses that is possible to run. If you don't, the client will probably ask for the results of a test method you didn't run! And then finally want a full coke oven test to make sure!

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Figure 1.

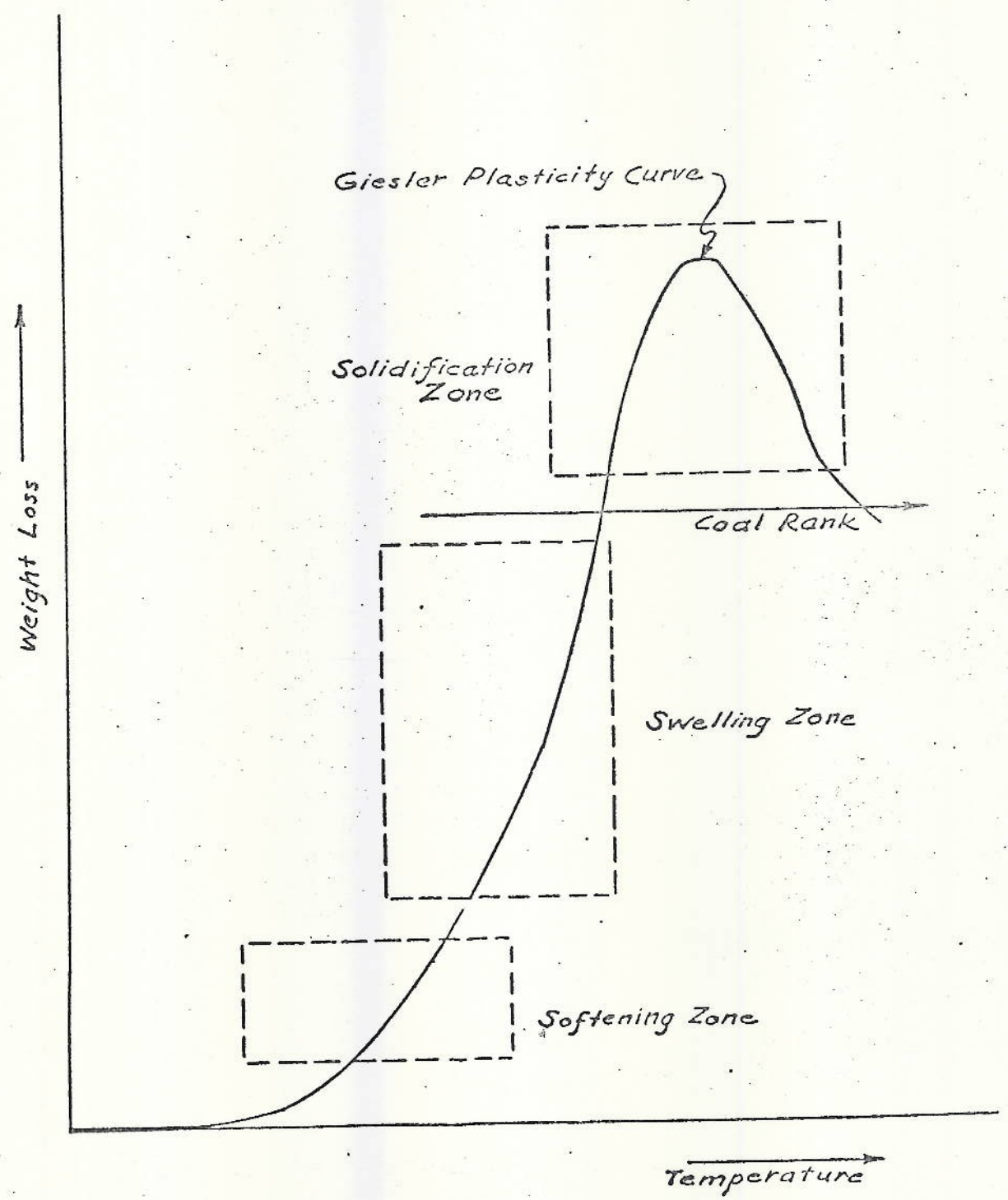


Fig. 1 Weight loss and Plasticity as a function of Temperature.

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