A CONTINUOUS CARBONITE™ PROCESS FOR MAKING FOUNDRY SIZE FORMED COKE

More exacting environmental regulation and legislation has driven development for new, clean and more efficient methods of coke production. These developments have been primarily focused on lowering emission levels and waste without compromising current product quality and cost.

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Twenty years ago, the author, along with others at Coal Technology Corporation (CTC), began work on an idea to develop a new continuous process to convert coal into coke that would meet all the environmental emission requirements enacted by the Clean Air Act for the years 1995 and beyond. It was the intent of this development to usher into being the "third generation" of coke making technology, which would produce a high quality coke in a continuous manner, be totally enclosed, be more efficient in operation with less capital cost to construct, and be capable of utilising a wide variety of both caking and non-caking coals.

The process for converting coal to char and hydrocarbon liquids is relatively simple and was commercially practised in the United States in the 1920s and 1930s to make smokeless fuel. Coalite, a coal-derived smokeless fuel, is still being produced in Britain in a batch pyrolysis process. The Hayes Process, used in the 1920s in the United States, was self-sustaining in that approximately half of the non-condensable pyrolysis gases were used to supply the heat needed to operate the retort. The major obstacle in the past to processing caking type coals, typically classified as metallurgical coals, in a heated screw-type reactor has been the inherent swelling characteristics of these coals. CTC conceived the idea of using a twin-screw reactor with interfolding screw flights rotating in counter-current direction with the capability of providing a forward-pause-reverse motion at different speeds to eliminate the plugging and fouling of swelling type coals as they become plasticised during the devolatil-isation phase near 550°C. Such a reactor was designed, constructed, and successfully operated for more than five years in the 10 ton per day pilot plant. This technology breakthrough in reactor design has become the key ingredient of the patent issued to Dr. Wolfe and CTC in September 1992, Patent No. 5,151,159. A subsequent process patent, which integrates the total processes together, was issued to Dr.Wolfe and CTC in March 1994, Patent No. 5,296,005.

The CTC/CLC® process consists of two stages. In the first stage, as shown in Figure 1, coal is processed through the twin-screw mild gasification reactor heated to between 650°C and 750°C at atmospheric pressure with air excluded. This process produces char, coal liquids, and

CTC COKEMAKING **FIRST PROCESS STEP**

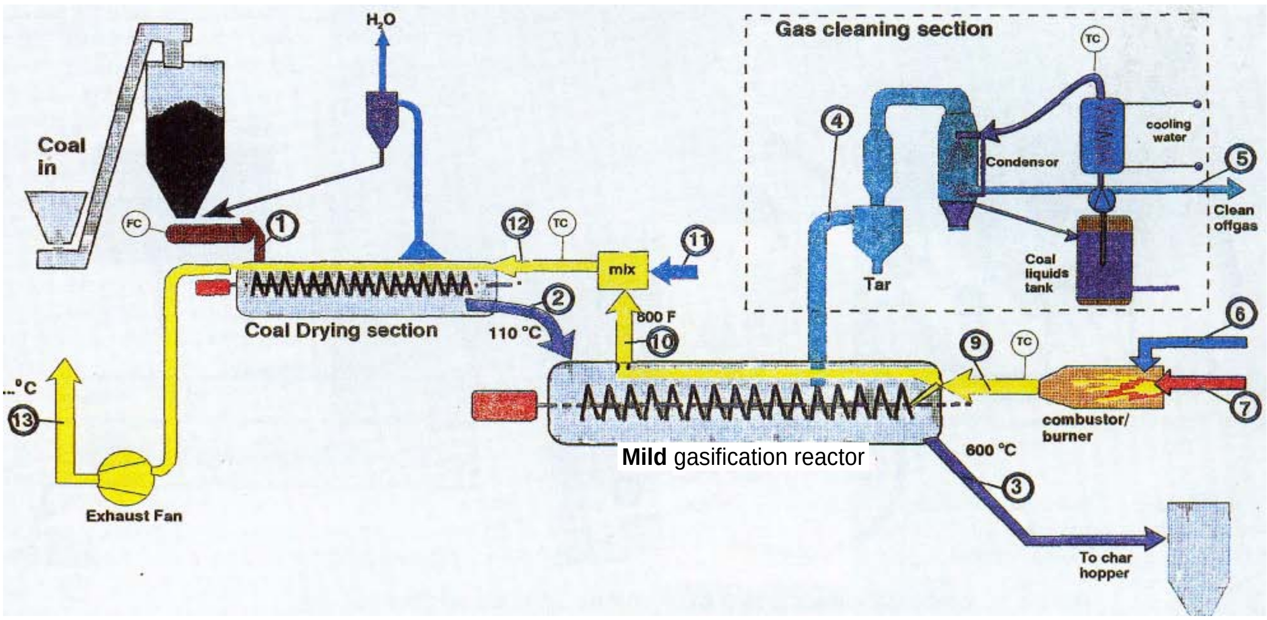

Figure 1. Char production - first processing step.

process gas in about 20 minutes. The char contains less than 10 per cent volatiles, the coal liquids evaporated at these temperatures are of high enough quality to allow further refining, and the non-condensable gas containing a heat value of 18.5 MJ/m^3 is recirculated for heating of the reactors. Char, now called Carbonite™ is a unique product in itself with its own commercial markets. The Carbonite contains 80 - 90 per cent carbon and has acceptable qualities for use as a carbon-reducing agent in the smelting of ferroalloys and in the mini-mill processing of scrap steel, (see Table 1).

to achieve the desired customer specifications, including coke strength after reaction (CSR) test, coke reactivity index (CRI), porosity, stability and density. The author believes that this process can provide a fully manufactured coke product to meet customer specifications.

In summary, the Carbonite Coke™ process technology is a two-stage continuous carbonisation process in which Carbonite is produced at 550°C in the twin-screw mild gasification reactor in the first stage. The Carbonite is then blended with various hydrocarbon binding materials, briquetted into various shapes and sizes, and calcined in a furnace at temperatures up to 1,200°C in the second stage. The total time of conversion of coal into high-quality coke is achieved in a continuous manner within three hours in an enclosed system. The off-gases are combusted and used to supply the internal heat needed in the process.

Coal/Char samples	Size	Grindability	Ash %	Sulphur %	Volatiles %	Fixed carbon %	Heat value MJ/kg	FSI*	Bulk density kg/m^3
Coal	100%+6.25 mm	74.97	3.32	0.69	28.49	68.19	34.9	9	839.4
Char lumps	85%+3.125 mm	39.61	4.40	0.57	7.60	88.00	33.4	0	442.2
Char fines	15%-3.125 mm	42.04	3.83	0.56	6.33	89.84	33.6	0	612.0

Table 1. CTC coal/char proximate analysis. (free swelling inde*

however, the largest market for the Carbonite will be for its further processing into Foundry and Metallurgical-type coke for the blast furnace and foundry furnace markets.

Carbonite™ processing into coke has been demonstrated in the second stage of the pilot plant. The second stage of Carbonite coke process as shown in Figure 2 involves grinding the Carbonite to a fine particle size, blending the prepared Carbonite with both liquid and solid binder products in a mixing process and forming the blended materials into briquettes or brick shapes. These briquettes of various sizes and shapes are then heated to between 1100 and 1200°C in a rotary furnace or tunnel kiln. The resulting coke is fully processed through this reaction step in less than three hours. The coke quality can be varied depending on the process conditions - which in all cases meets or exceeds the existing requirements for Foundry and blast furnace coke. In order to further produce a coke product from this process that resembles existing coke, a process was developed to make irregular shaped coke from the formed briquetted shapes which was referred to as "classic coke." One of the most unique characteristics of this process is that the coke is fully fused together, and not just bonded with a gluing substance. Also, in this way, the Carbonite Process can be

Ton quantities of coke briquettes have now been produced for specialised testing by various steel companies and independent laboratories. The coke testing has also been supported by the petrographic services offered by SGS Minerals Commercial Laboratory. A series of different tests have been completed with our coke by several different independent companies including General Motors, Intermet Foundry Company, Inland Steel, ARMCO Steel, Koppers Industries, Elkem Metals, the U.S. Department of Energy, and UEC/USX Steel Laboratories. These results compare the typical Carbonite coke quality to existing standard coke quality specifications for blast furnace application (see Table 2.

The data show that the Carbonite-manufactured coke meets or exceeds the basic coke characteristics for standard coke

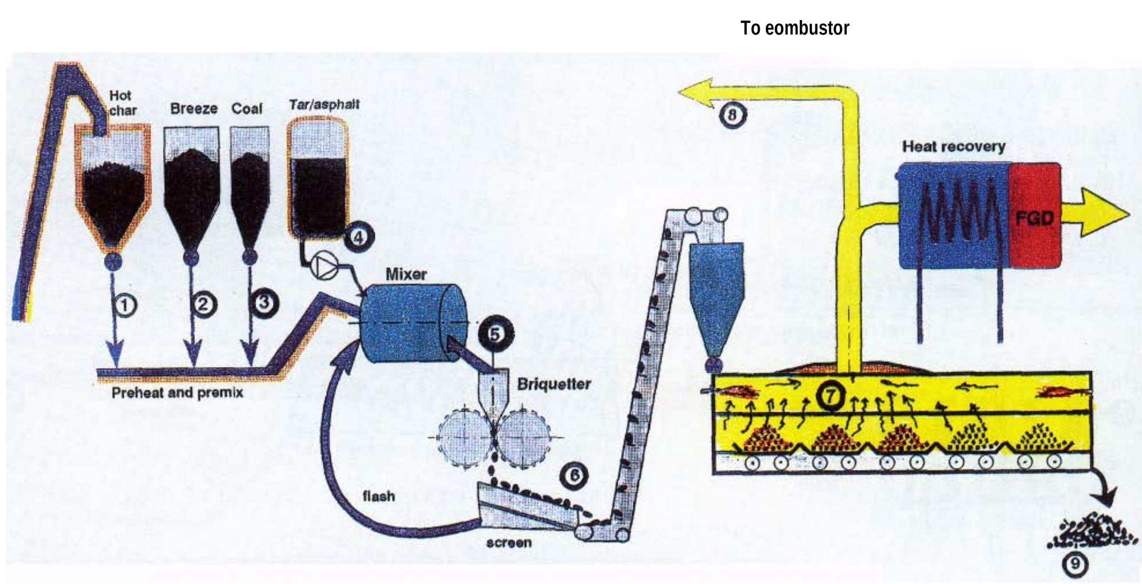

FIGURE 2. COKE MANUFACTURING STEP WHERE VARIOUS PRODUCTS ARE BLENDED AND CALCINED IN A FURNACE AT + 2100°F

Physical characteristics (%)	CTC continuous briquetted coke	Standard coke specifications[1]
CRI (Nippon Steel method)	24-31	32 max
CSR (Nippon Steel method)	65-74	55 min
Coke stability	61-66	58
Coke hardness	69	67
CRI (Bethlehem Steel method)	7-13	<15
Moisture	2 max[2]	5-7
Ash (dry basis)	7	8
Volatile (dry basis)	0.5-1.0	1 .0 max
Fixed carbon (dry basis)	92	91
Sulphur (dry basis)	0.6	0.7
Bulk density *	38	29

*Table 2. CTC formed briquetted coke compared with conventional blast furnace coke specifications. (*Lbs./Cu. Ft.)*

oven type coke in every category. The data also show that the coke strength can be made consistently superior to conventional oven coke, which will allow higher levels of pulverised coal injection (PCI) to be in conventional blast furnaces.

Although using lower cost coals in a briquetting formed coking process was the primary driving force in the 1970s, today the use of the continuous coking process is based more on environmental factors than the use of low cost/rank coals. Nevertheless, it has been possible to make, through the use of the process described here, acceptable quality coke from low-cost coal. As the coal is introduced continuously in the process through closed hoppers, all the coal gas is captured and condensed into usable liquids. Any uncondensed gases are combusted for process heat and co-generation. The environmental emissions normally associated with feed and coke removal systems in conventional coke ovens are nonexistent. A letter from the U.S. Environmental Protection Agency (EPA) in July 1993 classified the CTC/CLC® and Carbonite Coke Process as "a conversion of the coking type coals into three distinct new fuels forms of enhanced value and as such should be classified as fuel conversion plant under 40CFR, Section 52.21(b)(l)(iii)(q)."

The coke quality analytical results are similar to, or exceed, current foundry and blast furnace coke specifications. However, general acceptance of a new type of coke by a conservative steel industry must arise from its performance in actual commercial furnace tests. Since the CTC pilot plant produced a few tons of coke per day, and an acceptable blast furnace test would require over 20 kt, it was decided to direct the furnace tests towards the cupola foundry furnaces. However, that in itself posed some real technical challenges in the production of larger sized briquettes in the order of 100 x 150 x 130 mm (see Figure 3), as typically used by the foundry industry. Even though some of the first form coke briquettes were produced and tested in the early 1970s, it was not until CTC produced them that ton quantities of larger sized foundry coke briquettes been produced in the United States or in the world.

First, a series of one-ton tests were completed in a 0.7 m diameter test cupola located in Alabama. Tests were conducted with successful results using blends of 25 per cent, 50 per cent and 100 per cent of CTC produced formed coke, with the balance of coke in the first two tests made up by conventionally produced coke.

After the formed coke proved itself in the Alabama tests, Intermet Foundries Inc. agreed to conduct the first U.S. production foundry test using several tons of the formed coke at a 25 per cent blend in its production cupola in April, 1995. A large amount of data were accumulated on the cupola performance including back pressure, steel flow temperature and carbon pickup. The results of the eight-hour test showed no measurable difference as a result of the blend of the coke at this percentage compared to commercial foundry coke in furnace performance.

Based on the successful results achieved with a 25 per cent blend of the coke, Intermet agreed to conduct a much more aggressive test in which more than 10 tons of the foundry coke was tested at a 50 per cent blend for over five full hours of furnace operation. This test was conducted February 27-28, 1996 over 12 years ago.

The technical results showed the furnace to perform similarly to conventional coke in terms of product feed-rate, stability in the furnace, back pressure through the furnace, furnace temperature, and in carbon pickup. In addition, the performance of the furnace with regard to rate of scrap steel melt and tap temperature appeared to be slightly improved over conventional coke. This was predicted by Dr. Sy Katz of General Motors, an expert on foundry coke, who suggested that the higher density of the CTC coke would in turn deliver greater energy per cubic meter of coke than a conventional coke would be able to provide. It is likely, as additional tests are conducted with even greater percentages of the foundry coke, that the advantage of achieving higher furnace temperatures with less coke will be substantiated.

Figure 3. CTC foundry coke briquettes unloaded in feed hopper at Intermet Foundries, Radford, Virginia, USA.

Based on these successful furnace tests, General Motors entered into a contract with CTC to conduct an elaborate test program of the foundry coke in its production facilities using CTC's coke. The U.S. Department of Energy through the Morgantown Energy Technology Center has also agreed to participate in this test. CTC coke

Figure 4. Melted cast-iron plates from the GM test cupola using CTC

Was produced in support of this furnace test program which was completed in June, 1996 at the GM Defiance Plant and in August, 1996 at its Marquette Test Facility. The results were successful, with blends of up to 25 per cent in the production cupola in the GM Defiance Plant and with 100 per cent CTC Foundry Coke at the Marquette Test Cupola as shown above in Figure 4. The results of these tests were presented at the 101st American Foundrymen's Society Casting Congress Meeting in Seattle, Washington USA in April 1997.

Dr. Wolfe, the founder and owner of CTC in the 1990's and now the founder and owner of the Carbonite Corporation has continued to develop the Formed Coke Technology. During the past 8-10 years, numerous tests have been conducted to further improve both the design and efficiency of the process to the point that new patents are now pending on the more advanced process called the "Carbonite Formed Cokemaking Technology".

The most recent verification of this new improved process that accelerates both the production and reduces the emissions in the tunnel coking kiln was completed in June, 2009 at the General Shale Brick Plant in Virginia. The results of these most recent test on Foundry and Blast Furnace size coke is shown in photographs in Figure 5 and 6 and in Tables 1and 2.

These tests results are so significant that it clearly confirms, once again, that quality formed coke can be made by the CTC and the new Carbonite Formed Cokemaking Process.

Figure 5.   Mr. Hall (General Shale) and Dr. Wolfe conducting Formed Coke Test in Brick Tunnel Kiln

The formed coke produced is shown in the Figure 6. These formed coke samples were then collected and analyzed by the SGS commercial laboratories. The results are shown in Table 1.

Figure 6. Foundry Size Formed Coke and blending formulations

The Formed coke shown in Figure 6 was produced in different shape containers. These examples of formed coke illustrates the physical characteristics of the blends of Carbonite and coal having a high plasticity rating to melt and conform to various types of shapes. The use of the low volatile Carbonite allows these types of shapes to be formed with a balanced release of volatiles and the carbon goes through the transformation phase at temperatures ranging from 1950-2150 F.

The foundry coke samples shown above were sent off for analysis at the SGS commercial laboratory in Sophia, West Virginia. The results are shown in Tables 1 and 2.

Table 1
Physical Characteristics of Carbonite

Physical Properties	Carbonite
Moisture %	3.32
Ash %	10.09
Volatile Matter %	10.68
Fixed Carbon %	75.91
Sulfur %	0.68
Heat Value BTU/#	12,839
Free Swelling Index (FSI)	0

Table 2
Formed Foundry Coke analysis as compared to the ASTM standard Specifications for Blast Furnace coke.

Physical Charateristics	Foundry Size *	Std Specs Blast Furnace
Moisture %	1.6	1.0-1.5max
Ash (Dry Basis) %	8.9	<10
Volatile (Dry Basis) %	2.2	<2.0
Fixed Carbon %	87.3	~90
Coke Reactivity (CRI)	43.1	32 max
Coke Strength (CSR)	56.2	55 min
Coke Stability	50	58 min

*Note: These coke specifications are acceptable for foundry coke and are very close to the specifications for blast furnace coke. By changing the formulations, the formed blast furnace size coke made in this specific test did exceed the ASTM specifications for blast furnace quality coke.

Conclusions

Based upon these most recent formed coke experiments and those experiments performed by CTC during the late 1990's mentioned in this paper, the following conclusions can be made:

1. The patent pending Carbonite and previously CTC formed coke making technology shows clearly that a new method exist for making both foundry and blast furnace quality coke that is less expensive and more environmentally friendly that those cokemaking technology currently utilized.
2. The capital cost of the Carbonite Coke making process will be at least one-half that of conventional coke plants.
3. Both foundry size coke and blast furnace coke can be produced continuously using proven technology.
4. The environmental emissions will be significantly less than conventional coke making technologies and will meet current and future EPA regulations.
5. There will be a significant reduction in the cost to produce a ton of either foundry size coke or blast furnace coke.
6. The Carbonite Corporation is now seeking partners who will join them in financing , constructing, and operating the first continuous Carbonite Formed Cokemaking Commercial Plant.