

**RESEARCH ON PREHEATING COMBUSTION TECHNOLOGY OF  
RESIDUAL CARBON AND DEMONSTRATION PROJECT OF 100 TONS /  
DAY OF RESIDUAL CARBON BOILER**

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**Abstract:** Residual carbon is the solid residue after coal gasification, with basic characteristics of low volatile content, high ash content, high ignition points and burnout difficulties. It still remains a technical difficulty on achieving an effective and stable combustion for residual carbon in China or abroad. As early as 2004, the Institute of Engineering Thermophysics, Chinese Academy of Sciences, put forward the technical route of combustion with fuel preheating, that is to realize a high efficient combustion of low-volatile fuel based on the principle of preheating enhances combustion. In the decades from 2004 to 2014, a series of test platforms were built with different capacities of 30kW, 0.2MW and 2MW, on which a lot of experiments were carried out. Consequently, the preheating mechanism of low-volatile fuels including anthracite and gasified residual carbon, the high efficient combustion method of preheated fuel and the strategy of controlling pollutant emissions, were all obtained. In 2015, the demonstration project of 100 tons /day gasified residual carbon was built in Hechi city, Gaungxi Province. The raw material of the boiler, the solid residue of coal gasification in circulating fluidized bed, contains 0.64% of volatile and 60% of ash with the heat value of 3000 kcal/kg. The combustion heat of gasified residual carbon is used to generate the saturated steam with the pressure of 3.82 MPa and the temperature of 250 °C. This paper mainly describes the design parameters, technical process, flow field and commission characteristics of 100 tons / day gasified residual carbon boiler, providing a technical route and solution schemes for high efficient and clean combustion of low or ultra-low volatile fuels.

**Keywords:** gasified residual carbon; preheating combustion; demonstration project

## **1. Introduction**

Residual carbon is the solid residue after coal gasification, with basic characteristics of low volatile content, high ash content, high ignition points and burnout difficulties. It still remains a technical difficulty on achieving an effective and stable combustion for residual carbon in China or abroad.

As early as 2004, the Institute of Engineering Thermophysics, Chinese Academy of Sciences, put forward the technical route of combustion with fuel preheating, that is to realize a high efficient combustion of low-volatile fuel based on the principle of preheating enhances combustion. In the decades from 2004 to 2014, a series of test platforms were built with different capacities of 30kW, 0.2MW and 2MW, on which a lot of experiments were carried out. Consequently, the preheating mechanism of low-volatile fuels including anthracite and gasified residual carbon, the high efficient combustion method of preheated fuel and the strategy of controlling pollutant emissions, were all obtained.

In 2013, the experiment was carried out on the 30 kW test platform for gasified residual carbon, with the particle size ranging 0-100  $\mu\text{m}$ ,  $d_{50}$  of 41.6  $\mu\text{m}$  and  $d_{90}$  of 72.3  $\mu\text{m}$ . This residual carbon had 0.67% volatile, far

lower than that of pulverized coal, and the heating value was 3200 kcal/kg. The feed rate was 9.5 kg/h. The results showed that the gasified residual carbon can be preheated 900 °C at the condition of the primary air equivalence ratio was 0.3, the preheated fuel had a stable combustion with a uniform temperature profile and the maximum temperature 1126 °C, and the combustion efficiency was 95.1% with the carbon content of fly ash was 3.2%. In addition, the NO emission was 102 mg/m<sup>3</sup> and the conversion ratio of fuel-N to NO was 7.9%.

Also, in 2015, the experiments was carried out on the 2 MW pilot platform for the same fuel with the 30 kW test. The feed rate was 517 kg /h. The results showed that the gasified residual carbon was preheated 950°C at the condition of the primary air equivalence ratio was 0.15, the preheated fuel had a stable combustion with the temperature ranging from 900 °C to 1150 °C. The combustion efficiency of gasified residual carbon was 87.5% and the NO<sub>x</sub> emission was 83 mg/m<sup>3</sup>.

Based on a lot of experiments study, in 2015, the demonstration project of 100 tons/day of residual carbon boiler was built in Hechi city, Guangxi province. The gasified residual carbon was from the equipment of circulating fluidized bed coal gasification, and the combustion heat was used to generate saturated steam with the pressure of 3.82 MPa and the temperature of 250 °C.

This paper briefly describes the technical process, the flow field simulation and commission characteristics of the residual carbon boiler for 100 tons/day in Hechi, Guangxi Province, to provide technological support and series equipment for the high-efficient combustion using of gasified residual carbon.

## 2. Research on preheating combustion technology of residual carbon

The sample of gasified residual carbon was from circulating fluidized bed (CFB) coal gasification process, with its ultimate analysis shown in Table.1. The volatile content is 0.67% and the ash content is 60.66, obviously difficult to ignite and burnout.

Table1. The ultimate analysis of the gasified residue carbon

C <sub>ar</sub>	H <sub>ar</sub>	O <sub>ar</sub>	N <sub>ar</sub>	S <sub>ar</sub>	A <sub>ar</sub>	M <sub>ar</sub>	V <sub>daf</sub>	Q <sub>net</sub>
%	%	%	%	%	%	%	%	kcal/kg
39.08	0.2	0	0.26	1.62	60.66	0.06	0.67	3255

The size distribution of the gasified residue carbon is shown in Fig.1. The particle size ranges from 0 to 100 μm and the d<sub>50</sub> is less than 50 μm.

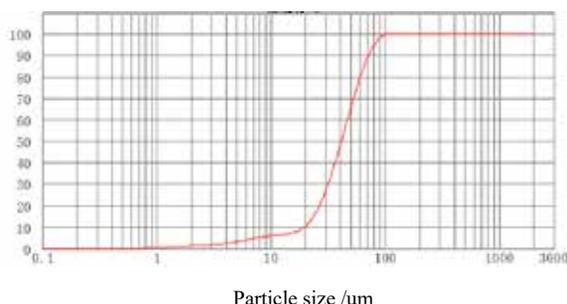


Fig.1 The size distribution of the gasified residue carbon

In 2014, the experiment was carried out in the 30 kW test rig, with its technical process shown in Fig.2. This system consists of three parts: a CFB, a down-fired combustor (DFC), and an auxiliary system. The CFB

is used to preheat gasified residual carbon to above 800 °C, the DFC is used to combust preheated fuel, and the auxiliary system is used to keep the test run well. Some descriptions on the test rig were given in some published paper.

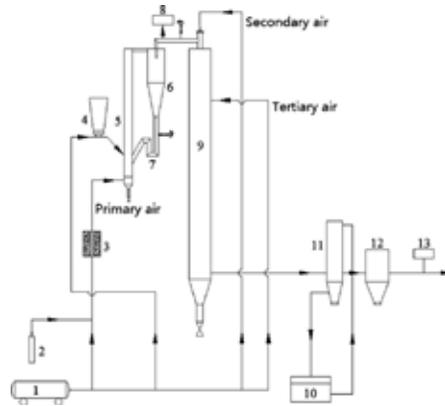


Fig.2. Schematic diagram of the test rig.

1. Air compressor, 2. liquefied petroleum gas, 3. electricity heater, 4. screw feeder, 5. riser, 6. cyclone, 7. U-valve, 8. Sampling port, 9. DFC, 10. water tank, 11. water cooler, 12. bag filter, 13. gas analyzer.

The experiment result show that the residual carbon can be preheated to 900 °C by a CFB preheater with partial combustion, and it can burn well in the DFC. The maximum combustion temperature in the DFC in 1126 °C and its combustion efficiency is 95.3%. NO<sub>x</sub> emission values can be declined by the combination of preheating air staging. NO emission is 102 mg/m<sup>3</sup> and the conversion ratio of fuel N to NO is 7.9%.

In 2015, for the same fuel, the experiment was carried out in the 2MW pilot test rig, built in our laboratory. The feed rate is 467 kg/h, and the heat capacity for the test is 1.87MW. The results also show that this kind of low volatile fuel can have a stable combustion state using preheating combustion technology. The combustion efficiency is 87.5% with NO<sub>x</sub> emission of 83 mg/m<sup>3</sup>.

### 3. Design parameters and technical process for demonstration project

#### 3.1 Design conditions

- Fuel type: gasified residual carbon (shown in Tab.1)
- Feed rate of the gasified residue carbon : 100 tons / day;
- Boiler operating pressure : 3.82 MPa;
- Saturated steam temperature : 249°C;
- Feed water temperature : 105°C;
- Exhaust gas temperature : ≤200°C.

#### 3.2 Technical process

The technical process of the gasified residual carbon boiler for 100 tons/day, showed in Fig.3, includes 5 systems: air supplying system, water system, material system, ignition system, and exhaust gas treatment system.

### **(1) Air supplying system**

The air supplying system includes primary air fan, secondary air fan, tertiary air fan, induced draft fan and exhaust gas recirculation fan et al. The air for gasified residual carbon combustion is divided into primary air, secondary air and tertiary air. The primary air, supplied by Root Blowers, was sent into the burner and the coal bunker for caring gasified residual carbon and coal, respectively. The secondary air, supplied by centrifugal fan, was sent into the bottom of the furnace to help preheated fuel combustion. The tertiary air, supplied by centrifugal fan, was sent into different height of the furnace after the preheating by low temperature air preheater and high temperature air preheater. The compressed air, supplied by air-compressor, was sent into ignitor and burner for atomization and combustion, respectively. The high temperature flue gas, flowing through heat recovery and bag filter, was sent to the chimney by induced draft fan. The recirculation flue gas, supplied by centrifugal fan, was extracted from the behind of the bag filter and to be sent into the bottom of the furnace. All the fans mentioned above are able to adjust the frequency to change operation cases and save energy.

### **(2) Water system**

The water system includes water tank, water pumps, deaerator and steam pipes etc. The feed water was firstly sent into the water tank, and secondly pumped into the deaerator to remove oxygen in the water, then transported into the economizer by a high pressure pump. After heated in the economizer, the water was transported to the boiler drum to distribute the furnace by concentrated descending tubes. In the furnace, due to the combustion of gasified residual carbon, the water was continuously heated and became saturated steam flowed into the boiler drum. The steam with high temperature and pressure was output by special pipes.

### **(3) Material system**

The material system includes ash bin, start silo and feeders etc. The gasified residual carbon in ash bin was fed into burner through the impeller feeder. The fly ash from combustion was totally collected into the bag filter, and loaded by a bulk machine to be carried out. Spiral feeder was used to feed the coal in the start silo into the burner.

### **(4) Ignition and combustion system**

The ignition and combustion system includes ignitor, burner and boiler etc. The ignitor was used for initially warming up, and turned off when gasified residual carbon fed into the burner. Also, the ignitor has the functions of flame detecting and flameout protection, with 0# diesel as fuel atomized by compressed air. The burner was one of the most crucial equipment for achieving a well-organized combustion, including stable, high efficient and clean combustion. The furnace was the major facility for combustion and heat exchange, in which the heat from combustion was transferred to the water by radiation and convection and used to produce qualified saturated steam.

### **(5) Exhaust gas treatment system**

The Exhaust gas treatment system includes bag filter and chimney etc. The bag filter was used to collect the fly ash from combustion, and the flue gas through bag filter flows into the chimney by the induced draft fan. The chimney was built with concrete brick structure.

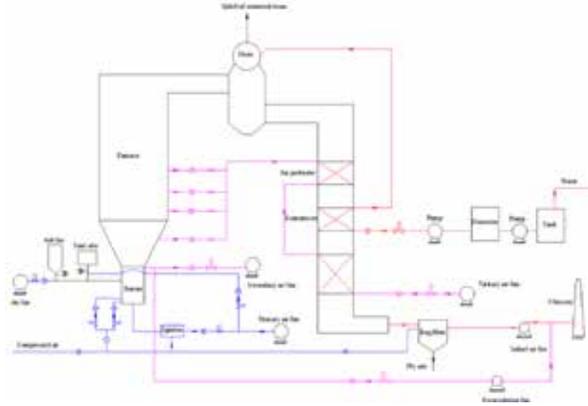


Fig 3. The technical process of the gasified residual carbon boiler

#### 4. Numerical simulation of flow field

##### 4.1 Calculating model

The furnace is 12300 mm long, with the upper section of 2520\*2520mm and lower section of 1460\*1460mm. The preheating burner is arranged in the center of the furnace bottom and the velocity of the nozzle is 15.4 m/s. Table.2 shows the distribution parameters of the primary, secondary and tertiary air. The heights of four layers tertiary air are 1500mm, 3000mm, 4500mm and 6000mm, separately. The structure and mesh pattern of the furnace are shown in Fig.4 with 60 thousand mesh.

Table.2 The distribution parameters of the primary, secondary and tertiary air

	Primary	Secondary	Tertiary 1	Tertiary 2	Tertiary 3	Tertiary 4
Velocity m/s	15.4	16.0	4.9	5.9	6.6	6.6
Air amount Nm <sup>3</sup> /h	2137	2564	2564	3077	3419	3419
Temperature °C	850	200	200	200	200	200

Continuity equations, momentum equations, K-E equations, energy equations and DO model are used in the numerical simulation. Velocity inlet is adopted for inlet boundary condition and the wall function method is adopted for solid wall.



Fig.4a Furnace structure



Fig.4b furnace mesh pattern

Fig.4 The structure and mesh pattern of the furnace

## 4.2 Results on flow field

The flow characteristics of high temperature char particles are considered in the flow field calculation. Fig.5 shows the Z direction velocity contours of the furnace while Fig.6 shows Y direction velocity contours of different Z cross sections in the furnace. It is evident that the main flow and the tertiary air flow are mixing well while diffusing and the tertiary air injection does not interfere with the overall upward movement of the main flow. With the increase of the furnace height, the mixing degree between the tertiary air and the main flow of the furnace increases and the filling degree of the furnace airflow becomes well.



Fig.5 The Z direction velocity contours of the furnace

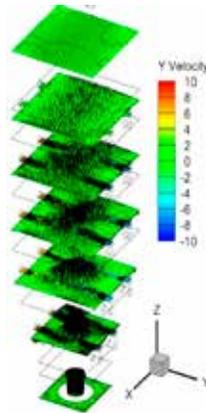


Fig.6 Y direction velocity contours of different Z cross sections in the furnace

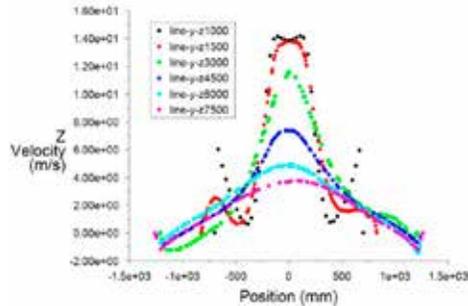


Fig.7 Z direction velocities at different sections

Fig.7 shows Z direction velocities at different heights of the center section of the furnace. The maximum velocity appears near the nozzle at approximately 15m/s (z=1000mm) and decays gradually in the process of rising along the furnace to the ultimate rate of 2-3m/s. The distribution of velocity has the characteristic of symmetry.

## 5. Construction of demonstration project

This demonstration project was designed in 2015 by the institute of engineering thermophysics, built in Hechi city, Guangxi Province in 2016, and will be commissioned in cold and hot state in 2017. The exterior of the residual carbon boiler for 100 tons/day is shown in Fig.8. The boiler theoretically generates 20t/h steam with the pressure of 3.82 MPa and the temperature of 250 °C for combusting 100 tons/day gasified residue carbon. Next, we will analyze the operation characteristics of this boiler with ultra-low volatile fuel.



Fig.8 The exterior of the 100 tons/day of residual carbon boiler

## 6. Conclusions

This paper briefly elaborates the technical process of gasified residual carbon boiler for 100 tons/day in Hechi, Guangxi Province, calculates the flow field in the furnace and analyses the characteristics of commission. The main conclusions are as follows:

- 1) Using preheating technology, the low volatile residual carbon can burn well also with a low NO<sub>x</sub> emission.
- 2) The demonstration project is firstly designed burning ultra-low volatile fuels for industrial boiler in China and abroad. The boiler consumes 100 tons residue carbon per day and generates qualified steam with the pressure of 3.82 MPa and the temperature of 250 °C.
- 3) The results of fluid flow calculating shows the flow field in the furnace is symmetrical and there is no recirculation zone in the furnace therefore the particle deposition can be effectively prevented. The tertiary air injection does not interfere with the overall upward movement of the main flow. Moreover, the mixing degree between the tertiary air and the main flow of the furnace aggravates as the height of furnace increases.
- 4) The 100 tons/day of residual carbon boiler in Hechi, Guangxi Province was already constructed and will be commissioned in 2017.

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