Validation Study on the Tiny-Oil Ignition Technology with Pure Oxygen for Combustion-Supporting in a 670 MWe Utility Lean Coal-Fired Boiler

Fan Fang, Qinglong Wu, Wanjun Yan, Wei Zhang and Hongguang Zhou
Xi’an Thermal Power Research Institute Co., Ltd (TPRI), Xi’an, China
Email: fangfan@tpri.com.cn

Abstract. Because of high ignition temperature of low-volatile coal, it brings great difficulties to apply the tiny-oil ignition technology in the fire-up process of a low-volatile coal-fired boiler. To save oil consumed, the tiny-oil ignition technology with pure oxygen for combustion-supporting was developed and was applied in a 670 MWe utility lean coal-fired boiler. This paper focused on the practical application of the technology. The test results indicated that the lean coal was ignited successfully, with flame temperatures nearly 300°C increasing and the carbon contents of fly ash 10~20% (absolute value) decreasing due to feeding small amount of pure oxygen into a tiny-oil ignition burner. Using the tiny-oil ignition technology with pure oxygen for combustion-supporting could be beneficial to saving about 80% fuel oil in the fire-up process, which demonstrated excellent practical results of the technology.

1. Introduction
Coal is by far the most abundant fossil fuel on the planet. Thus, coal-fired power plants account for a large proportion in power productions. It is well known that it is much more difficult to ignite coal than oil or gas. Therefore, to fire-up a coal-fired boiler in a power plant, fuel oil which is delivered by several oil guns with gun capacity of about 0.6-1.5 tons per hour, is input to the furnace firstly to pre-heat the furnace to appropriate high temperatures [1]. Then, pulverized coal is input to the furnace and ignited. With the furnace temperature increasing, more and more pulverized coal is input to the furnace with fuel oil quantity decreasing. During the firing-up process, large amounts of fuel oil should be used. For example, for a coal-fired 600 MWe utility boiler, more than 100 tons of fuel oil could be used in the firing-up process. Therefore, saving oil consumed has been spurred wide attention in coal-fired power plants. Thus, in view of high financial costs of oil used in the firing-up process in coal-fired power stations, some researchers have developed some oil-saving ignition technologies, such as tiny-oil ignition technology [2] and plasma-assisted ignition technology [3], which have already widely applied. Although tiny-oil ignition technology and plasma-assisted ignition technology have been widely used in bituminous-fired boilers, it is difficult to employ them in the ignition process of a boiler using low-volatile coal due to its high ignition temperature [4]. In addition, if tiny-oil ignition technology or plasma-assisted ignition technology is used to low-volatile coal, carbon contents of fly ash are high in the initial period of ignition, resulting into some adverse effects to air pre-heaters, dust collectors and desulfurization equipment. Therefore, it is necessary to develop an oil-saving ignition technology to low-volatile coal for the aim of saving financial costs of oil used in the firing-up process and safe operation of coal-fired plants.
The ignition temperature and burnout temperature of coal both decrease with the increase of oxygen concentration. Besides that, combustion characteristics of pulverized coal are improved at oxygen enrichment conditions [5]. The previous work had investigated the low-volatile coal ignition process used a tiny-oil ignition burner with pure oxygen for combustion-supporting in laboratory [6]. The experimental results indicated that low-volatile pulverized coal was ignited sufficiently using a tiny-oil ignition burner with feeding small amount of pure oxygen into strategic positions in the burner. Appropriate amounts of pure oxygen fed into a tiny-oil ignition burner could enhance combustion and burning-out of pulverized coal, which was beneficial to saving fuel oil in the firing-up process. Thus, it is a feasible oil-saving ignition method to low-volatile coal-fired boilers by combining tiny-oil ignition technology with oxygen-enriched combustion.

The low-volatile coal ignition process used a tiny-oil ignition burner with pure oxygen for combustion-supporting was investigated theoretically in our present work [6]. In this work, the technology was applied in a 670 MWe utility four-corner tangential fired boiler which was designed to fire lean coal, and we were authorized to test the ignition process. Therefore, this paper focused on the practical application of the technology for the aim of demonstrating practical results.

2. Project and Burner Introduction

2.1. Project Introduction

Figure 1 displays a schematic arrangement of burners in a 670 MWe utility four-corner tangential fired boiler. The furnace is designed to fire lean coal. Along furnace height at each of four corners, the furnace consists of six layers of coal-rich pulverized coal-air flow nozzles, from “Layer A” to “Layer F”. Above these six layers of coal-rich pulverized coal-air flow nozzles, the furnace is also designed six layers of coal-lean pulverized coal-air flow nozzles, from “Layer a” to “Layer f”. The primary coal-air streams from coal mills are centrifugally separated by a separator in pulverized coal pipe into two streams: coal-rich one and coal-lean one. The coal-rich pulverized coal-air flow is injected into furnace by a coal-rich pulverized coal-air flow nozzle. The coal-lean pulverized coal-air flow is injected into furnace by a coal-lean pulverized coal-air flow nozzle. Figure 2 shows the structure of a coal-rich pulverized coal-air flow nozzle and a coal-lean pulverized coal-air flow nozzle in detail.

![Figure 1. Schematic arrangement of burners.](image1)

![Figure 2. Arrangement of coal-air flow nozzles.](image2)

The tiny-oil ignition technology with pure oxygen for combustion-supporting was applied in the boiler for the aim of testing the ignition of low-volatile coal with saving fuel oil. The four coal-rich pulverized coal-air flow nozzles in the lowest layer (“Layer A”) and the four coal-rich pulverized coal-air flow nozzles in the second layer (“Layer B”) were changed to tiny-oil ignition burners with pure oxygen combustion-supporting.
2.2. Description of Tiny-Oil Ignition Burner with Pure Oxygen Combustion-Supporting

Figure 3 shows the horizontal scheme for a tiny-oil ignition burner with pure oxygen combustion-supporting. A main oil gun and an auxiliary oil gun are equipped on the burner as shown in figure 3. The main oil gun is equipped in the first combustion chamber. The auxiliary oil gun is equipped at the outlet of the nozzle. Two oxygen guns, a main oxygen gun and an auxiliary oxygen gun are installed at the outlet of the first combustion chamber and beside the auxiliary oil gun respectively. The characteristics of the oil guns and oxygen guns used here were shown in table 1. Due to the technology secrets, the exact locations and structures of the oxygen guns were not described in detail here.

The coal-rich pulverized coal-air flow is divided into two flows by Venturi structure at the inlet of burner, with concentrated flow in the centre and dilute flow around. The concentrated coal-air flow enters the first combustion chamber. Oil from the main oil gun is atomized and burns in the oil combustion chamber. The oil flame forms and subsequently ignites concentrated coal-air flow in the first combustion chamber. Next, the oil and pulverized coal flame extends from the first combustion chamber to the second combustion chamber, and the flame gradually diffuses from the centre gradually to around. Combustion characteristics of pulverized coal are improved at oxygen enrichment conditions [5]. Therefore, a main oxygen gun is installed at the outlet of the first combustion chamber, which is the strategic position in a tiny-oil ignition burner. The ignition temperature and burnout temperature of coal both decrease because of pure oxygen from the main oxygen gun, which strongly promotes the pulverized coal ignition and combustion at the first combustion chamber outlet, resulting in igniting dilute coal-air flow in the second combustion chamber more easily. Finally, most of pulverized coal is ignited and burns in the second chamber, and then directed into the furnace. Simultaneously, the combustion of pulverized coal at the burner outlet is promoted again by the use of an auxiliary oil gun and an auxiliary oxygen gun.

![Figure 3. Tiny-oil ignition burner with pure oxygen combustion-supporting.](image)

| Table 1. Technical characteristics. |
|-------------------------------------|
| Oil type | Diesel oil |
| Main oil gun capacity | 150kg/h |
| Auxiliary oil gun capacity | 100kg/h |
| Main oxygen gun | 100 Nm³/h |
| Auxiliary oxygen gun | 100 Nm³/h |

3. Experimental Sections

The tiny-oil ignition technology with pure oxygen for combustion-supporting is applied in the 670 MWe utility boiler. For the aim of demonstrating the practical effects of the technology, we were authorized to test the boiler ignition process.
The carbon contents of fly ash were tested repeatedly in the ignition process. Flue gases with constant speed were taken from a measuring point in the middle of air pre-heater outlet using a probe connecting with a pump. A filter cylinder connected at the end of the probe was used to filter flue gases for collecting the fly ashes. The method and instruments using here to sample fly ashes are same with those in the previous experimental research [6]. Then the fly ashes were taken to lab, and the carbon contents were analyzed.

Flame temperatures at tiny-oil ignition burner outlets were tested. Because the four coal-rich pulverized coal-air flow nozzles in "Layer A" were put into operation in the whole ignition process, we measured the flame temperatures outlet of them to demonstrate the practical effects of the technology. A Raytek 3i handheld pyrometer was used to measure flame temperatures. The temperature measured point was about 1m above the coal-rich pulverized coal-air flow nozzles because of furnace structure limitations. Thus, measured temperatures were much lower than real flame temperatures. The lean coal characteristics used in the ignition process are shown in table 2.

The test lasted about 820 minutes, which was from the beginning of pulverized coal-air steams from the first coal mill (Mill A) injected to the furnace to the moment of all oil guns and oxygen guns stopped when the power generation load had been to 430 MWe.

| Table 2. Coal characteristics used in the ignition process (as received basis, wt%). |
|---------------------------------------------------------------|
| Carbon   | Hydrogen | Oxygen | Nitrogen | Sulfur | Volatile matter | Ash   | Net caloric value |
| 59.21    | 2.91     | 4.78   | 0.87     | 1.49   | 15.65           | 22.04 | 22.08 MJ/kg       |

4. Result and Discussion

4.1. Effect of Pure Oxygen on Flame Temperatures

The flame temperatures at the outlets of the four coal-rich pulverized coal-air flow nozzles in “Layer A” were measured using a Raytek 3i handheld pyrometer. As seen in figure 4, at ~80 min of the ignition process, the flame temperatures at the outlet of the four coal-rich pulverized coal-air flow nozzles (corner #1~#4) in “Layer A” were nearly same. The oxygen guns in the three burners (#1~#3) of “Layer A” were put into service at ~90 min. However, from ~80 min to ~140 min, there was no pure oxygen feeding into the #4 burner of “Layer A”.

The flame temperatures outside of #1~#3 nozzles in "Layer A" increased quickly due to feeding pure oxygen, but the raising rate of the flame temperature of #4 nozzles was slow as shown in figure 4. The raised flame temperatures of #1 to #4 nozzles from ~80 min to ~140 min were 440°C, 436°C, 415°C and 140°C respectively, which indicated that the flame temperature was nearly 300°C higher because of the introducing of pure oxygen. The flames outside of nozzles in "Layer A" before and after feeding pure oxygen were observed, and the flame became much brighter due to pure oxygen feeding, which was similar to the lab experiments [6]. At 140 min, the oxygen guns in #4 burner in "Layer A" started up, resulting in the raising rate of the flame temperature increasing. Therefore, the flame temperatures and brightness both increased due to the introducing of pure oxygen to the tiny-oil burners, which was beneficial to burn-out of coal. The tiny-oil ignition burner with small amount of pure oxygen for combustion-supporting is suitable for igniting low-volatile coal.

In addition, the oil guns of #1 burner in “Layer A” stopped at ~170 min, and its flame temperature decreased quickly. After 30 minutes, the flame temperature decreased from about 1000°C to 420°C. After that, its flame temperature increased only about 110°C during next one hour, because the pulverized coal was only ignited by flames of other three nozzles of "Layer A". Therefore, in the initial stage of ignition, the fuel oil could not stop even if pure oxygen was introduced, otherwise the pulverized coal could not be ignited. It is because that the hearth temperature was low in the initial ignition process.

Figure 5 depicted the flame temperatures outside of four nozzles in “Layer A” from 550 min to 800 min. In these periods, all the oil guns and oxygen guns had been in operation. The flames were stable
and the flame temperatures were between 1100°C and 1250°C. The results shown in figures 4 and 5 indicated that the low-volatile coal is ignited and burn steadily in a tiny-oil burner with small amount of pure oxygen for combustion-supporting.

Figure 4. Graph of the flame temperatures at the outlet of four nozzles in “Layer A”.

Figure 5. Graph of the flame temperatures at the outlet of four nozzles in “Layer A”.

4.2. Effect of Pure Oxygen on Carbon Content in Fly Ash

The carbon contents of fly ash of the boiler were tested in the ignition process. As shown in figure 6, in the initial stage of ignition just using oil guns, the carbon contents of fly ash were relatively high, about 30%. With pure oxygen introduced into the burners in “Layer A” at ~90 min, the carbon contents of fly ash decreased to below 20% quickly. With time increasing, the carbon contents of fly ash decreased gradually and finally reached to about 10%. At ~200 min, the carbon content in fly ashes increased, because the oil guns of #1 burner in “Layer A” stopped. Therefore, pure oxygen introduced into tiny-oil ignition burners could effectively promote the ignition and combustion of pulverized coal and decrease the carbon contents of fly ash, resulting in increasing the efficiency of combustion and stability in the ignition process.

Figure 6. Carbon contents of fly ash.

At ~280 min, the second mill (Mill B) started up. Mill B and four burners in “Layer B” began to put into operation. Thus, the carbon contents of fly ash suddenly increased. With time increasing, the carbon contents of fly ash finally decreased to about 5% with two mills operating resulting into nearly no adverse effects to air pre-heaters, dust collectors and desulfurization equipment.
At ~650 min and ~780 min, the third mill (Mill C) and fourth mill (Mill D) with burners in “Layer C” and “Layer D” without oil and oxygen guns started up respectively. Thus, the carbon contents of fly ash also increased. However, because the whole temperature of furnace was high, the pulverized coal from burners of “Layer C” and “Layer D” burned abundantly. At ~820 min, the power generation load had been to 430 MWe, and all oil guns and oxygen guns stopped. The ignition process ended.

4.3. Effect of Pure Oxygen on Saving Oil
The low-volatile coal was ignited in a tiny-oil burner with small amount of pure oxygen for combustion-supporting in this test. The eight tiny-oil ignition burners, which used coal, a small quantity of oil and pure oxygen, could replace the role of big oil guns on furnace. In the whole ignition process, about 24 tons diesel oil and 31.5 tons pure oxygen were used. According to the statistics, about 120 tons diesel oil was consumed in previous ignition process using big oil guns on furnace. Using the tiny-oil ignition technology with pure oxygen for combustion-supporting could be beneficial to saving about 80% fuel oil in the fire-up process, which demonstrated excellent practical results of the technology.

5. Conclusions
In this work, the tiny-oil ignition technology with pure oxygen for combustion-supporting was applied in a 670 MWe utility lean coal-fired boiler, and we were authorized to test the ignition process.

(1) The lean coal was ignited in tiny-oil ignition burners with pure oxygen for combustion-supporting in a 670 MWe utility four-corner tangential fired boiler. Using the technology could be beneficial to saving about 80% fuel oil in the fire-up process with only small amount of pure oxygen, which demonstrated excellent practical results of the technology.

(2) The flame temperatures increased nearly 300°C, and the carbon contents of fly ash decreased 10-20% (absolute value) with pure oxygen fed into tiny-oil ignition burners, which showed that feeding small amount of pure oxygen into burners could promote the combustion of pulverized coal.

(3) The tiny-oil ignition burner with pure oxygen for combustion-supporting is suitable for igniting low-volatile coal in coal-fired boilers.

Acknowledgments
This work was supported by Technology Innovation Leading Program of Shaanxi(2018HJCG-15) and Huaneng Technology Project (HNNJ18-H03).

References
[1] Li Z Q, Liu C L, Zhao Y and Chen Z C 2010 Energy Fuels 24 375.
[2] Liu C L, Li Z Q, Zhao Y and Chen Z C 2009 Fuel 89 1690.
[3] Gorokhovski M A, Jankoski Z, Lockwood F C, Karpenko E I, Messerle V E and Ustimenko A B 2007 Combust. Sci. Technol. 179 2065.
[4] Li Z Q, Liu C L, Zhu Q Y, Kong W G, Zhao Y and Chen Z C 2010 Energy Fuels 24 41.
[5] Fan S Y, Zou Z, Gao J B and Cao Z D 2005 Proceedings of CSEE 25 118 (in Chinese).
[6] Xu D Q, Fang F, Zhou H G, Wang H J, Min H B and Yan X L 2012 Adv. Mater. Res. 608 1257.