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Steam Generators with Fossil Fuels and Environmental Effects of Gasoline

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ABSTRACT

Supercritical units usually work at a pressure of 24 MPa and above, which is higher than the critical water pressure of 22.09 MPa. A subcritical cylindrical steam generator usually works at about 13 MPa or 18 MPa. Many of the steam generators purchased in the 1970s and 1980s are cylindrical water tube types that operate at 18 MPa, produce superheated steam at 540$^{\circ C}$, and have one or two stages of steam reheating. These generators have the ability to burn pulverized coal and petroleum fuels, although petroleum fuels gradually abandoned due to the increase in price and problems related to their supply. Although natural gas still used in power plants in some parts of the world, due to its high cost, it now mostly used for domestic purposes in the United States of America. Anyway, natural gas is a clean burning fuel and relatively pollution free. The steaming capacity of modern power plant steam generators is high and its value can vary from 125 to 1250$\frac{kg}{s}$. Power plants are between 125 and 1300 megawatts. On the other hand, industrial steam generators are those that used in industrial companies and other institutions and include different types. These generators can be pulverized coal-fired water tube type steam generators, although they are powered by lump coal, oil or natural gas, and often a combination of them, as well as municipal waste, process waste energy, or other by-products also be used. In some of them even electric heating is used. Some of them are of the heat recovery type, in which the waste heat of industrial processes is used. These generators can also be of the fire tube type. Industrial steam generators usually do not produce superheated steam, but produce saturated steam or even only hot water (in this case, they can be called steam generators). These generators work at pressures from a few kilopascals to 10.5 MPa, and the steaming capacity (or hot water) they change from less than 1 to 125$\frac{kg}{s}$.

Introduction

Fire tube boilers have used since the end of the 18th century with various basic forms to produce steam for industrial purposes. Today, these types of boilers no longer used in large power plants. In this chapter, this type of boiler is included for historical reasons. In contrast, modern water tube boilers emphasized.

Fire tube boilers still used in industries and they produce saturated steam with a maximum pressure of 1.8 MPa and a capacity of 6.3$\frac{kg}{s}$. Although their size has increased, their general design has not changed significantly in the past 25 years. Fire tube boiler is a special form of shell type boiler.

A shell-type boiler is a container or a closed shell, usually a cylinder, that contains water, and a part of the shell, for example, its lower part, is simply exposed to the heat of the flame or gases from external combustion. Today, the shell boiler has evolved into newer forms such as electric boilers, in which heat is provided by electrodes placed in water. In another type of these boilers, the heat is supplied by the storage and in such a way that the steam produced in an external source pass through the pipes inside the shell. In both types of these boilers, the shell is not exposed to direct heat. The fire tube boiler is an evolved version of the shell boiler in

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which hot gases pass through the tubes instead of steam.

Due to the improvement of heat transfer, the efficiency of the fire tube boiler is much higher than the original shell boiler and its value reach about 70%. In fire tube boilers, the tubes are placed horizontally, vertically, or inclined, but horizontal tubes are more common. The furnace and hearth are located under the front end of the shell. Gases pass horizontally from the bottom and then change direction and then pass through the horizontal tubes and enter at the front. There are two types of fire tube boilers: (1) Boiler with fire box, (2) Scotch boiler. In a boiler with a fire box, a furnace or a fire box with fire tubes are placed inside the shell. In a Scotch boiler, combustion takes place inside one or more cylindrical combustion chambers that are usually located inside and near the bottom of the main shell. The gases exit from the back of the chambers and after changing the direction, they come to the front through the fire pipes and exit through the chimney. Liquid or gas fuels are usually used in scotch boilers.

Blue tube boiler: Initial examples

The forerunner of modern steam generators was the water tube boiler built by George Babcock and Stephen Wilcox in 1867. They called this boiler the blue tube boiler (non-explosive) which was a reference to the catastrophic explosions of boilers that happened a lot at that time. However, the commercial manufacture of water tube boilers did not materialize until the early 20th century, when the steam turbine, which required high-pressure, high-flow steam, was invented. Fire tube boilers needed a shell with a large diameter to have such high pressures and capacities. A shell with such a large diameter should be able to work under very high temperature and pressure stresses, which required the thickness of the shell. In addition, these types of boilers were prone to sedimentation and explosion, and their cost was unacceptably high. On the other hand, the steam pressure in the water tube boiler enters the tubes and into relatively small diameter cylinders, and thus the very high pressures of today's modern steam generators can be tolerated. Early water tube boilers were very similar in appearance to fire tube boilers, with the difference that high pressure water and steam were inside the tubes and combustion gases were outside the tubes. The water tube boiler has gone through several stages until its evolution.

Straight pipe boiler

The first boiler was a straight tube, in which straight tubes with an outer diameter of 3 to 4 inches were placed at an angle of 15, 8 inches apart from each other, between two vertical dividers. One of the dividers was a lowered that fed almost saturated water to the pipes. In these pipes, the water partially vaporized. The other part was the riser that received the mixture of liquid and steam. The density of the water in the lower part was higher than the density of the two-phase mixture in the upper part, and this difference between the densities caused the natural circulation of water in the clockwise direction. With the increase in boiler capacity, more than one branch of each section and more than one set of pipes were used. The two-phase mixture was introduced into the upper cylinder which was placed parallel to the pipes (longitudinal cylinder) or perpendicular to them (transverse cylinder). These cylinders received the feed water from the last feed water heater and gave the saturated steam to the super heater through the steam separator inside the cylinder that separated the steam from the bubble water. The lower end of the augers was connected to the muddy cylinder that collected the circulating water sediments.

A single longitudinal cylinder with a diameter of usually 4 ft (about 1.2 m) could only be equipped with a limited number of tubes and therefore had a limited heating surface. Horizontal cylinder boilers had one or more parallel cylinders depending on their capacity. These boilers were made with a heating surface of 93 to 930 m^2 and their pressure is limited to low pressures between 1.2 to 2.3 MPa and their steaming capacity is limited to 0.63 to $10\frac{kg}{s}$. In transverse cylinder boilers, due to their geometric shape, much more pipes can be used compared to long cylinders. These boilers were made with a heating surface of 93 to 2300 m^2, pressures from 1.2 to 10 MPa, and steam from 0.63 to $63\frac{kg}{s}$. In order to provide the maximum heat absorption of the pipes from the hot combustion gases and to minimize the blind spots of the gas, blades were placed along the pipes of both types of boilers to increase the number of gas passage paths to three.

Bent pipe boiler

Several types of bent tube boilers have been common. In general, instead of straight pipes between the cylinders or between the cylinder and the divider's, bent pipes were used in the bent tube boiler. The tubes were bent so as to radially enter or exit the cylinders. The number of cylinders was usually between two and four. As mentioned above, by installing gas blades, one or more gas passages were created. Here it is enough to refer to an example of bent tube boilers called four-cylinder Sterling boilers; this boiler was invented in the early 1890s and has undergone few changes since then. Unlike other bent tube boilers, this boiler had three upper cylinders and one lower cylinder (which is also called muddy cylinder), which respectively contained two-phase mixture and water. Sterling 's four-cylinder boiler worked as described below. The combustion gas flowed from the right side of the bottom of the furnace to the top. In this boiler, the steam cylinder was located directly above the water cylinder and had a row of curved pipes in front, that is, on the side of the incoming gases, and a row of pipes in the back. In the later designs of the boiler in the Sterling cylinder, only one gas path was used. In the latest designs of the Sterling boiler furnace, cooling walls are used, in such a way that the internal surfaces of the furnace are covered with pipes that carry the water of the boiler and come from the power plant. These pipes increase the heat absorption levels and protect the internal fireproof coating of the walls against high temperatures, which results in an increase in combustion rates and steam flow. In general, the Sterling boiler can adjust itself to highly variable load conditions, and it is considered a suitable boiler in places where it is difficult to maintain high water quality, and it is compatible with all types of fuels. This boiler has been used both on ships and on land.

Water tube boiler: Recent developments

The advent of furnaces with water-cooled walls, called water walls, eventually led to the integration of furnace, economizer, boiler, super heater, re heater, and air pre cooler into the modern steam generator. Water is also used to cool the walls of the economizer, super heater and other components such as retaining walls and partition walls. Using a large number of feed water heaters (up to seven or eight devices) means less savings and high pressure means a boiler with less surface area because the latent heat of evaporation decreases drastically with increasing pressure. Thus, modern high pressure steam generators need a super heater and are heater with a higher surface area and a boiler with a lower surface area than older units. Beyond 10 MPa pressures, the water pipes cover the entire surface of the boiler and unlike what we saw in the older designs in the previous two sections, there is no need for other pipes. Water at a temperature of 230 to 260^{oc} comes out of the high-pressure heater of the feed water and then enters the saver and leaves it as a saturated liquid or two-phase mixture with low quality and then enters the steam cylinder from the middle part. The water flows from the steam cylinder to the divider through the insulating pipes that are placed outside the furnace. Divider refers to the water pipes that cover the walls of the furnace and act as lifting pipes. Water in these pipes receives heat from combustion gases and evaporates to a greater extent. The difference in density between the water in the down pipes and the water pipes helps the water circulation. In the cylinder, the steam is separated from the boiling liquid and goes to the super heater and then to the high-pressure part of the turbine. After leaving this turbine, the steam returns to the re heater and then goes to the low-pressure part of the turbine.

Atmospheric air is preheated by gas after leaving the blower with forced flow, just before the gases are discharged into the atmosphere. After that, the air enters the furnace, where it mixes with the fuel and burns, and the temperature reaches about 1700^{oc}. The gases resulting from combustion give part of their energy to the water pipes and then to the super heater, re heater and saver, and then they leave it at a temperature of about 300^{oc}. After that, the gases leave the incoming air in the preheater and leave it at a temperature of about 150^{oc}. A blower pulls the gases out of the furnace and sends them to the chimney. The fact that the gases come out with a temperature of around 150 means the loss of the ability to do work in the power plant. However, this issue seems to be acceptable because (1) the gases must be at a temperature much higher than the condensation point temperature of the water vapor in the gases (the condensation point temperature is equal to the saturation temperature of the partial pressure of water vapor) to prevent the condensation of steam which causes the formation of acid and corrosion of metal components in the path of gas flow; and (2) the combustion gases must have enough lift to pass through the large amount of smoke at the top of the chimney in order to be well dispersed in the atmosphere.

Fuels and Combustion

Fossil fuels are formed as a result of air and organic decomposition and their chemical transformation in the earth. 30% is produced by the consumption of oil and natural gas. The rest is mainly produced in hydro and nuclear power plants. In the United States, the use of natural gas in power plants is gradually abandoned due to the necessity of using it in domestic and industrial purposes. Synthetic fuels are among the new combustion fuels that are in liquid or gas form and are mainly obtained from coal, oil rocks, and tar sands. Today, industrial by-products, domestic and industrial waste, and biomass account for a very small percentage of consumed fuels. In this chapter, we examine natural (fossil) combustion fuels with synthesis that are used in power plants, as well as their preparation stages and combustion systems.

Coal

Coal in general terms refers to a large number of organic solid minerals with different compositions and properties, but all of them basically have a large amount of carbon element in an amorphous form (without regular structure). Coal is found as layered sediments at different and often high depths, although sometimes it is also found near the surface of the earth. Usable coal reserves in the United States are estimated at 270,000 million tons. (These include reserves that are economically viable to extract in the foreseeable future) that exist in 36 of the 50 states of this country. Coal reserves in the United States are about 30% of the world's coal reserves. Coal can be divided according to its physical and chemical properties from different points of view. The most accepted classification method is the method proposed by the American Society for Testing and Materials (ASTM), and according to it, coal is divided into different grades based on the degree of metamorphism (change in shape and structure due to heat, pressure, and water). At the lowest level of this division is brown coal and at the highest level is anthracite (ASTM D388). Below, this division is introduced in descending order and briefly.

Anthracite

Anthracite has the highest rank among coals and 86 to 98% of its mass in a dry state and free of mineral substances, fixed carbon (carbon that is in an elemental state) and a small percentage, from 2 to 14% of its mass is volatile substances (it mainly forms methane (CH_4). Anthracite is shiny black, has a high density, and is hard and brittle. Anthracite with the maximum percentage of fixed carbon is in the form of graphite. Anthracite burns slowly and has the highest heating value after bituminous coal. Anthracite is mainly used in fuel-fired steam generators, and is rarely burned as a powder. In the United States, most of its mines are located in Pennsylvania. Meta anthracite which has more than 98% carbon, anthracite which has 92 to 98% carbon, and semi-anthracite which has 86 to 92% fixed carbon.

Bituminous coal

Bituminous coal, as the largest group, includes a wide range of coals that have 46 to 86 percent of fixed carbon mass and 20 to 40 percent of volatile matter. Its name is derived from the word bitumen, which is the same asphaltic substance that is obtained in the distillation of some fuels. Its heat value is in the range of 25600 to 32600$\frac{kj}{kg}$. Bituminous coal burns easily, especially if it is in powder form. The group of bituminous coals is divided into five sub-groups, which are: Bituminous coal whose volatile matter is low, medium and high, and the last type includes types A, B and C. The lower the volatile matter, the higher the calorific value of coal. Bituminous coal, which contains little volatile matter, is black-gray in color and has a granular structure, while the groups with high volatile matter are homogeneous or lamellar.

Bituminous coal

These types of coal form a group that generally have a lower calorific value than bituminous coal. Their heat value is in the range of 19300 to 26750$\frac{kj}{kg}$. This type of coal contains a high percentage of moisture, 15 to 30%, but its sulfur percentage is often small. Its color is black or brownish black and it has a homogeneous structure. Bituminous coal is usually burned in powder form. This group of coal is divided into three subgroups A, B, and C.

Coal wood species

This type of coal is at the lowest level of coal classification and its name Lignite is derived from a Latin word that means wood. This charcoal is brown in color and has a sheet structure, and you can often see the remains of wood veins in it. Its origin is often plants with a lot of resin, and therefore the moisture content is above 30%, and the volatile matter is high. Its heat value is in the range of approximately 14650 to 19300$\frac{kj}{kg}$. Since the humidity of this type of coal is high and its heating value is low, it is not economical to transport it to long distances for consumption, and it is usually used in power plants that are built near its mines. The wood coal group is divided into two subgroups A and B.

Peat coal

This type of coal is not classified by ASTM. Despite this, it can be considered as the first stage of coal formation from the geological point of view. Peat coal is anomalous material that includes decomposed plant matter and inorganic mineral matter. Its humidity reaches 90%. Peat coal is not very interesting as a power plant fuel. But it is found abundantly in many parts of the world. There are large mines of it in several states of America. Due to its abundance in several countries (Ireland, Finland, Soviet Union), it is used in power plants generating electricity and district heating.

Analysis of coal

There are two methods for analyzing coal: the direct method and the method of quantitative analysis of elements, both of which are based on mass percentage. Both methods may be based on received coal, which is suitable for combustion calculations, or on a moisture-free basis, in which changes in the moisture content of a coal load and even in different stages of pulverization are ignored, or based on a dry mineral matter-free basis, in which is avoided that the ash components are not the same mineral materials found in coal.

Direct analysis

This method is simpler than the other method that exists for analyzing coal and it is a method that easily provides important information for the consumption of coal in steam generators. The basic method of direct analysis is introduced in ANSI/ASTM Standards D3172. With this method, mass percentages of fixed carbon, volatile matter, moisture, and ash are determined. The percentage of sulfur is determined separately. Fixed carbon is the same element of carbon that is present in coal. In the direct method, its value is considered to be approximately equal to the difference between the mass of the original sample and the total mass of volatile matter, moisture and ash. Volatile matter, which does not include water vapor, refers to the part of coal that separates from it when the sample is heated in the absence of oxygen during a standard test (up to 955^{oc} for 7 minutes). Volatile matter includes hydrocarbons and other gases that are obtained as a result of distillation and decomposition. The moisture content is determined in a standard test and as a result of drying the sample in a greenhouse. This amount does not include all available water, which includes combined water and hydrated water. Many other terms are used for coal moisture, one of which is inherent moisture that exists in the natural state of coal and is considered as a part of mineral matter. In this case, of course, surface water is not considered. Ash is inorganic salts that exist in coal. Its value is determined in practice by measuring the non-combustible materials remaining from the combustion of dry coal during a standard test (at 750^{oc}).

Sulfur is determined separately in a standard test according to ANSI/ASTM Standards D2492. Sulfur is combustible. It also contributes to the heating value of coal. As a result of its combustion, oxides are formed, which become acid as a result of combining with water. These acids cause corrosion problems in the end part of the steam generator if the temperature of combustion gases reaches lower than their dew point temperature. In addition, they also cause environmental pollution.

The method of quantitative analysis of elements

This method is more scientific than the previous method by which the mass percentage of the chemical elements that make up the coal is determined. These elements include carbon, hydrogen, nitrogen, oxygen and sulfur. The amount of ash is also determined in general, and sometimes its amount is determined in a separate analysis. This analysis method is introduced in ANSI/ASTM Standards D3176.

Calorific value

The calorific value of the fuel, which is $\frac{kj}{kg}$ its unit, may be determined based on received coal, dry, or dry and without ash. The calorific value is the amount of heat transferred when the products resulting from the complete combustion of coal or any other fuel are ignited until reaching the initial temperature.

Mechanical fuel gauges

Almost all coal can be burned in incinerators. Combustion in the fuel injector, with the exception of manual combustion, is less efficient than other methods. Because of its low efficiency, this method is usually used in boilers that have low capacity and the amount of steam they produce is less than $50\frac{kg}{s}$. Although the designers are trying to limit the use cases of fuel burners to boilers with a steam capacity of about 12.6 $\frac{kg}{s}$. These low capacities are the result of practical limitations related to the size of fuel burners and the relatively low rate of combustion in them, which require a wide furnace to produce a certain amount of steam. On the other hand, pulverized coal and cyclone combustion have high combustion rates and are more flexible in terms of design, so that they can burn millions of kilograms of coal per hour, which is the feed of modern steam generators, in taller and narrower furnaces. Despite this, fuel sizes maintain their role as an important part of steam generating systems. Mechanical fuel injectors are usually divided into four major groups. These groups, according to the way of feeding coal to the furnace, are: Spreading fuel, bottom-feeding fuel, swinging hearth fuel, and mobile hearth fuel. The spreader fuel injector is the most common fuel injector for steam capacities from 9.5 to 50 $\frac{kg}{s}$. This type of fuel burner can burn all kinds of coals, from bituminous coal, which has a high rank, to charcoal, and even some secondary residual fuels such as wood waste, wood pulp, tree bark, etc., and is responsive to rapid load changes. In the spreader incinerator, coal is fed from a hopper to the distribution units, and each unit has a reciprocating feed plate that transfers the coal from a hopper on an adjustable spreader plate to a wheel equipped with curved blades. There are a number of these distribution mechanisms that bring the coal into the furnace and distribute it evenly on the fuel burner. At first, the air is fed into the furnace through the air flow that is under the hearth and flows upwards. This air is called under fire air. Fine coal particles, which make up about 25-50% of the injected coal, rise with the air and burn while suspended. Larger particles fall on the hearth and burn in a relatively thin layer. Another part of the air, which is called the air on the fire, is blown into the furnace from the top of the coal injection site. Blowers with forced flow are used to blow the air under the hearth and the air on the fire. This refueled is equipped with devices for collecting and re-injecting coal dust, as well as controlling the amount of coal and air flow so that their amounts are proportional to the demand of the load on the steam generator. The problem with stationary spreader incinerators was the transfer of ash, which was done by hand at first. Later, this work was done by closing some parts of the firebox and cutting off the air supplied from that part without affecting other parts of the firebox. Spreader fuel injectors became widely used only after the use of fuel injectors with movable hearths and continuous ash discharge in the late 1930s. Fuel burners with mobile furnaces, as a group, include fuel burners with chain furnaces.

These fuel injectors consist of fire pits, joints, or connecting devices that are connected to each other in the form of an endless belt and are driven by a drive gear wheel at one end and a gear wheel mechanism with a fixed axis at the other end. Coal may be injected in the above way or fed directly from a funnel and through an adjustable orifice on the movable hearth, which regulates the thickness of the coal layer. The ash is also emptied into the ash pit, which is placed at one of the two ends according to the direction of movement of the fire pit. Continuous cleaning fireplaces that are designed in a back and forth or oscillating manner have also been invented. These are also suitable for the combustion of certain types of coals, just like the fuel feeders feeding from below. However, the fuel burner with a movable hearth and continuous ash discharge has a high combustion rate and is still used as a superior fuel burner. The ignition of the newly imported coal in the fuel as well as the combustion of its volatile matter, which is obtained as a result of distillation, is done as a result of the radiant heat transfer of the burning gases. The combustion of the coal bed continues and as the fuel mover moves to the other end, the bed becomes thinner and when the fuel mover goes around, the ash falls into the pit. Sometimes vaults are built inside the furnace so that the combustion process can be done better by reflecting the heat on the coal bed.

Combustion of coal powder

The development of commercial methods for pulverized coal combustion is a turning point in the history of steam production. These methods made it possible to build large, efficient and reliable steam generators and power plants. The concept of coal combustion (powder) which was previously called by this title, goes back to the times of Carnot, Diesel, and Thomas Edison and many other people. So that Carnot proposed the idea of using it in the Carnot cycle. In his first experiment, Diesel used coal powder in the engine that is now called and Thomas Edison improved the combustion in cement kilns by using it and thus increased their efficiency and production. But coal powder was successfully used in the power plants of this company only after the pioneering efforts of John Andersen and his colleagues and the introduction of the Wisconsin Electric Company. The motivation of the initial efforts for the combustion of coal powder originated from the idea that if the coal is in the form of particles, the gas will burn well and easily. Later, other encouraging factors such as the increase in the price of oil and the existence of vast resources of coal were proposed for the use of coal powder, so that today it can be said that history is repeating itself in the case of coal consumption.

Many theoretical works on the combustion mechanism of powder and coal started in the early 1920s. The mechanism of grinding and pulverizing is not well known from a theoretical point of view and it is a debatable issue today. Probably the most accepted law in this case is the law that was published in Germany in 1867, which is called Rittinger's law, according to which the work required to change the size of an object to a smaller size is proportional to the surface area of the object or matter. However, this and other laws do not consider many of the processes involved in pulverizing coal, and many of the advances made in coal pulverized furnaces rely heavily on correlations and experimental designs. For the satisfactory combustion of coal powder in a furnace, two conditions are necessary:

(1) The presence of a large amount of very fine coal particles so that they can pass through the sieve with mesh number 200. This provides easy ignition of coal due to the high surface to volume ratio of these particles.

(2) The presence of the smallest possible number of coarser particles, which increases the combustion efficiency. These coarser particles should contain a very small number of particles with sizes greater than a certain limit so that they usually cannot pass through a sieve with a mesh of No. 50. Such particles cause the formation of slag and decrease in combustion efficiency. The size of the bituminous coal that is ready to be transported after extraction from the mine, and it is called coal from the mine, is about 8 inches. Lumps that are too big are broken, but they do not pass the coal through the sieve. Other sizes of coal are called by specific names, such as lump (in 5), which is used in manual combustion and household use, egg (in 2 × 5), walnut ($1\frac{1}{2}$in × 2), fuel ($1\frac{1}{2} \times \frac{3}{2} in$), and small ($\frac{3}{4} \times 0\ in$meaning $\frac{3}{4} in$or less).

According to ASTM D 310, anthracite coal has similar types, which are: Broken ($4\frac{3}{8} \times 3in$), black wheat ($\frac{4}{10} \times \frac{5}{16} in$) and rice ($\frac{5}{16} \times \frac{3}{16} in$). Coal is usually converted to the appropriate size required by a pulverizing mill with a cyclone furnace before being transported to the power plant.

If the coal is too large, it must pass through the crushers that form part of the coal conveying system and are usually placed at a convenient point in the coal conveying system. The amount of coal fed to the pulverizing mill is equal$1\frac{1}{4} \times 0in$, and the amount of coal required for cyclone furnaces is equal$\frac{1}{4} \times 0in$.

Crushing machines

Coal crushing machines have many commercial types, some of which are used in special cases. Ring crushing machine, or stone crusher and hammer mill are two types of them that are used to prepare coal for further pulverization. Coal is fed from above and as a result of the action of the rings that are rotated eccentrically with the help of a wheel, or by the blows of hammers that are connected to the wheel, it is crushed. Adjustable rods that act like a sieve determine the maximum size of coal discharged. Wood and other foreign materials are also crushed, but usually a trap is installed to collect scrap pieces (metals and other materials that cannot be crushed).

Ring crushers and hammer mills can be used inside or outside the power plant, these machines reduce the size of coal$\frac{3}{4} \times 0\ in$. In this way, a large amount of coal soil is prepared in them, which is suitable for subsequent pulverization, but this soil is not suitable for combustion in a cyclone furnace. The coal rotary wheel helps to mix the fuel with the primary air, and the tangential doors built inside the wind chamber make the primary combustion air and the secondary air turbulent, which causes a better mixing of the secondary air with the mixture of fuel and primary air coming out of the rotary wheel. The total ratio of air to fuel is greater than the stoichiometric ratio (the ratio required for complete combustion in terms of chemistry) and at the same time, it is enough to ensure complete combustion of the fuel without wasting energy, that is, without increasing the sensible heat of the air too much.

Table 1. Additional air required for the combustion system of some fuels

Excess air, percent	System	Fuel
15-20	Powder, the furnace is completely quenchable with water	Coal:
15-40	Powder, relatively water-cooled furnace	
30-60	Fuel dispenser	
15-50	Chain stove and mobile fuel dispenser	
10-15	Chopped, cyclone oven	
5-10	Oil burners	Petroleum fuel:
10-20	Multiple fuel burners	
5-10	Gas burners	Gas:
7-12	Multiple fuel burners	

Table 1 shows the range of additional air required for optimal combustion of some fuels as a percentage of theoretical air. The initial ignition of burners is done in various ways, including by spraying light oil fuel, which is also ignited by a spark. To ensure self-sustainability of the flame, the lighter usually remains active for a sufficient period of time. Control can be done manually or remotely. Oil and gas lighters are only kept lit for a few seconds. But in the case of charcoal powder, the lighters usually remain lit for a long time, sometimes up to several hours, so that the temperature of the combustion area increases sufficiently and the stability of the flame is ensured. Also, it may be necessary to activate the lighter at very low loads, especially when the volatile material of the consumed coal is low. The rotating wheel is a part of the burner that has serious construction issues and usually needs to be replaced once a year or more.

Conclusion

Combustion in the cyclone furnace, which was realized in the 1940s, is considered the most important step in coal combustion after the implementation of coal powder combustion in the 1920s. Now, this type of combustion is widely used to burn lower rank coals that contain a high percentage of ash, between 6 and 25%, and high volatile matter, which is usually more than 15%. It is in such conditions that it is possible to achieve the high combustion rates that are needed. Coals with a high percentage of moisture can also be used provided they are preheated. The only limitation is that the ash should not contain a high percentage of sulfur or a high ratio$\frac{Fe_2O_3}{(CaO+MgO)}$. By using this type of coal, materials with a high melting temperature such as iron and iron sulphide may be formed in the slag, in which case the main advantage of cyclonic combustion becomes neutral. The main advantage of this type of combustion is the transfer of a large amount of ash, about 60%, in the form of slag/melt, which collects in the walls of the cyclone due to centrifugal force and is emptied into the separate slag tank located below. Therefore, only 40% of the ash goes out with the flue gases, while in the combustion of coal powder, its amount reaches about 80%. This causes the wear and dirtying of the steam generator surfaces to be significantly reduced and also the size of the dust collector filters with the filter housing in the output part of the steam generator is reduced. Another advantage of the cyclone furnace is that only coal is used, and therefore there is no need for coal pulverizing equipment and the size of the boiler is also reduced. In the cyclone furnace, coals of such sizes are consumed that on average 95% of them can pass through the sieve with mesh number 4. The disadvantages of this type of furnace are the high pressure in the blower with forced flow and therefore the need for more power consumption, the inability to use the coals mentioned above, the formation of more nitrogen oxides in the combustion process (NO_x), which increases air pollution.

Cyclone is basically a water-cooled horizontal cylinder that is placed outside the main boiler furnace, crushed coal is fed into it and it burns at a very high rate of heat. Coal combustion is complete before the hot gases produced enter the boiler furnace. The crushed coal enters the cyclone burner in the left part along with the primary air, which constitutes approximately 20% of the combustion air or secondary air. The primary air enters the burner tangentially and as a result gives a centrifugal movement to the coal. The secondary air also enters at a high speed tangentially from the top of the cyclone and applies another centrifugal force to the coal. A small amount of air called the third air also enters the cyclone from the center. The rotating movement of air and coal increases the volume density of the released heat to about 4700 to 8300 $\frac{kw}{m^2}$ and brings the combustion temperature to more than 1650^{oc}. These high temperatures cause ash to melt in the form of liquid slag that covers the surface of the cyclone. Finally, the slag is discharged through the slag valve to the slag tank located at the bottom of the boiler furnace, where it is frozen and transferred after being cut into pieces. A layer of slag that is formed on the walls of the cyclone acts as an insulator and prevents excessive heat loss through these walls and helps to improve the efficiency of the cyclone combustion. At these high temperatures, more NO_x is formed in the combustion gases. These gases leave the cyclone through the opening on the right side and enter the main furnace of the boiler. Therefore, the combustion is done in a relatively small cyclone, and the only task of the boiler's main furnace is to transfer heat from the gases to the water pipes. Cyclone furnaces are also suitable for burning oil and gas fuels. The primary ignition is carried out by means of small fireproof gas or oil burners placed in the secondary air valves. Cyclonic combustion systems, such as coal powder systems, may be of the charcoal or storage type, or of the direct combustion type. Coal type system, especially for bituminous coals in cyclone combustion, is more used in comparison with coal powder system. In the cyclone system, both combustion in one wall and combustion in mutual walls are common. But the second method is preferred in large steam generators. The size and number of cyclones for each boiler depends on the size of the boiler and the desired response to the load because the common range of load change for each cyclone with good performance is from 50 to 100% of its nominal capacity. The diameter of the cyclones varies from 2 to 3 meters and the heat released in them varies from 47,000 to 125,000 kW respectively.

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Authors' Contributions

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