

Use of Lignin as an Alternative Fuel

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Abstract – possibility to use lignin as an alternative fuel in boilers of small-scale power engineering is analyzed. Main sources of raw materials for lignin production, as well as characteristics of lignin are described. Features of lignin combustion and design concepts necessary for available boilers modernization are discussed.

Key words – lignin, pellets, modernization, alternative fuel, renewable fuel, power-efficiency.

I. Introduction

Modern world power engineering is affected by two main factors. First one is continuous increase of demand for power along with rise of prices for primary sources of energy. Second one is environmental pollution, which became extremely acute in last decades. The current circumstances force many countries to increase oil and gas production (in case of explored reserves availability), as well as rapidly develop nuclear power engineering and thermal power engineering based on organic fuel. Increase of atmospheric emission of harmful substances produced as a result of organic fuel combustion induces people to develop new technologies in industry and power engineering.

High-powered boilers built yet in soviet times to provide people and plants with heat and steam, became unprofitable today. Obsolete and worn equipment, as well as its expensive maintenance cause considerable expenses and reduce heat supply reliability. In such conditions new equipment implementation, as well as existing equipment upgrade using advanced modern approaches is very urgent.

The current situation in Ukrainian market of energy carriers is almost critical. Main type of fuel used in municipal services is natural gas. Recovery of gas in Ukraine does not satisfy the demand even for 10-15 %. So, the country is dependent on external suppliers of natural gas, price for which increases rapidly. Use of another energy sources as well as alternative types of fuel (solid and liquid fuel, solar and wind energy) are underdeveloped and have certain disadvantages, namely need of transportation by railway or motor transport, difficulty or, sometimes, impossibility of storage, wastes formation after combustion (high ash content), harmful atmospheric emission, considerable primary capital investments for equipment.

Instead in Ukraine there is considerable amount of renewable industrial wastes, from which fuel can be cheaply obtained and efficiently used. The wastes of hydrolysis production of lignin can be such wastes. Sawdust and other wastes of woodworking industry, sunflower seeds' husk, corncobs and cereal crops straw can be used as raw materials for this production. Lignin is highly calorific fuel and available and renewable raw material for fuel pellets production.

II. Characteristics of lignin

Lignin is an organic substance which, along with cellulose, is constituent of higher plants' tissues. Lignin is irregular high-molecular compound of three-dimensional structure build of branched macromolecules mostly consisting of substituted phenols residues.

Lignin is considered as non-hydrolysable part of a plant tissue. The plant tissue of hardwood trees contains 18-24 % of lignin that of softwood trees – 27-30 %, cereal crops' straw – 12-20 % by weight. Elemental composition of lignin obtained from various plants is about as follows, % by wt.: C - 63, H - 6 and O - 31. Lignin is contained in cell walls and intercellular space of plants and strengthens cellulose fibers (Fig.1).

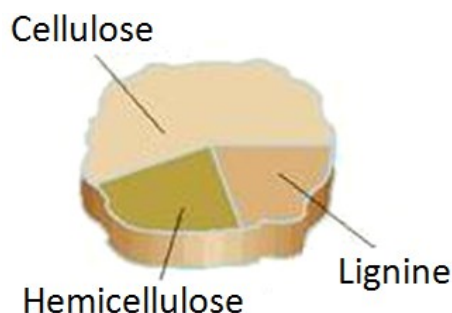


Fig. 1. Plant tissue composition

Together with hemicelluloses, it ensures mechanical strength of stems and stalks. Lignin is physically and chemically incorporated into the structure of plant tissue and its efficient recovery by industrial methods is difficult engineering problem.

Lignin is not separate substance but it is a mixture of aromatic polymers of similar structure. That is why it is impossible to draw its exact structural formula. At the same time, it is known, which structural units does it consists of and by what bonds are these units bound into a macromolecule. The monomer links of lignin macromolecule are called phenyl propane units, because these structural units are phenyl propane derivatives. Softwood lignin almost completely consists of guaiacyl propane structural units. In addition to guaiacyl propane units hardwood lignine contains considerable amount of syringyl propane units. Some lignins, mainly from herbs, contain units without methoxy groups – hydroxyphenyl propane units.

Lignin contains 40-88 % of lignin itself, 13-45 % of polysaccharides, 5-19 % of substances of lignohumic complex and 0.5-10 % of ash. Lignin ash composition: Al_2O_3 – 1 %; SiO_2 – 93.4 %; P_2O_5 – 1.5 %; CaO – 1.5 %; Na_2O – 0.3 %; K_2O – 0.3 %; MgO – 0.3 %; TiO_2 – 0.1 %.

Calorific value of dry lignin is 5500-6500 kcal/kg and is comparable with calorific value of equivalent fuel (7000 kcal/kg). The calorific value of the product with moisture content of 18-25 % is 4400-4800 kcal/kg and the value of the product with moisture content over 65 % is 1500-1650 kcal/kg.

From physicochemical point of view lignin in its primordial form is complex shaving-like stuff with

particle size ranging from few millimeters to few microns or even less, moisture content in which is up to 55-70 %.

Study of lignins obtained at different plants showed the following average fractional particle size distribution: more than 250 μm - 54-80 %, less than 250 μm - 17-46 %, and less than 1 μm - 0.2-4.3 %. In terms of structure, part of hydrolysis lignin is not a dense body, but is an extended system of micro- and macro pores. Value of its internal surface area is determined by moisture content (760-790 m^2/g for wet lignin and only 6 m^2/g for dry one). Such feature of macro- and microstructure of lignin and its chemical structure determines of its combustion features.

III. Use of lignin as a fuel

The annual world production of technical lignins is about 70 million tons. And though there are many publications where technical lignin is considered as valuable chemical raw material, from which broad range of industrial goods can be obtained, its use is very limited in practice. It is because, for example, decomposition of lignin into more simple chemical compounds (phenol, benzene etc.) is more expensive compared to these products obtainment from oil or gas, at the same quality of the final products.

Difficulties of industrial processing of lignin are caused by complexity of its structure, diversity of its structural links and bonds between them, as well as low stability, which leads to irreversible change of its properties as a result of chemical or thermal influence. In addition, the wastes of hydrolyzed lignin (industrial wastes) do not contain natural lignin, but considerably altered lignin-containing substances.

Due to the difficulty of lignins processing only up to 2 % of technical lignins are used as chemical raw material, the rest is burnt at power plants or land-buried in waste burials. Therefore, use of technical lignin, as well as its mixtures with shorts of coal-concentration, for fuel pellets production is very promising, especially for municipal and small-scale power engineering. Besides being highly calorific domestic fuel, lignin can also be used as reducing agent in ferrous and non-ferrous metallurgy, substituting coke, semi-coke and charcoal.

The conclusion about reasonability of lignin use as a fuel can be made based on its following characteristics: solid carbon content up to 30 %, flash point 195 $^{\circ}\text{C}$, self-ignition temperature 425 $^{\circ}\text{C}$ and smoldering temperature 185 $^{\circ}\text{C}$. Self-ignition temperature for: lignin aero-gel 300 $^{\circ}\text{C}$, lignin aero-dredge 450 $^{\circ}\text{C}$; lower concentration limit of flame spread 40 g/m^3 ; maximum pressure of explosion 710 kPa; maximum rate of pressure rise 35 MPa/s; minimum flash energy 20 MJ; minimum explosive oxygen content 17 %.

Hydrolysis lignin is capable of transformation into viscoplastic state under pressure about 100 MPa. This fact causes one of promising direction of hydrolysis lignin use, namely its use in form of pellets (Fig.2).

Fuel pellets of lignin are high-quality fuel with calorific value up to 5500 kcal/kg and low ash content. During combustion the lignin pellets burn with colorless flame, and do not effuse soot of fume. Main physico-chemical properties of fuel pellets made of lignin are given in table below.



Fig. 2. Fuel pellets

TABLE

PHYSICO-CHEMICAL PROPERTIES
OF FUEL PELLETS MADE OF LIGNIN

| Property | Unit | Value |
|----------------------|------------------------|------------|
| Calorific value | kcal/kg | up to 5500 |
| Density | g/cm^3 | 1.25 – 1.4 |
| Apparent density | kg/m^3 | up to 700 |
| Moisture | % | 8 – 12 |
| Ash content | % | 0.5 – 10 |
| Solid carbon content | % | 25 – 30 |

IV. Design features of furnaces for lignin combustion

The process of lignin combustion in technological furnaces without direct heat emission has considerable differences compared to the furnaces of steam boilers. There no heat rays receiving surface and, consequently, to avoid ash scorification the aerodynamic conditions of the process must be thoroughly calculated. Torch furnace of Shershnev system, providing rather high efficiency for highly dispersive fuels is most appropriate for lignin combustion.

In such furnaces the fuel is burnt as a suspension in furnace volume. It is achieved due to the fuel to be supplied into the furnace by a feeder cached up by the air flow created by the streams of tangential air blowing and moving along with the air in the furnace volume combusted in turbulent flow. The volume of such furnaces has oval form and due to this under the influence of whirling air flows large fuel particles drop out on the slope, slip down from it and are cached up again by the air flow. Another advantage of the furnace of such design is a possibility to dry wet fuel directly in the furnace volume, thus combining drying and burning processes.

Conclusion

Therefore, to provide efficient combustion of lignin at existing power plants their modernization by means of extra equipment installation is required. This equipment includes special furnaces (prefurnaces), which can be installed instead of burners. Complexification of boiler design in this case is justified, because it allows to transfer the boiler to use of cheap and available alternative fuel.