

Research and Optimum Design of the Biological Materials Gasifier

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Abstract: The overall design plan shall be made according to the thermo-chemical characteristics of the biological materials and the planned key technical indexes. Also, the theoretical research and optimum design of the various structures of the gasifier shall be made according to the rules on burning, thermal conduction and energy balance. The authors design a unique hearth and high-intensity turning grate, and put forward the reference value for gasification intensity and the secondary air supply coefficient, they further explore the general rules of the design of biological materials gasifier and provide the design principle of the key technical indexes.

Keywords: biological material gasifier; thermo-chemical characteristics; gasification intensity, secondary air supply coefficient, low heat value of gas

0. INTRODUCTION

The effective utilization of the biological resources have become an important problem for the sustained development of the agriculture in our country. The development and application of the central gas supply technology through the gasification of biological materials has blazed an effective way for the large-scale utilization of biological resources in China, which is of great significance for reducing the environmental pollution, improving the energy-consuming structure in rural areas and promoting the sound development of agriculture. As the core equipment of this technology the research and design of biological gasifier will be of paramount significance. For this reason, the author conducts the theoretical research and optimum design on the gasifier according to the thermo-chemical characteristics, and further explores the general rules on the design of biological material gasification and provides the design principles of key technical indexes.

1. ANALYSIS ON THE THERMO-CHEMICAL CHARACTERISTICS OF BIOLOGICAL MATERIALS

The types of the biological materials are varied, so their thermo-chemical characteristics vary considerably from each other^[1]. As far as the technical system of central gas supply through gasification of biological materials, it is not the case that all the agricultural stalks can be gasified ideally^[2]. Some biological materials like straw can not be used for the gasifier independently because they have large specific volume and high content of ash and are easy to cause oven expansion and ablation^[3]. The following is the analysis of the thermo-chemical characteristics^[4]

of three common materials in rural area: corn cob, peanut hull and corn stalk.

Tab.1 Thermal chemical characters of several agricultural crops straw

Type	Water Content (%)	Volatile Component (%)	Fixed Carbon (%)	Ash (%)	Thermal Value (kJ/Kg)
Corn Stalk	4.87	71.95	17.75	5.93	16281
Corn Cob	4.39	76.6	13.67	5.34	16397
Peanut hull	12.2	77.02	7.36	3.42	16140

Tab.2 Element analysis of several agricultural crops straw

Type	Carbon (%)	Oxygen (%)	Hydrogen (%)	Nitrogen (%)	Sulphur (%)
Corn Stalk	45.43	36.24	6.15	0.78	0.13
Corn Cob	46.30	37.80	5.60	0.57	—
Peanut hull	45.93	37.62	5.28	1.10	0.11

The theoretical research and optimum design on the gasifier according to the thermo-chemical characteristics of high volatile component, good reaction property of carbon and less ash content.

2. DETERMINATION OF THE OVERALL PLAN OF THE BIOLOGICAL MATERIALS GASIFIER.

2.1 Research & Design Principle

1) High efficiency of gasification, good quality of gas; 2) good adaptability of materials; 3) solid and reliable with stable operation; 4) simple structure, convenient operation and low price.

2.2 The key technical Indexes Plan to be Reached

1) Gasification efficiency > 74%, the low level thermal value of the biological materials > 5.5 MJ/Nm³; 2) CO Content in gas < 20%, O₂ Content < 1.0 %. Impurity Content (tar and ash) < 30 mg/Nm³; 3) The gasification can run stably for at least four hours.

2.3 Design of the Overall Structure

1) Type selection of the biological materials gasifier

The most important characteristic of the downdraught gasifier lies in that all the outcome of the drying and pyrogenation will pass through the oxidation layer, most of the tar produced will be decomposed at high temperature, even the water will participate in the reaction and produce flammable gas^[5]. This kind of oven is applicable for solid fuels like the stalks of agricultural crops or woods who have high content of volatile component. It has many advantages like simple structure, fixed height of effective layer, stable work performance, fuel addition during the operation and so on, and is suitable to be used for the central gas supply at village level in rural areas^[6].

The working principle of such oven is shown in Figure 1, the inner area of the oven can be divided into five parts at the working state: drying zone, pyrogenation zone, burning zone, gasification zone and cooling zone.

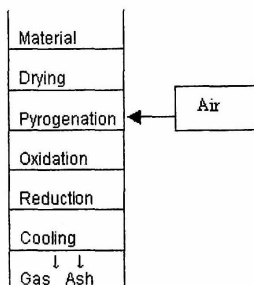


Fig.1 The schematic diagram of gasification

The foregoing five gasification stages must conform to the following relationship in theory:

$$\frac{dQ_1}{dt} > \frac{dQ_2}{dt} \quad (1)$$

Among which,

Q₁—The heat quantity produced by oxidation burning;

Q₂—The heat quantity needed for reduction and decomposition to produce flammable gas.

Formula (1) shows that the heat quantity generated by the burning must meet the heat quantity absorbed by the process of drying the materials and reducing the burning outcome into flammable gases. Only by meeting this requirement can the material flow, gas flow and energy flow form constant and stable quality and energy exchange.

2) Design Plan

The inner layer of the downdraught fixed bed gasifier is insulation layer, the middle layer is ring gas passage, the outer layer is recycling cooling water. The top of the oven is operation space, the middle lower of the oven is a grid which can be turned with an outside handle, the bottom of the oven is a space for ash. The frame structure of the gasifier is welded by Q235 steel; the insulation layer is constructed by high-aluminum cement and refractory; the Grate is made of 2G35Cr24N27SiN refractory steel. The general structure of the gasifier is shown in Figure 2.

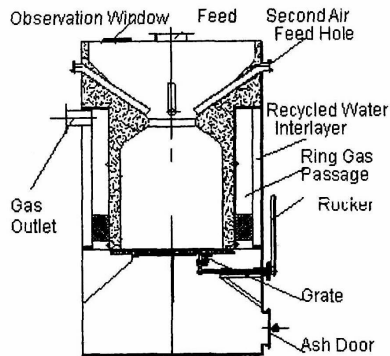


Fig.2 The General Structure of Gasifier

3 OPTIMUM DESIGN OF THE STRUCTURE OF THE BIOLOGICAL MATERIAL GASIFIER

3.1 Determination of the Key Parameters of the Biological Material Gasifier

1) Determination of the gasification intensity

The main chemical reaction in the hearth of the gasifier is $C + O_2 = CO_2$ and $CO_2 + C = 2CO$. $H_2O + C = H_2 + CO$, which indicates that it is a chemical reaction between solid carbon and gases (O₂, CO₂, H₂O). Such chemical reaction is not homogeneous, it only reacts on the solid surface. How much carbon will participate the reaction in unit period will be decided by the diffusion speed of the molecules and the speed of the chemical reaction. Among the above reactions, the reduction reaction speed of CO₂ is lower than other reaction speed considerably, so it is the main reaction^[7] deciding the gasification intensity of the gasifier.

The gasification intensity has a great influence to the gasification effect of the biological materials, so the research and design of the gasification intensity is

the key part of the design of biological material gasifier. We control the gas output of the gasifier by adjusting the by-pass valve to change the gasification intensity and find that: when the gasification intensity is at low level, the biological material gas has high LHV (low heat value) and high content of impurity, this is because the reduction layer is now at the diffusion zone, the speed of the chemical speed is higher than the diffusion speed of gases; when the gasification intensity reaches a certain value, the gas has high LHV (low heat value) with the minimum content of impurity. The gas quality is best because the reduction layer is now at the balance zone, namely, the speed of the chemical reaction equals to the gas diffusion speed; when the gasification intensity keeps improving, the LHV (low heat value) decreases suddenly, the content of the impurity rises considerably, this is because the reduction layer is at the dynamic zone, the speed of the chemical reaction is less than the gas diffusion speed; when the gasification intensity is too strong, the flammable component in the biological material gases will become less and less with high content of impurity, which makes the gas cannot be ignited in the practical operation of the gasifier.

So when choosing the gasification intensity, the hearth temperature shall be high enough for cracking of carboncoal tar^[6] and water volatilization to obtain quality gas, on the other hand, the gasification efficiency shall be relatively high. The temperature of the gas on the outlet of the gasifier shall not be too high to prevent the ablation of the purifying system under high temperature. The gasification chosen by the author is $q=200\text{kg/m}^2\cdot\text{h}$. To ensure the temperature of the oxidation zone is high enough, The oxidation zone of the gasifier is designed to be a V-shaped structure, whose area is half of the reduction zone, in addition, adjustable secondary air inlet around the gasifier is designed to increase the burning intensity of the oxidation zone, which makes the oxidation reaction more intense, improves the temperature of the oxidation zone and decrease the impurity content in the gas and relieves the burden of the purifying system radically.

2) Determination of the actual air quantity

During the gasification of biological materials, complex thermo-chemical reaction is occurring between the biological materials and the air, among which the ER is an important parameter, namely, the ratio between the actual air quantity and the theoretical air quantity. The ER is decided by the types of the biological materials and the types of the gasifier. Generally speaking, the ER shall be controlled to between 0.25-0.40, ER shall be higher when the biological material has high content of water or less volatile component, otherwise, the ER shall be lower^[9].

3) Control of the secondary air supply coefficient.

The secondary air supply coefficient is defined as the ration between the secondary air supply quantity and the actual air quantity. During the operation of the gasifier, the control of the secondary air supply coefficient is of paramount significance. It can influence directly the stable operation of the gasifier and the quality of the biological material gas. The

related test indicates that: when the secondary air supply coefficient is relatively low, the gases have high LHV (low heat value) and high content of impurity; when the secondary air supply coefficient reaches a certain value, the gases have moderate LHV (low heat value) and minimum content of impurity; when the secondary air supply coefficient keeps improving, the LHV (low heat value) of the gases will decrease and the content of impurity will rise; For the fixed bed downdraught gasifier, the secondary air supply coefficient shall be controlled to between 20-25% provided that the impurity content of the gases conforms to the state standard. Meanwhile, this ratio is not a fixed value, during the ignition stage of the gasifier, the secondary air supply inlet can be opened completely to increase the temperature of the hearth because the various reaction layers haven't formed, the secondary air supply coefficient can be decreased to the above range during the stable operation stage of the gasifier according to the actual conditions of the biological materials.

3.2 Optimum Design of the Various Structures of the Gasifier

1) Design of the Grate

The Grate is the part that is most easily to be damaged. The gasifier on the present market need to replace the grate once a year. So the design of the grate of great importance to the stable operation of the gasifier. In structure, the grate of the downdraught gasifier shall meet the requirement of even distribution of the gasification agent and the smooth discharge of the ashes and remaining carbon. The material shall have enough resistance against ablation and deformation under high temperature. The hand-turned grate selected in this article has overturn angle of 45° and is cast by high temperature refractory steel, which has enough resistance against ablation and deformation. The normal position of the grate is shown in Figure 3, the limit position of the grate is shown in Figure 4.

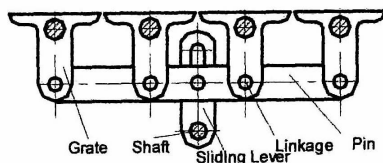


Fig.3 Normal Position Figure of Grate

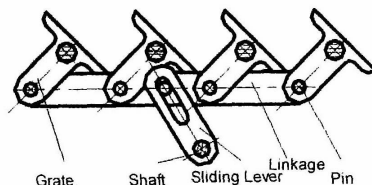


Fig.4 Limit Position Figure of Grate

2) Selection of the refractory

The gasification works intermittently and is under the recycled thermal stress, collision is easy to happen during the operation, so the refractory must have certain service life and intensity under high temperature. Cast integrated with high-aluminum cement refractory can meet this requirement.

3) Outlet passage of gas

During the gasification of the biological materials, it is easy to produce large amount of ash, the ring gas passage around the hearth of the gasifier will make the gas rise along the ring passage after it is sucked out through the grate, the speed of the gas flow will decrease because the large section of the ring gas passage, which makes the large article of ash fall into the ash space. Such passage can also increase the temperature inside the hearth and make the carboncoal tar in the biological material to crack, and thus increase the LHV (low heat value) of the gas and decrease the content of the impurity in the gas.

4) Interlayer of the recycled water

There is an interlayer of the recycled water on the out layer of the gasifier, which can not only decrease the temperature of the gas but also limit the surface temperature of the gasification and thus ensures the safety of the operator.

4. CONCLUSION

1) Gasification intensity is the key factor for the gasification effect. The author puts forwards the reference value for the design of the gasification intensity, which has reference significance in the design of the fixed bed gasifier.

2) The secondary air supply coefficient has great influence to the gasification intensity and gas' LHV (low heat value) and so on. The design of the adjustable secondary air supply inlet makes it possible to control the secondary air supply coefficient when using different materials or at the ignition stage or different stages of the stable operation and thus achieve the ideal gasification effect.

3) The unique structure of the hearth. The V-shaped structure in the oxidation zone of the hearth whose section is half of the reduction zone, can not

only improve the gasification efficiency and the gas' LHV (low heat value) but also decrease the content of the impurity in the gases.

4) High-intensity material for the hearth and the advanced construction technology. The liner of the gasification is cast by high-aluminum refractory, which is convenient for field installation and can improve the service life of the gasifier.

5) Quality grate material and convenient turning structure. The grate is made of refractory steel, although the cost is relatively higher, it makes the grate has the same service life as long as the gasifier, so the operation of the gasification system will be more reliable

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