Application and Discussion of Dual Fluidized Bed Reactor in Biomass Energy Utilization

Haibin Guan, Xiaoxu Fan, Baofeng Zhao*, Liguo Yang and Rongfeng Sun

Energy Research Institute, Shandong Academy of Sciences, Jinan 250014, China

*Corresponding author e-mail: zhaobf@sderi.cn

Abstract. As an important clean and renewable energy, biomass has a broad market prospect. The dual fluidized bed is widely used in biomass gasification technology, and has become an important way of biomass high-value utilization. This paper describes the basic principle of dual fluidized bed gasification, from the gas composition, tar content and thermal efficiency of the system point of view, analyzes and summarizes several typical dual fluidized bed biomass gasification technologies, points out the existence of gas mixing, the external heat source, catalyst development problems on gas. Finally, it is clear that the gasification of biomass in dual fluidized bed is of great industrial application and development prospect.

1. Introduction
Biomass as a major form of solar energy conversion and accumulation, is a clean renewable energy. In the energy conversion will not produce a lot of harmful SO₂ and other pollutants, almost zero CO₂ emissions, biomass energy utilization will account for about 50% of global energy consumption by 2050.[1] Biomass due to its own containing up to about 70% of the volatile raw material properties, is very suitable for gasification technology to generate as much as possible to use gas.[2] Biomass gasification technology has become one of the most efficient and practical methods of biomass energy conversion. In recent years, dual fluidized bed biomass gasification technology has been paid more and more attention by scholars both at domestic and abroad. This paper introduces the basic principle of dual fluidized bed biomass gasification technology, analyzes and summarizes the existing forms and discusses their advantages and problems, in order to provide a reference for the dual fluidized bed technology research and development and application promotion work.

2. The Basic Principle of the Dual Fluidized Bed Gasification
The dual fluidized bed gasification system mainly includes two interconnected gasifiers and combustion furnaces. The gasifier has a bubbling fluidized bed, a circulating fluidized bed, a two-stage fluidized bed, a U-shaped fluidized bed, moving bed or down-bed and other forms [3].

The general form of a dual fluidized bed gasification system consists of two interconnected fluidized beds: an endothermic gasifier and an exothermic combustion furnace for the drying, pyrolysis, gasification and combustion of the biomass are decoupled; gasifier is mainly a water vapor as a fluidized medium bubbling bed, the combustion furnace is generally a fluid or pure oxygen as a fluidized medium of the rapid bed; the biomass residual carbon generated by gasification with the material into the combustion furnace, the release of heat by combustion with the material into the endothermic gasifier,
to achieve self-heating system to improve the carbon conversion rate and system thermal efficiency.[4] The basic principle of the dual fluidized bed gasification process is shown in Figure 1.

![Figure 1. The basic principle of the dual fluidized bed gasification.](image1)

3. The Research Status of the Dual Fluidized Bed Gasification

According to the known literature, the earliest dual fluidized bed biomass gasification design concept was proposed by Japanese scholar Kunii. He built a small dual fluidized bed gasification demonstration device in 1975, focusing on the complete sealing of combustion reactors and gasifiers [5]. In order to improve the quality of gas and the stability and economy of the system, the researchers at domestic and abroad put forward the different dual fluidized bed design scheme, and on this basis, a lot of experimental research was performed. Because of the important effect of the material circulation system on the gas quality and stable operation of the dual fluidized bed, this paper divides the dual fluidized bed into two kinds, internal circulation dual fluidized bed and external circulation dual fluidized bed according to the different material circulation system.

3.1. The Internal Circulation Dual Fluidized Bed System

The internal circulating fluidized bed mainly achieves the large-scale internal circulation of the particles in the bed through the non-uniform wind, which enhances the material's horizontal mixing and prolongs the residence time of the granular material in the bed. And this is conducive to the stability of the fuel in the bed, fast combustion, so that the bed material combustion process more stable and full.

![Figure 2. The internal circulating dual fluidized bed by Japan Gunma University.](image2)

Xiao [6,7] from Japan's Gunma University conducted an in-depth study on the low-temperature gasification of biomass based on Ni/Al$_2$O$_3$ catalyst in a dual fluidized bed with internal circulation. The
gasification device is shown in Figure 2. The device is divided into three parts: combustion chamber (I), gasification chamber (II) and return chamber (III). The combustion chamber and the gasification chamber are connected through the return chamber and the material circulation is realized. Compared with the general internal circulation dual fluidized bed, the presence of the return chamber reduces the influence of the gas string mixing between the combustion chamber and the gasification chamber on the gas quality to a certain extent. Ni/Al₂O₃ catalyst and the subsequent development of a lignite-supported nickel-based catalyst for the application of biomass gasification at a relatively low temperature of 600 °C - 700 °C to get the tar content of only 0.3 g/m³ of the gas, reduce the heat loss of steam gasification, improve the system thermal efficiency.

**Figure 3.** The internal circulating dual fluidized bed by China Zhejiang University.

Fang M. X. [8, 9] from China Zhejiang University designed the internal-circulation dual fluidized bed and established a small test device, the design concept is through the upper and lower openings of the device will be divided into gasification chamber and combustion chamber. Through the two rooms of the uneven pressure caused by the air between the two rooms to achieve the material cycle. The influence of the size and arrangement of the return hole on the material circulation system was studied. The internal circulation dual fluidized bed has no external return device, the structure is simple and compact, the operation is relatively stable, but it is difficult to avoid the gas string mixed gas quality impact between the gasification chamber and the combustion chamber. The gasification device is shown in Figure 3.

3.2. The External Circulation Dual Fluidized Bed System

Compared with the internal-circulation dual fluidized bed, the addition of the external return device is a typical feature of the outer-circulation dual fluidized bed, which avoids the gas string mixing between the combustion chamber and the gasification chamber, and has been making tremendous progress in industrial applications.

Hofbauer [10-12] from Vienna University of Technology began to do research on biomass gasification in dual fluidized bed since 1994 in Austria. Through the optimization design of the feeder and the use of water vapor as the feeder fluidized medium, to solve the gas backmix problem in the internal-circulation dual fluidized bed between the gasification chamber and the combustion chamber, get N₂ volume fraction of only 1%-3% of the biomass gas, has been successfully applied to Güssing operation of the 8 MWth dual fluidized bed biomass demonstration power plant in Austria, 2002, the gasification device shown in Figure 4. Hofbauer et al. contrasted the effect of quartz sand, olivine and calcite as recycled bed materials on gasification results. As olivine and calcite on the tar have a catalytic role, resulting in higher quality gas. In particular, due to the absorption of calcite bed material for CO₂, the hydrogen concentration in the gas was significantly increased at a lower temperature of 645 °C. The tar contents in the gas were 8.2 g/m³, 3.1 g/m³ and 1.4 g/m³, and the volume fraction of H₂ was 35.4%, 42.0% and 73.9%, respectively.
Xu et al. from Japan IHI Company proposed a two-stage dual fluidized bed gasification device in 2007. The main feature of the device is the gasification unit of the gasification chamber is divided into two sections. The reaction of the lower section is similar to that of the bubbling fluidized bed, while the main role of the upper section is to reduce the influence of the particles in the bubbling fluidized bed and to further purify the syngas. The content of tar in the product gas is 20%-25% lower than that in the general dual fluidized bed under similar conditions, and the gasification efficiency is increased by 7%. However, since the residence time of the fuel particles in the gasifier is shorter than the fuel retention time of the dual fluidized bed, the gasification efficiency is still needed to be improved [13]. The gasification device is shown in Figure 5.
Guan [14-16] proposed a three-stage fluidized bed gasifier in the study of coal/biomass co-gasification at low temperatures. The gasifier consists of three reactors: a riser combustor, a coal gasification bubbling fluidized bed, and a descending bed for the pyrolysis and reforming of the volatiles. Unlike the general dual fluidized bed gasifier from the bubbling fluidized bed feed, the fluid from the three-stage fluidized bed gasifier is fed from the down-bed. The existence of the down-bed prolongs the contact time between the volatiles produced by rapid pyrolysis and the carbon in the down-bed to several tens of seconds. The interaction of volatile and carbon can promote tar cracking, reduce tar content in the product gas, and reduce the chemical energy loss to below 10%. The gasification device is shown in Figure 6.

![Figure 6. The triple-bed external circulating dual fluidized bed.](image1)

![Figure 7. The interconnected fluidized bed gasifier by China Southeast University.](image2)
The research of dual fluidized bed technology in China is still in the development stage, the application of industrial applications is rarely. Shen L. H. [17] from Southeast University established a dual fluidized bed biomass gasification thermal test research device. Named it an interconnected fluidized bed gasifier. The effect of gasification reactor Temperature T, water vapor and biomass mass ratio S/B on gasification results was discussed through experimental study. The interconnected fluidized bed satisfactorily solves the problem of gas backlash between the combustion reactor and the gasification reactor, enabling the stable and continuous production of high-quality products without N₂. The gasification device is shown in Figure 7.

In view of the high moisture content of some biomass, it is necessary to dry and then gasify the gas, and Dong L. P. [18] from the Chinese Academy of Sciences Process Engineering Institute proposed a decoupled dual fluidized bed gasifier capable of direct gasification of biomass with high water content. Its design concept is mainly with the lower part of the partition will be divided into two areas of the gasification chamber U-shaped bed, relying on the uneven distribution of materials from the low-speed area to the high-speed area of the flow. The decoupling of the drying/pyrolysis and gasification/reforming processes not only improves the residence time in the gasification chamber, but also the water vapor generated in the low-velocity zone can promote the steam vaporization process in the high-speed zone. In addition, the coke produced in the low-speed zone also enters the high-speed zone as the material flows, which contributes to the catalytic cracking of the tar. The design of the decoupled dual fluidized bed enables the bed material to achieve unidirectional flow from the low velocity zone to the high-speed zone in the gasification chamber, extending the residence time of the fuel in the gasification chamber, improving the quality of the gas and carbon conversion rate. The gasification device is shown in Figure 8.

![Diagram of decoupled dual fluidized bed gasifier](image)

**Figure 8.** The decoupled dual fluidized bed gasifier by the Chinese Academy of Sciences Process Engineering Institute.
3.3. Contrast and Analysis
The internal-circulation dual fluidized bed has the advantages of simple structure, good stability, and no need to worry about the control problem of the return device. Through the non-uniform wind distribution, the horizontal mixing in the internal fluidization condition is sufficient. The bed temperature is generally between 600 °C-800 °C. It is difficult to coking and has good gas producing quality. It has higher calorific value and hydrogen content. But the problem of gas mixing between the combustion chamber and gasification chamber limits its application.

The material circulation rate of external circulation dual fluidized bed is larger, and the gasification intensity is higher, which is the most extensive circulating fluidized bed type in the biomass gas industry application, and the calorific value of the gas is up to 12-15 MJ/m³. Bed temperature is usually between 850 °C-1100 °C, less tar. However, improper operation at high temperatures prone to coking, the need to add a certain amount of external auxiliary fuel, or can not achieve the desired gas temperature. The return system is difficult to control, easy to cut down, easy to change into low-speed portable bed when the feed rate is low.

Dual fluidized bed gasification technical requirements and research costs are high. At present, although many countries have carried out industrial trial operation and production, but most of the operation of the biomass gasification plant is to rely on government funding to be able to maintain. Therefore, the industrialization of dual fluidized bed biomass gasification technology is not only scientific research, but also economic problems.

4. Conclusion and Prospect
Dual fluidized bed biomass gasification technology will be biomass raw materials into high-quality combustible gas, improve the efficiency of biomass energy for the further use of biomass and deep processing provides a great convenience. After years of research and development, dual fluidized bed biomass gasification technology has made great progress. However, the research of key technologies needs to be further improved and perfected. In the future, we should strengthen the researches on the coupling mechanism of biomass gasification reaction system, the mechanism of catalyst function play and the coordination of process control system and engineering control.

In the increasingly pressing global energy situation, biomass is becoming more and more important in the energy structure system as a renewable energy source after the three largest fossil energy renewable energy. Dual fluidized bed biomass gasification is one of the key technologies for the efficient use of biomass cleaning. There is a vast space for the development both at domestic and abroad. The future will be widely used in heating, gas supply, power generation, hydrogen production, synthesis of liquid fuels and other industries, will play a more important role in sustainable development of energy.

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