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Power Engineering

Prospects of Waste-to-Energy Using the Fluidized Bed Technology

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(Presented by Academy Member Ramaz Khurodze)

Abstract. The management of scrap tires presents a serious ecological and economic challenge worldwide. Due to the negative impact on the environment, disposal methods such as landfilling, burial or open burning are strictly unacceptable. Similarly, the removal of residual biomass from grape processing in wineries is prohibited due to the risks associated with counterfeiting. Consequently, the only legally permissible and eco-friendly approach to utilize both this biomass and the by-product "tire chips" derived from the scrap tire processing instead of "Low Temperature Circulating Fluidized Bed" technology is their combustion using the low-emission "High Temperature Fluidized Bed" technology developed by the authors. This technology enables the generation of substantial amounts of energy while maintaining emissions of harmful substances within permissible regulatory limits. The effective utilization of the energy potential of the aforementioned waste streams while ensuring positive ecological outcomes, which previously had been impossible due to the lack of an appropriate combustion device. This limitation has been overcome through the development of an innovative device based on "High Temperature Fluidized Bed" technology. *© 2025 Bull. Georg. Natl. Acad. Sci.*

Keywords: waste-to-energy, fluidized bed, biomass, GHG emissions, energy efficiency

Introduction

The disposal of scrap tires presents a significant environmental concern. Some case studies argue against tire combustion due to pollutant emissions, but others highlight that Waste-to-Energy (WtE) technologies can be more environmentally friendly than mechanical recycling. Although various laboratory studies have explored the pyrolysis and gasification of scrap tires, only few industrial-scale plants currently exist. This is largely due to the inefficiencies of the Low Temperature Circulating Fluidized Bed technology, which is prone to operational issues such as combustion interruption and slag buildup.

At the Georgian Technical University, an innovative combustion device has been developed that enables High Temperature Fluidized Bed combustion, previously considered infeasible. This technology addresses the limitations of Low Temperature Circulating Fluidized Bed systems and allows for stable and efficient combustion of various low-grade solid fuels, including biomass and tire-derived fuels.

Design and operation of the high temperature fluidized bed technology. Fluidized Bed Combustion technology has gained interest for its ability to efficiently utilize low-grade, inexpensive solid fuels. A key environmental benefit is the reduction of sulfur and nitrogen oxide emissions through chemical reactions within the combustion chamber.

In High Temperature Fluidized Bed systems, sulfur oxides are mitigated by adding materials like limestone or dolomite into the bed. These compounds undergo thermal decomposition and react with sulfur to form stable calcium sulfate ($CaSO_4$), achieving sulfur capture efficiencies up to 90%. The residual sulfur dioxide (SO_2) concentration in the flue gas is typically 200-400 mg/m^3. Key factors influencing sulfur capture include (Reddy et al., 1999; Ray et al., 2014):

- Molar ratio to Ca/S (optimal range 2-3);
- Temperature (optimal range 800-900°C).

The High Temperature Fluidized Bed combustion device developed by the authors of this article (Patent No. P6828, 20.03.2018) offers multiple advantages over Low Temperature Circulating Fluidized Bed combustion technology:

- Inert material isn't required in the fluidized bed;
- Absence of temperature limitation to 900-950°C allows easier automatic control;
- Absence of fuel concentration limitation in the combustion chamber allows achieving the highest thermal load of Q_F = 20-22 MW/m^2 (for the low temperature circulating bed Q_F = = 6-8 MW/m^2);
- Wide control range for power adjustment (30-100%).

The combustion device operates based on a pulsating fluidized bed mechanism. Feed air supplied by a fan enters a channel and is directed exclusively through the annular gap between a rotating grille and the inner surface of a directional cylinder. The grille is mounted at an inclination of 5-10° relative to the horizontal plane and rotates along with the central shaft. Due to this inclination, as the grille rotates within the cylinder, the air gap undergoes oscillatory motion in the vertical plane. This motion induces a pulsating air flow into the combustion chamber, vertically affecting the fluidized bed, which ensures the high intensity and stability of the combustion process. Simultaneously, fuel is introduced into the fluidized bed along with the pulsating air stream. This mechanism enhances both the mixing and the combustion intensity within the bed. The pulsation, driven by the vertical oscillation of the grille, occurs with a gradually decreasing amplitude of acceleration. This results in improved homogenization and stability of the fluidized bed throughout the combustion chamber volume, promoting efficient combustion (Johnsson et al., 2002).

The absence of a horizontal stabilizer of vibration in the fluidized bed eliminates the formation of zones with varying hydrodynamic resistance. As a result, the bed exhibits uniform hydrodynamic characteristics throughout its entire volume. This uniformity facilitates a highly intense and stable combustion process by enabling the optimal distribution of feed air. Consequently, the combustion system operates efficiently, utilizing the required amount of air without unnecessary losses.

The disc is capable of movement in both the horizontal and vertical planes. In the horizontal plane, it maintains a constant acceleration amplitude, while in the vertical plane, the acceleration amplitude decreases monotonically. This behavior influences the relative acceleration of the vibration, contributing to the overall dynamics of the fluidized.

$$K = \frac{A \cdot W^2}{g} > 1 ,$$

where K is the relative acceleration of vibration; A is the vibration amplitude, m; g – gravitational acceleration, m.s^{-2}; $W = 2 \cdot \pi \cdot f$ is the angular speed of vibration, rad. s^{-1}; f – vibration frequency, s^{-1}.

A directional cylinder is rigidly attached to the combustion chamber and in this cylinder is inserted a sliding grille, which is an elliptical disc inclined at 5-10 degrees to the horizontal plane.

The combustion device, equipped with a fluidized bed burner, demonstrates high efficiency and is particularly well-suited for the combustion of solid fuels characterized by large structural heterogeneity and fine particle size.

The combustion chamber employs a two-stage combustion process designed to minimize the formation of fuel-derived nitrogen oxides. In the first stage, pulsating fluidization and partial gasification of the fuel take place at temperatures below 900°C. Due to these relatively low temperatures, the formation of thermal nitrogen oxides in the fluidized bed is significantly reduced. At this stage, only a portion of the total combustion air is supplied, while the remaining air is introduced in the second stage for the complete combustion.

This staged air supply strategy, combined with the fluidized bed's mixing characteristics, ensures a lower overall production of nitrogen oxides. As a result, the concentration of nitrogen oxides in the flue gases typically does not exceed 290 mg/m^3. In the second stage, complete combustion of the gaseous products is achieved through co-combustion with gaseous fuel (40-50% ratio) at a higher temperature of approximately 1200°C.

In addition to these environmental benefits, fluidized bed combustion offers significant operational advantages. Notably, the high relative velocity of gas flow with respect to solid particles enhances the combustion process, contributing to its intensification. As a result, the thermal efficiency of the fluidized bed device can reach values as high as 22 MW/m^2 of bed surface area within the combustion chamber.

The table presents the measured concentrations of harmful emissions released into the atmosphere during the combustion of different fuels, alongside those from natural gas, which is utilized in the second combustion stage (40-50%). The utilization of renewable biomass results in net-zero greenhouse gas emissions, owing to its classification as a carbon-neutral energy source and co-firing tire chips with biomass results in significantly lower GHG emissions than natural gas is shown.

Results

Experimental validation confirms that the developed device on High Temperature Fluidized Bed Combustion technology enables:

- Stable and efficient combustion of biomass, tire chips, and their mixtures;
- Significant reduction in GHG and pollutant emissions;
- High thermal efficiency, surpassing traditional Low Temperature Circulating Fluidized Bed systems.

Table. Technical characteristics of fuels

Title	Biomass	Tire chips	Natural gas	Tire chips+Biomass
Calorific value, J/kg	20 000	27 000	35 000	23 000
Calorific value, kWh/kg	5.56	7.50	9.70	6.28
Emission factor, kg CO_2/kWh	0.00	0.230	0.202	0.172
SO_2 , mg/nm^3	-	200	-	116
NO_2 , mg/nm^3	224	290	730	138

Conclusions

- Emissions of NO_x and SO_2 are significantly reduced due to optimized two-stage combustion;
- Inert mass isn't required in the fluidized bed;
- First-stage combustion temperatures are maintained between 900-950°C;
- The combustion chamber achieves a specific capacity of QF = 20-22 MW/m^2;

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ენერგეტიკა

ნარჩენებიდან ენერგიის მიღების პერსპექტივები მდუღარე შრის ტექნოლოგიის გამოყენებით

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მსოფლიოში სერიოზულ ეკოლოგიურ და ეკონომიკურ პრობლემას წარმოადგენს ამორტიზებული საბურავების უტილიზაცია. გარემოზე უარყოფითი ზემოქმედების გამო მათი გადაყრა ნაგავსაყრელებზე, მიწაში ჩამარხვა ან უშუალო დაწვა ყოვლად დაუშვებელია. ასევე, ღვინის ქარხნებში გადამუშავებული ყურძნის ნარჩენი ბიომასის გატანა აკრძალულია ფალსიფიცირების რისკებიდან გამომდინარე. შესაბამისად, აღნიშნული ბიომასის ლოკალიზაცია და ამორტიზებული საბურავების გადამუშავებით მიღებული ქვეპროდუქციის ე.წ. „საბურავის ჩიფსის" უტილიზაციის ერთადერთი ლეგალური გზა არის მათი დაწვა „მაღალტემპერატურული მდუღარე შრის" დაბალემისიური ტექნოლოგიით, რაც შესაძლებელს ხდის კოლოსალური რაოდენობის ენერგიის გენერაციას და გამონაბოლქვ აირებში მავნე ნივთიერებების შემცველობის დასაშვებ ზღვრებში შენარჩუნებას. აღნიშნული ნარჩენების ენერგეტიკული პოტენციალის ეფექტური უტილიზაცია დადებითი ეკოლოგიური ეფექტით შეუძლებელი იყო სათანადო საცეცხლე მოწყობილობის არარსებობის გამო, რისი საშუალებაც „დაბალტემპერატურული ცირკულაციური მდუღარე შრის" ტექნოლოგიით მომუშავე დანადგარებისგან განსხვავებით, ავტორების მიერ შექმნილმა „მაღალტემპერატურული მდუღარე შრის" ტექნოლოგიით მომუშავე დანადგარმა მოგვცა, რომელიც სხვადასხვა ქვეყანაში შესაძლებელს ხდის ძვირადღირებული იმპორტული ბუნებრივი აირის მნიშვნელოვანი რაოდენობის ადგილობ-

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