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「課程博士用」

学 位 論 文 の 要 旨

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学位論文題目	Novel reactor and system design/simulation for carbon-based energy conversions （炭素ベースのエネルギー変換のための新しい反応器及びシステムの設計とシミュレーション）		

学位論文要旨

Energy is an important foundation of human survival and society development, and the world's energy demand is still increasing year by year. Nowadays, carbon-based energies are still the major section in the world's energy consumption. For a long time in the future, carbon-based energies cannot be replaced completely. Thermochemical conversion is considered as the best way to convert carbon-based energies into various convenient energy since it realizes the possibility of removal of harmful impurities, such as tar, sulfur and so on. In general, the products are usually cooled down before purification because the purification technologies at high temperature condition are not yet mature. However, a large amount of exergy is always lost during cooling and purification processes. Therefore, the process design with complete tar conversion and highly efficient exergy recuperation is the key issue in the carbon-based energy utilization system. This dissertation, on the one hand, considers novel design and optimization of gasifier to give a guidance in application of the multi-stage gasification system. On the other hand, advanced small-scale biomass power generation system and highly efficient dry reforming of methane system were designed and analyzed. It includes 6 chapters.

Firstly, a Eulerian-Eulerian model incorporating the kinetic theory of granular flow was adopted to simulate the gas-solids flow behaviors in a dense downer below a conventional downer, which could be used for the further pyrolysis of coal and/or decomposition of tar on the generated char before the char and tar are completely separated in a triple-bed combined circulating fluidized bed (TBCFB) system. The high solids holdup in the dense downer can enhance the heat transfer to completely pyrolyze coal as well as decompose the heavy tar, avoiding the negative impact of pyrolysis products on the char gasification. In order to obtain the optimal structural parameters and operating conditions and evaluate the performance of this dense downer, the influences of downer diameter, cone angle and solids mass flux on the hydrodynamic behaviors were investigated in details. The results demonstrate that the solids holdup in the dense downer can be increased, however, the maximum solids holdup is limited to approximately 0.4 owing to the ultimate carrying capacity. Moreover, it is found that there is a peak solids holdup in the annular region near the wall whereas many particles concentrate at the center in the high-density operation states. Meanwhile, the unique solids radial distribution could be caused by the radial movement of particles. Moreover, the intense collisions and turbulence caused by high velocity could inhibit agglomerates, which should be benefit for the heat transfer. It is expected that these results could offer a guidance for the design of such a dense downer for effective improvement of the efficiency of the pyrolyzer.

Secondly, a small-scale high-efficient combined heat and power generation system with a

separated-type biomass gasification process combining the energy/exergy recuperation is proposed for the first time. The spatial subdivision of the processes for the biomass pyrolysis, char combustion, tar reforming and catalyst regeneration is adopted by using a separated-type biomass gasifier design to realize the optimization of each conversion step and improve the whole system performance. To obtain the maximum power generation efficiency, the energy flow and exergy flow in the system are analyzed in details and the operating condition of the gasification system is optimized. The results demonstrate that the relatively low temperature as well as low steam/carbon ratio in the tar reformer should be conducive to the improvement of energy and exergy efficiencies. In the optimum operation condition, the biomass input of 548.86 kW (higher heating value) could generate 263.65 kW of electrical power with the total energy and exergy efficiencies of 37.9% and 43.2%, respectively, in which 153.44 kW of energy could be recuperated back to the gasification process by air and steam with 136.56 kW of energy obtained from gas turbine exhaust to enhance the whole power generation efficiency. It is expected to provide a new design concept for the development of high-efficient small-scale biomass gasification system for the combined heat and power generation.

Finally, a novel separated-type autothermal dry reforming of methane (ATDRM) system with the circulating fluidized bed and exergy recuperation is proposed and simulated, in which the methane dry reforming combined with methane partial oxidation by circulating fluidized bed is considered. The spatial subdivision of dry reforming and partial oxidation processes is used to eliminate the negative effect of the products of CH_4 partial oxidation on dry reforming of methane (DRM) reactions and further improve the CO_2 conversion efficiency. The results demonstrate that the novel separated-type ATDRM system can achieve an exergy efficiency of 87.2%. About 1055.7 kW of exergy can be recuperated from the crude syngas cooling process and reused for CO_2, O_2 and CH_4 pre-heating. In this system, the largest exergy destruction occurs in the partial oxidation reactor, which accounts for about 63.1% of the total exergy loss. With the conventional ATDRM system as reference, although the exergy of separated-type ATDRM system decreases approximately 0.1%, the CO_2 conversion can be substantially increased by about 11.3%.

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