Agitated Fluidized Bed Thermochemical Energy Storage for Industrial Waste Heat Recovery System

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1. Introduction

Optimum utilization of residual heat is often hampered by economic and technical boundary conditions. It is also affected by the mismatch between supply and demand with regard to quality, quantity, time, and location. It is estimated that about 10% of current total UK energy consumption is discharged into the atmosphere as waste [1-2]. With an appropriate technology a large proportion of this waste heat could potentially be recovered for useful applications and thus minimize energy consumption and CO_2 emissions.

In recent years, thermal energy storage has emerged as a significant means by which residual heat may be recovered for later utilization. However, thermal energy stores do not in their own right save energy, in fact energy and thermodynamic availability is always lost in a storage process. In this regard various methods of storing energy form an important set of "enabling" technologies which increase both the cost effectiveness and energy conservation potential of storage systems. Close review of various storage methods has shown that thermochemical energy storage process in inorganic oxides has the potential to become probably the most effective and economic method of storing and utilizing waste heat. There are however technical and scientific problems such as inadequate heat and mass transfers associated with thermochemical energy reactors, which remain to be overcome. Various related studies have in the past been carried out. For instance Fuji *et al.* [3] experimented on an integrated metal foam reaction bed as supplement to retaining shape of reactant during reaction process, and ultimately to enhance the storage performance. Goetz *et a.l* [4] evaluated the impregnation of reactants in consolidated blocks of natural graphite and observed dynamic limitations of heat transfer in the grains and in the bed. Groll [5] reviewed the operational characteristics of different types of fixed reaction beds and found their performances to be affected by unequal diffusivity of the chemical species and inadequate heat and mass transfers through the reaction beds. Darkwa *et al.* [6-10] have also carried out analytical and experimental evaluation of an integrated fixed bed thermochemical energy reactor but yet to overcome the associated problems. Fluidized beds are considered to be favorable for rapid exothermal reactions due to the large specific surface area available for reaction and short residences times for gas or solids. However, factors such as minimum fluidization velocity (u_{mf}), i.e. the velocity at which fluidization begins, and the velocity at which pneumatic transport begins (i.e. terminal velocity) do influence the performances of fluidized bed. There is also the problem of bubbles associated with $u_{mf,}$ which tend to affect the combined heat transfer coefficient and thus the mode of heat and mass transfers in fluidized beds. Such parameters would therefore have to be considered and incorporated into the system. To this end, a double-acting agitated fluidized bed thermochemical energy storage system is proposed for an analytical investigation.

2. Key Features

The developed model was based on adiabatic condition during adsorption process and therefore the dimensionless heat transfer parameter was taken as zero. However by considering appropriate values greater than zero, the model should be capable of investigating isothermal and non-isothermal conditions. There was no consideration of bubbles in the column hence there was no heat transfer due to convection and radiation. Heat transfer in the axial direction by effective conduction was therefore the dominant mode. The analytical results show how the dimensionless parameter ϕ which is related to the minimum fluidisation velocity (umf), affects moisture concentration and temperature in the reactor during adsorption process. By considering constant overall mass transfer coefficient, higher ϕ value means lower umf value. As shown in Fig. 3 and 4, both moisture concentration in the fluid phase and adsorption capacities were greater for higher ϕ values than the lower values. In Fig. 5, as expected the reaction temperature increased with adsorption capacity until a saturation point was reached. Even though the model was simplified by neglecting temperature distribution in the radial position of each particle, the lowest ϕ value did achieve the highest optimum bed temperature thus indicating the importance of effective diffusivity in adsorption process. During the simulation process the moisture concentration level in the reactor increased from 40% after the first 100 min to a maximum of 86% concentration level at time period 1200 min as illustrated in Figs. 6 and 7. As shown in Figs. 8 and 9, the optimum corresponding temperatures in the reactor were obtained as 39°C and 170°C respectively but were achieved between 0.2 m -1.2 m along the column length and within the same simulation time period.

3. Conclusions

Even though exothermic reaction was slow due to low u_{mf} and inadequate diffusion process it is clear from the results that the potential for achieving optimum adsorption capacities and heat evolution within shorter periods does exist. There is therefore the need to optimize the parameters that influence minimum fluidization velocity which are identified as the particle sizes, the fluid velocity, viscosity and the densities of both fluid and the adsorbent particles. The study has helped to gain insight into column performance in a thermochemical fluidized bed reactor system as well as the establishment of the basis for experimental evaluation.

4. References and Bibliography

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Author's Biography

Dr. Darkwa is a Reader in Sustainable Energy Systems at the Nottingham Trent University, UK and has undertaken number of industrial, EU and Research Council (EPSRC) funded research projects in excess of £4 million. He has been involved in organizing and delivering number of conferences for bodies such as the American Institute of Aeronautics and Astronautics (AIAA) at the International Energy Engineering Conversion Conferences (IEEC 2001-2006) in the USA, and the International Energy Agency (IEA) for the Annexes 10 and 17 events. He is an international member of the Terrestrial Energy Systems Technical Committee for the AIAA and a member of EU energy management expert advisor to the Western Balkan Countries. He also regularly review papers for journals such as Applied Thermal Engineering, Energy World, Power and Energy Journal, Solar Energy and the International Journal for Energy Research. His research interests are in the following areas: Green Transport Technology, Energy Storage in Phase Change Materials, Thermochemical Energy storage systems, Energy modeling, Energy in Buildings, Multi-phase Heat and Mass Transfers, Waste Minimization, Energy, Environment, Renewable Energy Technologies.