KEYNOTE SPEAKER

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CARBON CAPTURE AND UTILIZATION IN SMART URBAN SYSTEMS: A CIRCULAR APPROACH TO WASTE MANAGEMENT

Concurrent treatment of wastes, energy or resource recovery and carbon capture can be realised in advanced Waste-to-Energy (WtE) process facilities. The strategic integration of the three key concepts contribute towards establishing smart urbanization which is sustainble and efficient. This work explores and assesses three different approaches on carbon capture from WtE flue gas through (a) application of advanced metal-organic framework (MOF) sorbents with outstanding stabilities and favorable characteristics for selective CO_2 uptake, potentially enabling their deployment in the temperature swing adsorption (TSA) process; (b) application of a new CO_2 mineralization strategy coupled with resource recovery techniques, electrochemical alkali generation from brine and the treatment of desalination brine for an economically viable integrated process; and (c) application of a CO_2 capture process through high temperature calcium looping process using novel sorbents derived from calcium-rich ashes (incineration bottom ash, incineration or gasification fly ashes), collected from commercial WtE plants and a demonstration scale slagging gasification facility in Singapore.

Metal-organic frameworks (MOFs) are highly effective adsorbent materials because the large surface area, excellent selectivity, high adsorption capacity, tunable porosity, and reversible adsorption-desorption properties, which can be adjusted during synthesis, allows for efficient gas capture, separation, and storage. Typically, the carbon capture process using MOFs involves a cyclic adsorption-desorption mechanism. In this process, MOFs initially adsorb CO_2 from flue gas until equilibrium is reached, after which the captured CO_2 is released through either pressure swing adsorption (PSA) or temperature swing adsorption (TSA). These cyclic processes allow for continuous carbon capture, making MOFs a highly promising material for long-term operation. Although MOFs have shown promising results in environments with high CO_2 concentrations (about 10-30%), challenges arise in scenarios with lower CO_2 concentrations (about 4-12%). Furthermore, the presence of impurities include moisture, SO_2, NO_x, and H_2S in flue gas can cause poisoning of the MOF's active sites, reducing its adsorption capacity and stability. It is important to develop advanced MOF materials and optimize cyclic processes to enable effective and scalable carbon capture in a pilot-scale MSW incineration plant. During the investigation, approximately 120 m^3/h of flue gas (consists of 25 mg/m^3 NO_x, 25 mg/m^3 SO_2, and 4.5% CO_2) from a Waste-to-Energy Research Facility (WTERF) is directed into the carbon capture unit, demonstrated promising performance of the carbon capture system.

Seawater reverse osmosis desalination (SWRO) is a vital technology for low cost and energy requirement water production, but currently produces about 1.4 times of desalination brine discharged into the sea for every cubic metre of SWRO filtrate produced. The desalination brine, also known as concentrated seawater, contains high concentration of magnesium and calcium ions is considered to be a viable source for electrochemically assisted CO_2 mineralisation. In this work, the desalination effect of electrochemistry for simultaneous utilization and treatment of desalination brine (56.0 ± 2.1 g/L) into seawater level (32.0 ± 1.4 g/L) was explored. The results demonstrate chemical self-sufficiency for desalination brine treatment (removing Mg^{2+} and Ca^{2+} to below ppm level), electrochemically recovering chlorine (up to 99% selectivity, and hydrogen gas (up to 97% selectivity), and conversion of desalination brine into reclaimed seawater discharge (RSD). The RSD is further chemically dechlorinated and neutralised to pH 7.3 to be safe to discharge into the sea. The excess alkali brine is used to capture additional CO_2 in the form of bicarbonates achieving net abatement in climate change impact (9.90 CO_2 e/m^3) after product carbon abatements are accounted.

Ashes generated as by-products (or waste residues) of the thermal treatment of waste materials are applied as raw materials for the research study on high temperature calcium looping process (CaL). CaL is a method of post-combustion capture features the use of dual fluidised bed reactor, consisting of; a carbonator and calciner. Incineration bottom ash (IBA), which is the main solid residue generated by the incineration of municipal solid waste (MSW) and gasification fly ash (GFA) was collected from a demonstration scale slagging gasifier at WTERF operated by Nanyang Technological University, Singapore. GFA consists of a mixture of sorbent used for flue gas treatment, particulates and solid residues from the air pollution control unit. The processes and techniques used for pre-treating and converting the ashes to functional sorbents that are subsequently applied in high temperature fluidised bed reactor systems for CO_2 capture by calcium looping are developed. The performance of the ash-derived sorbents is further examined in a hot fluidised bed reactor system in the laboratory.