Feasibility Study of Micro-Nuclear Reactor Thermal Output for Air Rotary Kilns in the High-Temperature Manufacturing of Portland Cement Clinker

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ABSTRACT:

Cement manufacture produces 8% of global anthropogenic carbon dioxide emissions. The process releases CO_2 when the primary raw material, limestone ($CaCO_3$), is converted to lime (CaO); in addition, the CaO undergoes a process called clinkering that requires temperatures close to 1500 ^oC to produce quality cement. These two features, combined with the extensive use of cement, makes the decarbonization of this industry a challenge. The current approach for decarbonization of this industry is two-prong: switch to raw materials that do not release CO_2 when processed and minimizing the combustion of fuels by making the process energy efficient.

The clinkering process is very challenging due to the high temperature, and it would be difficult to substitute combustion. However, in most modern cement plants, the calcination process (the conversion of $CaCO_3$ to CaO) takes place separately in a preheater/calcination tower. Flue gases from the rotary kiln and an additional burner heat the solids to the 900 ^oC, the temperature required for calcination. Out of the plant's total fuel consumption, 70 to 80% goes to the kiln burner and the rest to the burner in the calcinator/preheater unit. It is in this last process unit where an opportunity arises for nuclear microreactors, based on two observations: the calcination temperature is achievable with current core designs, and a single 15 MWth reactor can provide enough energy in the form of heat to replace the calciner burner in a 2000 ton/day cement plant. The microreactor's primary heat exchanger can provide hot air that, when mixed with flue gases from the rotary kiln, would achieve full calcination of the material entering the preheater/calcination unit. The reduction of CO_2 content in the gas current is expected to lower the calcination temperature, reducing the energy requirement of the process even more.

The present proposal will answer the following questions regarding the use of a microreactor:

- Are calcination kinetics affected by the operation with a gas current containing less CO_2? Will this change in operating conditions affect the quality of the final product?
- Can the volume of air required for operation be heated to the target calcination temperature?
- What are the investments, risks and payoffs associated with providing heat of nuclear origin?

To get answers to these questions, project personnel will perform pertinent laboratory studies on heat transfer and calcination chemistry; data obtained from these studies will be used to design the microreactor's primary heat exchanger, making sure the design is compatible with an existing production facility located in Nazareth, PA which will be used as the case study. A techno-economical optimization will be performed to show if the substitution of the calciner burner with a nuclear microreactor translates into economic benefits for cement plant operators while helping them achieve their sustainability goals.