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A SYSTEM DESIGN FOR CO2 CAPTURE WITH HYDROGEN AND METHANOL PRODUCTION IN A CEMENT PLANT

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I. INTRODUCTION

Engineers and scientists strive to develop creative and groundbreaking solutions to address the pressing challenges of climate change and increasing global energy demands [1]. The cement industry is a substantial contributor to global CO_2 emissions, accounting for about 8% of the total [2]. In addition to its impact on global warming, this industry also poses a risk of terrestrial and marine ecotoxicity and abiotic depletion [3]. Although efforts have been made to incorporate geopolymers in concrete to enhance sustainability, conventional concrete is still more widely used [4]. The construction industry is predicted to fuel cement production growth, with estimates projecting an increase of 12-23% by 2050 [5]. In the production of cement, the majority of the CO_2 emissions are associated with the manufacturing of clinker. To create clinker, a combination of limestone, which serves as a calcium source, and other substances such as aluminium, silicon, and iron in the form of clay and sand is crushed and ground. This precalcined mixture is then heated to approximately 1450 ◦C in a rotary kiln and converted into calcium aluminate, calcium ferrite, and other compounds [6]. This mixture is referred to as clinker and is subsequently combined with gypsum to produce cement. The chemical reactions involved in this process can be summarized as follows: clay decomposition, dolomite decomposition, calcite decomposition, and alumina's reactions with various oxides. Both the breakdown of calcite and dolomite as well as the interaction of alumina with different oxides result in the formation of CO_2. Its production can also result from other chemical events like sintering. Numerous techniques have been developed to lower CO_2 emissions, such as the calcium looping method, which can extract up to 98% of the gas from flue gas streams. The carbonator and calciner, two fluidized beds, cooperate in this process to separate CO_2. CaO in the carbonator undergoes a reversible chemical reaction with CO_2 in the flue gas to form $CaCO_3$. The following is an explanation of this reversible chemical reaction: $CaO + CO_2 \rightarrow CaCO_3$. The main objective of this study is to meet the fundamental needs of a small residential community in Canakkale, Turkey, by proposing an innovative multigeneration system that generates four beneficial outputs. Along with producing hot water and electricity, the system will also produce important energy carriers including hydrogen and methanol. The community's increased energy needs will be fulfilled by renewable resources, and the methanol will be manufactured using CO_2 gathered from a cement plant's calcium looping technology to improve sustainability. Comprehensive energy and exergy assessments are part of the study's analysis, which assesses how well the system operates in its designated environment

.II. ANALYSIS

The proposed system is analysed thermodynamically to identify the mass flow rates, enthalpies, pressures, and temperatures of flows entering and exiting the system. The exergy destruction rate is determined to locate irreversible losses within each component of the system. The modelling is done using the EES software under specific assumptions, along with the balance equations written for mass, energy, entropy and exergy. The chemical reaction taking place in the methanol reactor is $CO_2 + 3H_2 \rightarrow CH_3OH + H_2O$.

The overall energetic and exergetic efficiencies of the system are determined by

$$\eta_{en,ovr} = \frac{\dot{W}_{net} + \dot{Q}_{HW} + \dot{m}_{H3}LHV_{H3} + \dot{m}_{CH3OH}LHV_{CH3OH}}{\dot{m}_{CO2}h_{CO2} + E_{WT} + \dot{Q}_{Solar} + \dot{Q}_{Fuel}}$$

$$\eta_{ex,ovr} = \frac{\dot{W}_{net} + \dot{Q}_{HW}\left(1 - \frac{T_0}{T_S}\right) + \dot{m}_{H3}ex_{H3} + \dot{m}_{CH3OH}ex_{CH3OH}}{\dot{m}_{CO2}ex_{CO2} + E_{WT} + \dot{Ex}^{\dot{Q}_{Solar}} + \dot{Ex}^{\dot{Q}_{Fuel}}}$$

where $\dot{W}_{net}$ is net power produced by the proposed system and is calculated as

$$\dot{W}_{net} = \dot{W}_{HPT} + \dot{W}_{LPT} + \dot{W}_{Exp} - \dot{W}_{Pump1} - \dot{W}_{Pump2} - \dot{W}_{Pump3} - \dot{W}_{Pump4} - \dot{W}_{Pump5} - \dot{W}_{Pump6} - \dot{W}_{Comp1}. - \dot{W}_{Comp2}. - \dot{W}_{Comp3}.$$

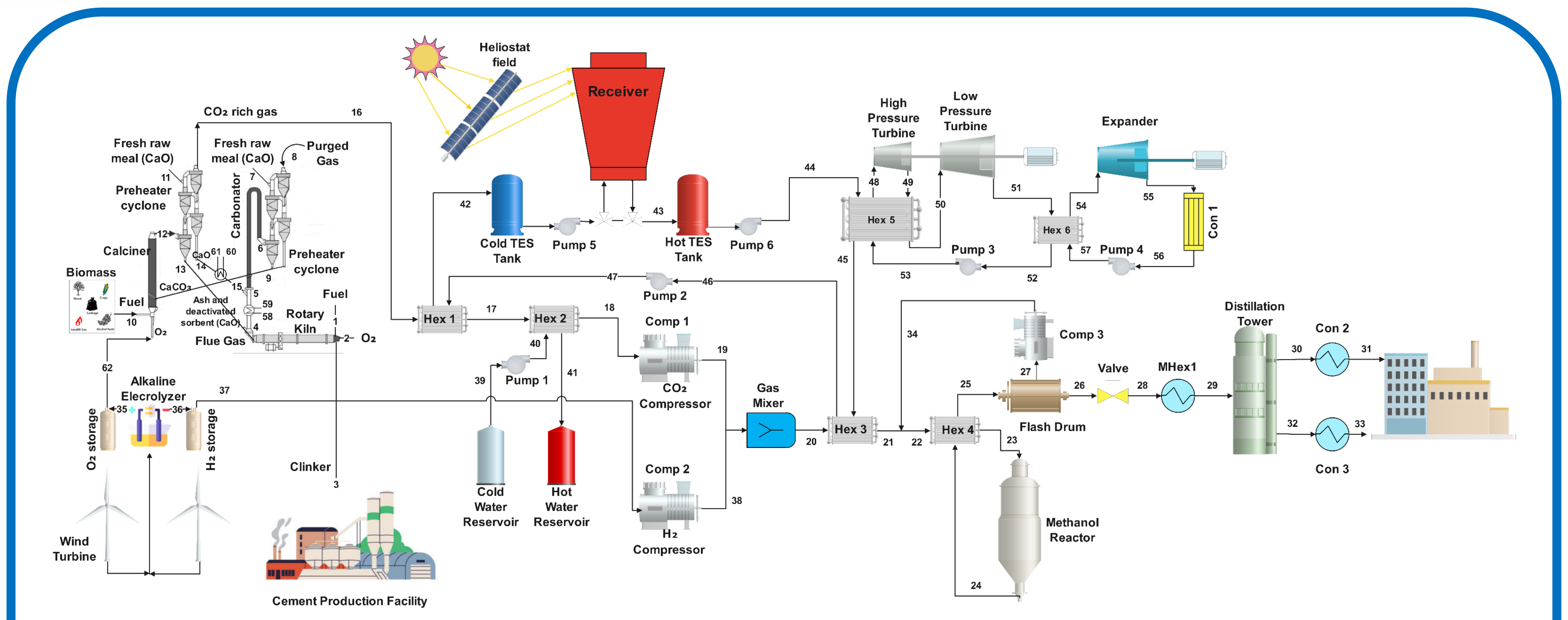

Figure 1. Schematic view of the integrated system proposed for cement plants.

III. RESULTS AND DISCUSSION

As a result, the High-Pressure Turbine (HPT) has a noteworthy exergy destruction of 2625 kW, whereas the Heat Exchanger 5 (HEX5) has the most exergy destruction of 5449 kW. The exergy destructions of the Pump4, Comp3, HEX1, and Comp2 subsystems are found to be 3.29, 4.05, 4.59, and 6.16 kW, respectively. Here it can be seen that HEX5 has the highest exergy destruction and Pump4 has the lowest exergy destruction. A parametric study was conducted to evaluate the performance of the integrated system, taking into account the first and second laws of thermodynamics. The study examined the impact of varying the mass flow rate of carbon dioxide supplied to the integrated system and the effect of changing the ambient temperature on system performance. Fig. 2 show the effect of temperature on the system's energy and exergy efficiencies. As the temperature increases from 263 to 313 K, the energy efficiency improves from 66.42 to 72.86%, exergy efficiency increases from 56.75 to 61.62%. Fig. 3 depicts the impact of varying carbon dioxide input on methanol production. As the carbon dioxide flow rate escalates from 0.01 kg/s to 0.1 kg/s, the corresponding methanol flow rate also ascends from 0.007273 kg/s to 0.07273 kg/s.

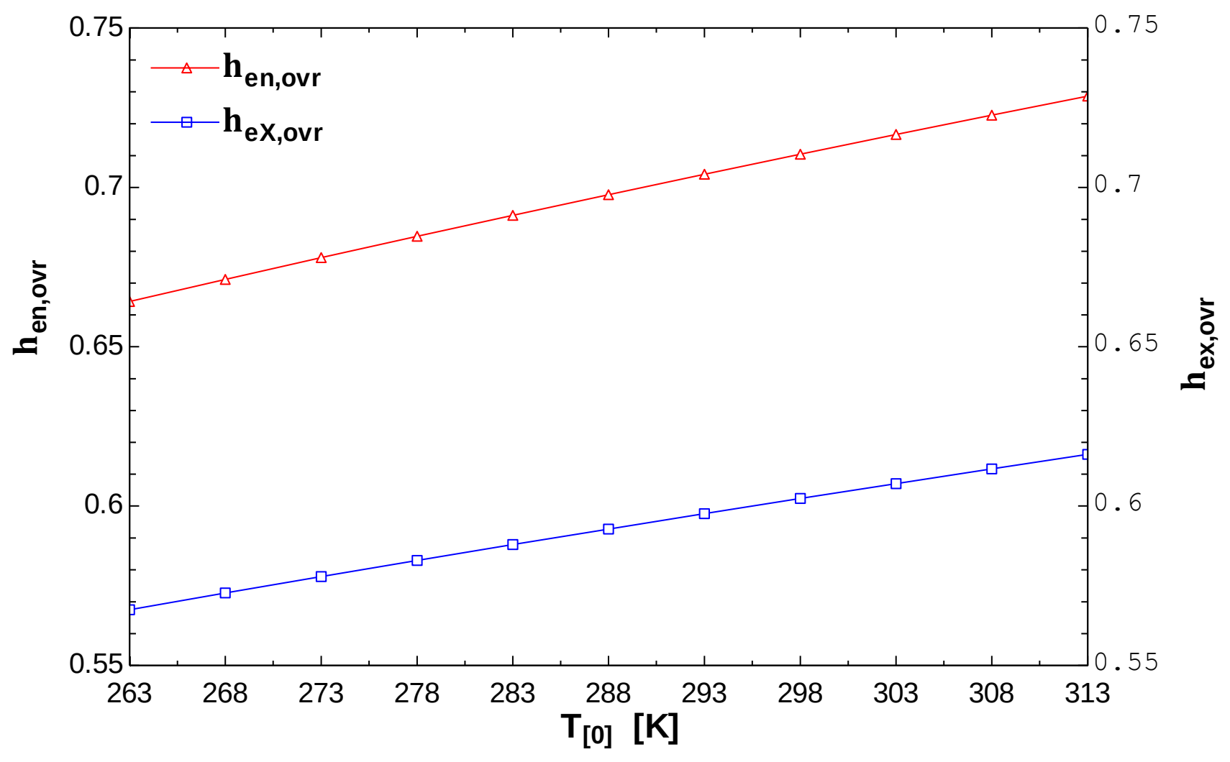

Fig 2. Variation of the ambient temperature with overall efficiencies.

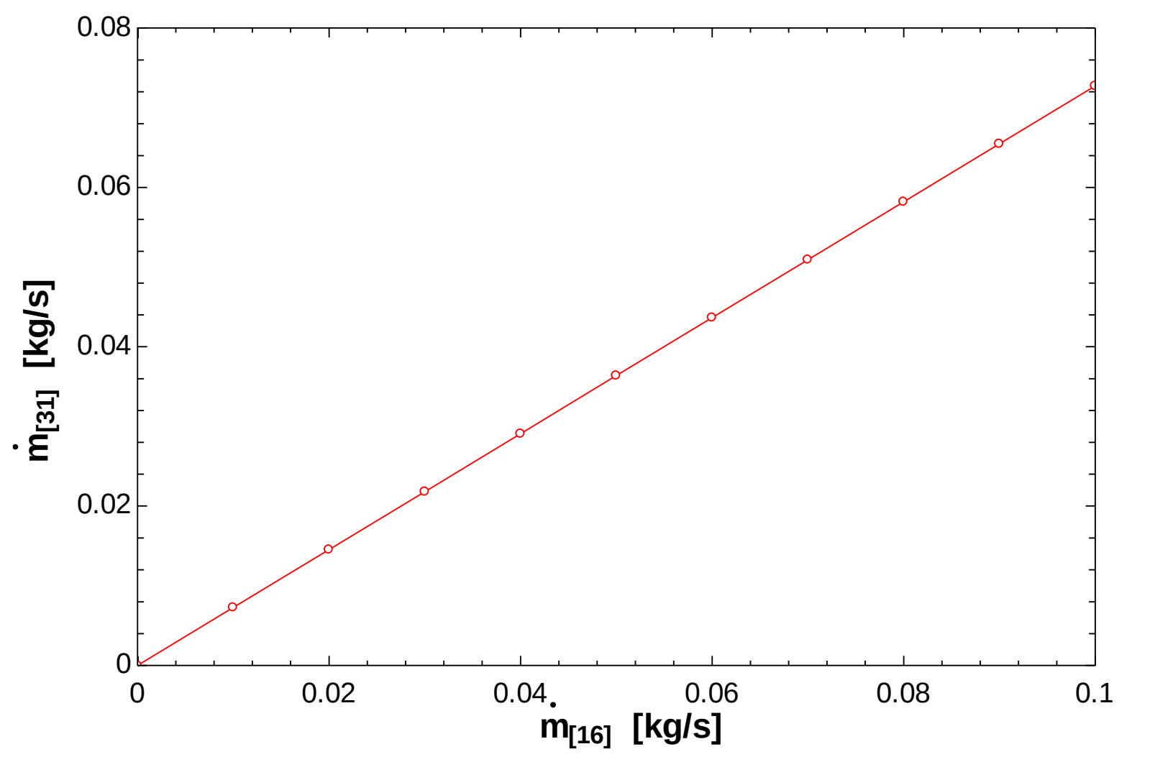

Fig 3. Exchange of supplied carbon dioxide with methanol

III. CONCLUSIONS

The following are the main conclusions drawn from the proposed integrated system for cement plants. Firstly, the net power produced, methanol flow rate, and hydrogen flow rate produced under specified conditions were 5528 kW, 0.04082 kg/s, and 0.002063 kg/s, respectively. Moreover, the produced hot water flow rate was calculated as 0.22296 kg/s. Secondly, the energy efficiency and exergy efficiency of the system were calculated to be 71.26% and 60.42%, respectively. These findings demonstrate the effectiveness of the proposed integrated system for cement plants in terms of power production and energy efficiency.

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