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Role of the Pakistan Cement Industry towards the Achievement of Net Zero Goal by Mid-Century: A Review from a Waste Heat Recovery Perspective †

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Abstract: Owing to high energy-intensive operations, cement production is responsible for global 6–8% of CO_2 emissions and, thus, can be a major contributor in the net zero mission. Pakistan's cement industry can produce 69 million tons of cement per year and has an overall share of 5.3% in economy. One ton of cement production releases approximately one ton of carbon dioxide. Therefore, it is necessary to decarbonize this industry. Two strategies can be employed (waste heat utilization and CO_2 capturing) for the decarbonization of the cement industry. This comprehensive review article is focused on the waste heat recovery potential and the technologies employed to utilize this potential for the cement industry of Pakistan.

Keywords: net zero goal; decarbonization; waste heat recovery; steam Rankine cycle; cement industry; CO_2 emissions; carbon neutralization; solar power generation; multigeneration systems

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1. Introduction

Over the past three decades, a steep incremental trend in carbon dioxide emissions has been observed, which is the main driving factor for global climate change. The two major contributors in CO_2 emissions are fossil fuels and industry. To protect humanity from the dangerous effects of climate change, all stakeholders should create strategies to minimize the CO_2 emissions. The main strategy for CO_2 emissions minimization is the net zero goal. All stakeholders (researchers, scientists, engineers, technologists, and companies) around the globe are increasingly trying to achieve the net zero goal. It simply means the removal of CO_2 as we produce by 2050. Achieving net zero means obtaining equity between greenhouse gases' production and removal from the atmosphere. It can only be operationalized through political, social, and improved techno-economic systems. Net zero has two components, namely, waste heat recovery and CO_2 capturing. This review study will only focus on waste heat utilization from cement production plants in Pakistan.

The net zero strategy is applicable for energy and nonenergy sectors. Despite substantial improvement in the energy sector, the nonenergy industry produces 31% of all process, with combustion CO_2 emissions and essential materials (e.g., steel, iron, cement and lime, nonferrous metals, chemicals, paper, and pulp) being responsible for approximately 22% of global CO_2 emissions over the last few decades [1]. Steel, iron, cement, chemicals and some other sectors have high needs to process heat and chemical reaction emissions, thus are named hard-to-abate industrial sectors. That is the reason these industrial sectors are the big candidates for CO_2 emissions and, thus, waste heat utilization.

Waste gases from cement production plants are usually released at high temperatures and mass flow rates and thus have significant potential for utilization. The quantity of

heat released from the cement production plants to the atmosphere can be a considerable amount of the consumed energy for production process. Power production from waste gas utilization can provide a significant amount of the energy requirement for cement plants and can play a significantly important role in the net zero goal achievement.

Conventional technologies employed globally for power production, by utilizing waste heat from the industrial sector and other sources, are steam-driven Rankine cycles (single flash and dual pressure cycles), organic fluid-driven Rankine cycles [2], and Kalina cycles. Steam-driven Rankine cycles are mostly employed for the utilization of waste heat from cement industries situated in South Asia and Asia because the temperature of the exit gases from the air quenching cooler (AQC) and suspension preheater (SP) is high. Furthermore, the working fluid employed in these cycles is water, which is safe and environmentally friendly. Supercritical CO_2 (sCO_2)-driven Brayton power cycles are the emerging technology for power generation from waste heat. These cycles are beneficial in terms of high thermal efficiency, compact turbo-machinery, eco-friendly attributes, and cost-effectiveness [3,4].

The basic purpose of this review article is (1) to keep an eye on the contribution of the Pakistan cement sector in the net zero goal achievement, (2) to identify the shortcomings in this global cause, and (3) to propose a methodology which can fulfill the shortcomings in the decarbonization of the Pakistan cement industry.

2. Materials and Methods

The Pakistan cement industry's energy consumption is approximately 11% of the total industrial energy consumption in Pakistan. Depending on the technology and the age of cement production units, the average annual electricity consumption lies between 90 and 130 kWh. Out of 25 existing cement production plants (with 50 production lines), 11 waste heat recovery (WHR) systems are installed, possessing a worth of more than 110 MW capacity. The remaining waste heat utilization potential from the cement industry is 100–200 MW [5].

2.1. Recent Developments in the Cement WHR Sector of Pakistan

Researchers are continuously proposing solutions for the betterment of the Pakistan cement WHR sector. Ali et al. [6] used back propagation neural networks to predict the power of the waste heat utilization system of a Attock Cement Pakistan Limited and compared the results with the actual WHR cycle that was thermodynamically analyzed. Their results show 19.75% thermal efficiency and 10.06 MW power generation. Most significantly, the comparison of the actual WHR cycle and the predictive model concluded that data science is a strong alternative for thermodynamic modeling to evade hefty calculations.

2.2. Bestway, the Pioneer Cement Industry of Pakistan in Carbon Neutralization

Bestway is the largest cement production group in Pakistan with five production sites and eight production lines. The production capacity of the Bestway group is approximately 15.3 MT per 300 days. All the sites of Bestway are equipped with solar power generation and waste heat recovery (WHR) plants, which is the biggest step towards the net zero goal. The Bestway group fulfill their 45–50% energy needs through WHR and solar power generation. The Bestway group recently inaugurated its 7200 tpd plant in Mianwali, which fulfills its 50% energy requirement from solar renewable power generation and is hence called the greenfield cement production plant. Details of the Bestway group are enclosed in Table 1 below.

Table 1. Contribution of Bestway cement group for net zero goal.

Sr. No.	Bestway Cement Production Sites	Production Lines	Installed Solar Power Capacity	Installed WHR Capacity (MW)	Important Information Related to Solar Installations
1	Mianwali	1	20 MW	9	**Technology:** Roen captive solar energy. **Annual power generation:** 97,992 MWH. **Reduction in levelized cost of energy:** 40%. **Annual CO_2 emissions reductions:** 60,265 tonnes.
2	Hattar	2	6.4 MW	6 (line 1), 9 (line 2)	
3	Chakwal	2	15.2 MW	15	
4	Farooqia	2	14.4 MW	7.5	
5	Kallar Khar	1	14.8 MW	9.8	

2.3. Proposed Methodology for Pakistan Cement Industry Decarbonization

No one can deny the importance of the stand-alone waste heat utilization system; however, for more efficient and intelligent waste heat utilization, a multigeneration/sectorial integration system can be a good solution. These systems can produce multiple outputs at the same time with the same heat source. In this study, the same type of multigeneration system is proposed for the decarbonization of the Pakistan cement industry, i.e., to maximize the power output from WHR system and CO_2 capturing at the same time without disturbing cement production (Figure 1). Table 2 summarizes the installed waste heat recovery technologies for cement plants in Pakistan.

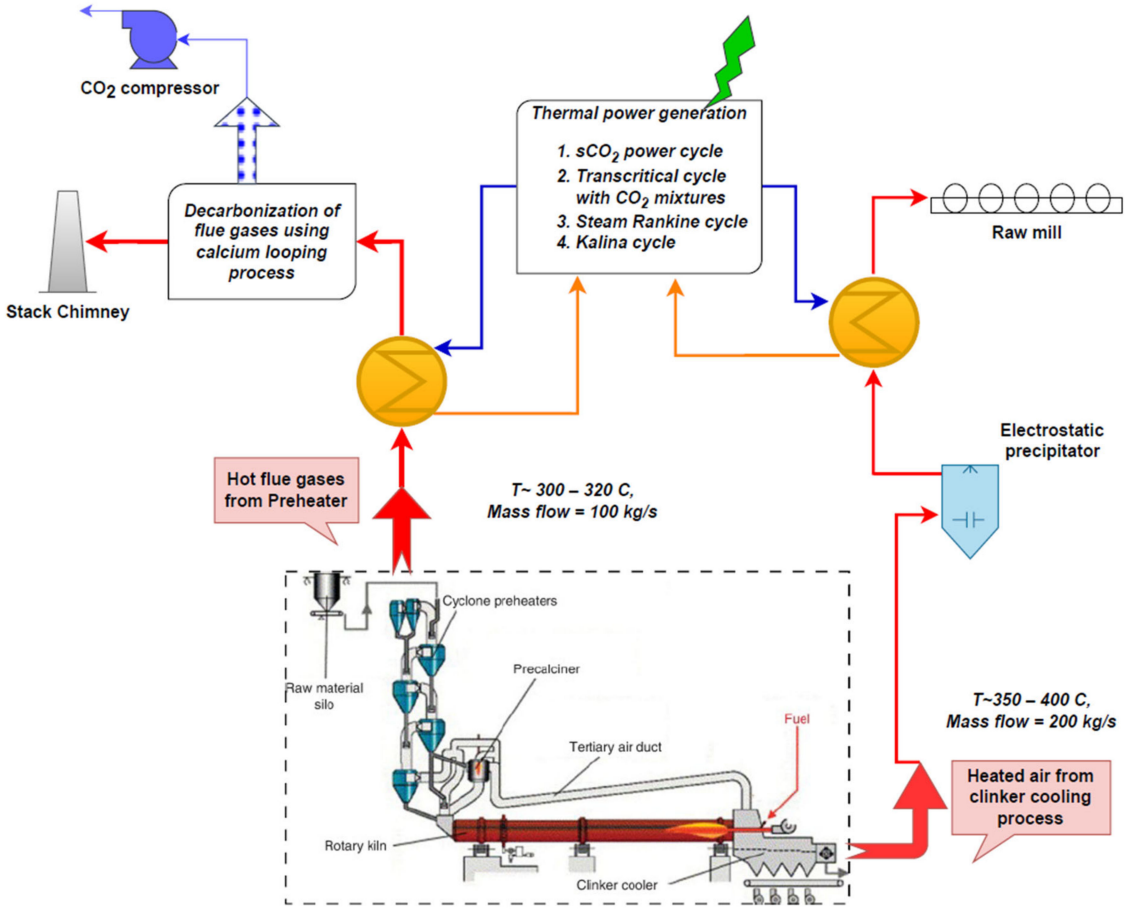

Figure 1. Proposed methodology for Pakistan cement industry decarbonization.

Table 2. Summary of waste heat recovery technologies for cement industries in Pakistan [5].

Cement Industry	Kiln Type/No of Lines/ Capacity (tpd)	Total Installation Cost (USD)	WHR Capacity (MW)	Net Zero Goal in Terms of CO_2 Savings (t/y)	Power Generation (MWh/y)
D.G Cement (D.G. khan Plant)	4/5 stage preheater/2/6700	15 million	10.4	40,332	70,088
(Khairpur plant)	Rotax 2/1/6700	11.8 million	8.5	28,542	61,301
Cherat Cement	Rotary/1/3200	9.3 million	7	25,761	41,730
Attock cement (Hub Plant)	4 × 64 Rotary/2/5200	18.6 million	12	37,908	58,320
Fecto Cement	Dry/1/2600	7.2 million	6	19,584	38,400
Karachi Plant	Rotary/2/6600	9.1 million	10	33,820	58,291
Lucky Cement	Dry/3/9000	12.54 million	15	42,992	87,437

3. Conclusions and Future Recommendations

The purpose of highlighting the waste heat potential of the Pakistan cement industry is to grab the attention of the research community, policy makers and investors in order to create strategies to decarbonize the industry. This can only be operationalized by also considering CO_2 capturing techniques. No CO_2 capturing facility is available for any cement production plant in Pakistan. So, conducting initial research and creating feasibility plans is recommended for the implementation of CO_2 capturing technology retrofit with waste heat recovery technologies for the Pakistan cement industry.

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