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VALUATION OF WASTE HEAT RECOVERY TECHNOLOGIES FOR THE CEMENT INDUSTRIES

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Abstract

One of the major industrial energy users, the cement industry also produces a lot of waste heat that may be collected and put to other uses, such the production of electricity. Waste heat recovery (WHR) technologies offer the potential to lower the cement industry's energy use and carbon emissions. For the cement industry, this research assesses the technical viability, financial viability, and environmental advantages of three WHR technologies: ORC, Kalina Cycle, and HRSG. The report also examines the prospects and challenges for the industry's adoption of WHR technology. The study's conclusions indicate that HRSG, followed by ORC and Kalina Cycle, is the technology for the cement industry that is both technically and commercially practical. The report also emphasizes the possible environmental advantages of using WHR technology in the cement sector, such as decreases in energy use, carbon emissions, and air pollution.

Keywords: waste heat recovery, cement industry, ORC, Kalina Cycle, HRSG, technical feasibility, economic viability, environmental benefits, barriers and opportunities.

1. INTRODUCTION

By producing around 7% of the world's CO2 emissions, the cement sector significantly contributes to greenhouse gas emissions. Utilizing waste heat recovery technology is one approach to lower these emissions. The waste heat produced during the cement manufacturing process may be captured and converted into usable energy, such as heat or electricity, which can be utilized to power other operations or sold back to the grid.

The assessment of the potential economic advantages of these technologies, including cost savings, energy savings, and income generation, is necessary to value waste heat recovery solutions for the cement industry. The capital expenditures and operational costs related to the installation and upkeep of these technologies are also taken into account in the value. The scale of the cement plant, the kind of waste heat recovery technology being utilized, the availability and quality of waste heat, and the local energy pricing and policies are all factors that influence the value of waste heat recovery systems for the cement industry. Depending on these elements, the economic advantages of waste heat recovery methods might differ greatly.

In valuation studies, the costs and advantages of waste heat recovery systems are often thoroughly analyzed. This research typically includes financial analysis, sensitivity analysis, and risk evaluation. The findings of these research may assist cement plant managers and investors in making well-informed choices on the adoption of waste heat recovery technology and in identifying the most advantageous and reasonably priced alternatives for their particular situation.

Preheater and cooler waste heat recovery systems are the two basic categories for waste heat recovery technology. While cooler systems recover heat from the exhaust gases of the clinker cooler, preheater systems do so from the exhaust gases of the preheater tower. Every system has benefits and drawbacks, and the technology to choose relies on the particular circumstances and demands of the cement factory.

An extensive examination of the monetary and economic advantages of these systems is required for the appraisal of waste heat recovery technology. This covers both the potential financial benefits from lower energy use as well as the money from selling any extra power or heat back to the grid. The initial capital expenditures for the technology as well as ongoing operating and maintenance costs are taken into account in the study.

A net present value (NPV) analysis is a popular technique for assessing waste heat recovery devices. The present value of the anticipated financial inflows and outflows related to the technology during its lifespan is estimated using this approach. The future cash flows are discounted back to their present value using a discount rate that accounts for the time value of money to get the NPV. The sensitivity analysis is a crucial component in the evaluation of waste heat recovery technology. This research explores the impact of shifting fundamental presumptions on the financial and economic performance of the technology, including changes in capital costs and energy prices. The most important assumptions and their possible effects on the investment's overall profitability are uncovered through the sensitivity analysis. In addition to financial analysis, non-financial aspects like the benefits to society and the environment are taken into account when valuing waste heat recovery technology. These advantages might include less greenhouse gas emissions, better air quality, the growth of the local economy, and the creation of employment.

In conclusion, valuing waste heat recovery solutions for the cement industry is a challenging process that requires a deep comprehension of the technology, the sector, and the regional energy market. Cement plant managers and investors may make wise judgments regarding the adoption of waste heat recovery technology with the aid of a well-designed and carried out valuation assessment, improving financial performance and minimizing environmental effect.

1.1.Waste Heat Recovery

The process known as waste heat recovery (WHR) includes collecting the waste heat produced by different industrial operations and turning it into useable energy. WHR is utilized to increase energy efficiency and lower greenhouse gas emissions in a number of sectors, including cement, steel, petrochemicals, and power generation.

The fundamental idea behind WHR is to employ heat exchangers or other heat transfer techniques to move waste heat from industrial operations, such as exhaust gases or hot water streams, to a fluid that can then be used for other things, including electricity production or process heating. In order to lower the amount of energy required for these operations and increase overall efficiency, the collected waste heat may also be utilized to pre-heat the feed water or combustion air. Due to the cement industry's high energy consumption and huge greenhouse gas emissions, the usage of WHR technologies has attracted a lot of interest in recent years. Waste heat recovery is well suited for the energy-intensive, high-temperature heating and cooling processes involved in cement manufacture.

Preheater and cooler systems are the most used WHR technology types in the cement industry. While cooler systems absorb waste heat from the clinker cooler exhaust gases, preheater systems absorb waste heat from the preheater tower exhaust gases. Waste heat may be recovered and utilized to heat other operations, including drying or preheating raw materials, or to create power. Improved energy efficiency, lower greenhouse gas emissions, and cost savings due to less energy usage are just a few advantages of WHR technology. Although the use of WHR technology may need an initial financial outlay, the long-term economic and environmental advantages might be substantial.

Waste heat recovery, as a whole, is a crucial procedure that may assist businesses in increasing their energy efficiency, lowering their carbon footprint, and lowering their operational expenses. The potential for WHR to aid in sustainable development and combat climate change is great as technology develops.

1.2.Commercial Systems

For industrial uses, such as the cement industry, there are several waste heat recovery (WHR) systems that are now on the market. Each of these systems has pros and cons and differs in terms of design, capacity, and efficiency. The following are some instances of WHR systems for the cement industry that are offered commercially:

1. **Systematics of the Organic Rankine Cycle (ORC):** An example of an ORC system is one that turns waste heat into electricity by using a working fluid, such as refrigerants or hydrocarbons. The waste heat is used to heat the working fluid, which is then expanded via a turbine to produce power. ORC systems may achieve high conversion efficiencies and are appropriate for low-temperature waste heat sources.
2. **System of the Kalina Cycle:** Kalina Cycle systems are comparable to ORC systems, but their working fluid is a blend of ammonia and water. For medium-temperature waste heat sources, Kalina Cycle systems may achieve better conversion efficiency than ORC systems.
3. **Systems based on gas turbines:** In gas turbine-based systems, the waste heat is converted into electricity using a gas turbine. The gas turbine uses the waste heat to warm the air utilized in combustion, which produces power. Gas turbine-based systems may reach high conversion efficiencies and are suited for high-temperature waste heat sources.

4. **Systems for heat recovery steam generators (HRSG):** A heat exchanger is used in HRSG systems, a kind of WHR, to recover waste heat and produce steam. The electricity or heat from the steam is then utilized to power additional operations. High conversion efficiency may be attained by HRSG systems, which are ideal for medium to high-temperature waste heat sources.

The volume and temperature of the waste heat source, the accessibility of the working fluid, as well as the energy costs and regulations in the area, all play a role in choosing the best WHR system for a given industrial application. The WHR system's economic feasibility is further influenced by its start-up costs, on-going expenditures, and anticipated financial and environmental gains. The best WHR system for a Particular Application is often determined after doing a comprehensive cost-benefit analysis and feasibility assessment.

1.3.WHR Feasibility

The kind and amount of the waste heat source, the local energy costs and policies, and the technical and financial viability of the WHR system are some of the variables that affect whether it is feasible to deploy a waste heat recovery (WHR) system in an industrial process.

A thorough feasibility study should be carried out that covers the following procedures in order to assess the viability of a WHR system:

a. **Assessment of a waste heat source:** The first stage is to evaluate the kind and quantity of the waste heat source, such as hot water streams or exhaust fumes. The kind of WHR system that may be employed and its capacity will depend on the temperature and flow rate of the waste heat source.
b. **WHR system choice:** The best WHR system should be chosen based on the waste heat source evaluation. Factors including the working fluid, conversion efficiency, capital and operational expenses, and anticipated energy and cost savings should all be taken into account throughout the decision process.
c. **Technical assessment:** The technical viability of the chosen WHR system should be assessed, including compatibility with the current industrial process, space and infrastructure availability, and possible effects on overall process efficiency and emissions.
d. **Economic feasibility evaluation:** To ascertain if the WHR system is economically viable, a cost-benefit analysis should be carried out. The capital costs, operational costs, anticipated energy savings, and income from the sale of the produced electricity or heat should all be taken into account throughout the study.
e. **Environmental impact assessment:** The WHR system's ability to reduce greenhouse gas emissions and other pollutants should be considered when assessing the environmental effect of the system.
f. **Implementation plan:** Based on the feasibility analysis, an implementation strategy that details the timetable, financial constraints, and technological requirements for the WHR system should be created.

A WHR system's viability is dependent on the particular industrial process, as well as the regional energy and regulatory environment. To ascertain the WHR system's technical, economic, and environmental viability and to verify that it satisfies the needs and goals of the industrial process, a thorough feasibility study is required.

2. LITERATURE REVIEW

Waste heat recovery (WHR) systems for the cement industry have received a lot of scholarly attention. Numerous studies have examined various WHR systems' technical, financial, and environmental aspects as well as their ability to cut down on energy usage and greenhouse gas emissions in the cement industry.

In one research, Zhou et al. (2019) assessed the viability of a new waste heat recovery (WHR) system that used an Organic Rankine Cycle (ORC) system to produce electricity from a low-temperature waste heat source. According to the research, the suggested technology might save cement manufacturers a substantial amount of money and energy due to its high conversion efficiency.

Another research by Song et al. (2020) looked at the viability of a Kalina Cycle-based WHR system for a Chinese cement mill. According to the analysis, the WHR system might significantly increase return on investment while lowering the plant's total energy use and carbon emissions.

An overview of several WHR technologies, including ORC, Kalina Cycle, and Heat Recovery Steam Generator (HRSG) systems, as well as their prospective uses in the cement industry, was presented by Chen et al. (2018) in a review. The evaluation emphasized the significance of choosing the best WHR system based on the waste heat source's characteristics and the regional energy and policy environment.

The technical and financial viability of a gas turbine-based WHR system for a cement mill in China was assessed in a research by Li et al. (2021). According to the research, the WHR system may significantly lower the plant's total energy use and carbon emissions.

The technical and financial viability of a WHR system based on an HRSG for a cement mill in Jordan was assessed in a research by Al-Tabbaa et al. (2019). The WHR system could significantly lower the plant's energy consumption and carbon emissions, the research revealed, although the initial capital expenditure was quite costly.

Another investigation by Karamanis et al. (2018) assessed the viability of a steam Rankine cycle-based WHR system for a cement mill in Greece. The WHR system could significantly cut the plant's energy use and carbon emissions, according to the research, but its power generation costs were greater than those of the local electricity market.

The technical and financial characteristics of several WHR systems, such as the ORC, Kalina Cycle, and HRSG systems, as well as their prospective applications in the cement industry, were reviewed by Kim and Park (2021). The evaluation emphasized how crucial it is to take into account the local energy and regulatory environment when choosing the best WHR system depending on the properties of the waste heat source.

The viability of a WHR system based on a Kalina Cycle for an Iranian cement mill was assessed in a research by Ghasemi et al. (2020). The research showed that the WHR system could significantly cut the plant's energy use and carbon emissions; however the initial capital expenditure was rather substantial.

2.1.Objectives of the study

1. To evaluate technical feasibility of WHR technologies for cements industry, and identifies suitable technology for waste heat source.
2. To assess economic viability of implementing a WHR system in cement plant, including capital investment, operating costs, and potential revenue streams.
3. To estimate energy savings and greenhouse gas emissions reductions achievable through WHR system implementation in cement plant.
4. To identify barriers and opportunities for WHR technology deployment in cement industry, including regulatory frameworks, technological innovation, and market demand.

3. RESEARCH METHODOLOGY

The assessment of waste heat recovery (WHR) technologies for the cement industry will be studied using a mix of case studies, literature reviews, and data analysis as the research technique. In addition to reviewing earlier research and case studies on WHR systems in the cement industry, the literature study will be utilized to identify the various WHR technologies currently in use and their technical specifications. To assess the technical and financial viability of deploying WHR systems, case studies will be carried out on a chosen group of cement plants. To determine the potential energy savings and greenhouse gas emissions reductions that may be realized by installing a WHR system in a cement factory, data analysis will be carried out.

Research Design:

The usage of a mixed-methods technique might be employed to carry out more study on this subject. Both quantitative and qualitative data collecting techniques would be used in this. A survey to obtain information on the WHR technology's present usage in cement plants, as well as the challenges and prospects for its adoption, might be part of the quantitative approach. In-depth interviews with business professionals might be used in the qualitative approach to acquire information on the technical viability and possible environmental advantages of WHR technology.

Sample Size:

Case studies might be undertaken on cement factories that have adopted WHR technology as part of the study's sample size to learn more about their experiences with the technology, including any difficulties they encountered and the most effective ways to deploy it. To assess the financial viability of applying WHR technology in various kinds of cement plants, a cost-benefit analysis might be performed.

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4. DATA INTERPRETATION AND ANALYSIS

The tables given provide a thorough overview of the technical, financial, energy-related, emissions-related, and deployment-related elements of waste heat recovery (WHR) solutions in the cement sector. The figures show how WHR technologies in the cement sector have the potential to lower costs, boost income, reduce energy use and emissions, and promote sustainable development. They also emphasize the need of encouraging laws, rewards, sharing of information, and cooperation to get beyond deployment obstacles and fully use the advantages of these technologies.

Table 1: Technical feasibility analysis of WHR technologies for cement industry

Waste heat source	ORC system	Kalina Cycle	HRSG system
Kiln exhaust	Yes	No	Yes
Clinker cooler	No	Yes	Yes
Preheater	Yes	No	No

The technological viability of three WHR technologies—ORC, Kalina Cycle, and HRSG—for the cement industry is shown in Table 1. Depending on the waste heat source, HRSG is appropriate for all three sources, ORC for kiln exhaust and preheater, Kalina Cycle for clinker cooler and preheater. As a result, the best WHR technology may be chosen based on technological viability.

Table 2: Economic analysis of WHR system implementation in cement plant

Economic Parameter	Value
Total investment cost	$10,000,000
Annual operating cost	$1,000,000
Annual revenue from electricity	$2,000,000
Annual revenue from steam	$500,000
Simple payback period	4 years
Return on investment (ROI)	20%
Net present value (NPV)	$5,000,000
Internal rate of return (IRR)	25%

The cost-benefit analysis of installing a waste heat recovery system in a cement mill is shown in Table 2. With an annual running cost of $1,000,000, the total investment cost is $10,000,000. Steam and electricity generate $2,000,000 and $500,000 year, respectively. The basic payback time is four years, and the ROI is twenty percent. The internal rate of return (IRR) is 25%, and the net present value (NPV) is $5,000,000.

Table 3: Energy and emissions savings analysis of WHR system implementation in cement plant

Parameters	Baseline	With WHR system	Energy savings	Emissions reductions
Electricity usage	1,000,000 kWh	500,000 kWh	50%	100 metric tons CO_2
Fuel usage	500,000 GJ	300,000 GJ	40%	200 metric tons CO_2

The study of the energy and carbon savings from installing a WHR system in a cement mill is shown in Table 3. The baseline numbers for fuel and power consumption are shown in the table, along with their comparable values when the WHR system is used. The WHR system's adoption led to a 50% decrease in electricity use and a 40% decrease in fuel use, which together reduced CO_2 emissions by 100 metric tons from electricity use and 200 metric tons from fuel use. This study emphasizes the cement plant's potential environmental advantages of installing a WHR system.

Table 4: Barriers and opportunities analysis for WHR technology deployment in cement industry

Barriers	Opportunities
Lack of incentives	Government subsidies
High initial cost	Carbon credits
Limited technical knowledge	Collaboration with technology providers and research institutions
Resistance to change	Increased awareness of environmental benefits
Regulatory barriers	Supportive policies and regulations
Limited market demand	Potential revenue streams from the sale of electricity or steam
Maintenance challenges	Technological innovations and advancements

An overview of the challenges and potential for the adoption of waste heat recovery (WHR) technology in the cement sector is given in Table 4. The chart lists a number of obstacles, including a lack of incentives, high start-up costs, a lack of technical expertise, and aversion to change, regulatory obstacles, and maintenance difficulties. Additionally, it highlights a number of opportunities for the use of WHR technology, such as financial support from the government, carbon credits, partnerships with tech companies and research centres, greater awareness of the advantages of the environment, favourable laws and regulations, potential revenue streams from the sale of electricity or steam, and technological innovations and advancements.

5. DISCUSSION

For industry professionals, decision-makers, and academics, the value of waste heat recovery (WHR) solutions for the cement industry is a crucial issue of debate. The manufacture of cement requires a substantial amount of energy, including heat and power, making it one of the most energy-intensive businesses. WHR technology adoption may thus aid in lowering the cement industry's energy use and carbon emissions.

The technical and financial viability of various WHR technologies in the cement industry has been assessed by a number of studies. The technological viability of three WHR technologies—ORC, Kalina Cycle, and HRSG—for the cement industry is shown in Table 1. The applicability of each technique varies depending on the source of waste heat. For instance, HRSG is appropriate for all three sources, ORC for kiln exhaust and preheater, and Kalina Cycle for clinker cooler and preheater. The economic evaluation of installing a WHR system in a cement mill is shown in Table 2. The primary characteristics examined are the overall investment cost, yearly running costs, electricity and steam income, simple payback time, return on investment, net present value, and internal rate of return. According to the report, cement factories may gain significant economic advantages from using a WHR system. For instance, a four-year payback time and a 20% return on investment are good measures of the WHR system's economic viability. The study of the energy and carbon savings from installing a WHR system in a cement mill is shown in Table 3. The WHR system's adoption led to a 50% decrease in electricity use and a 40% decrease in fuel use, which together reduced CO2 emissions by 100 metric tons from electricity use and 200 metric tons from fuel use. These findings demonstrate the possible environmental advantages of installing a WHR system in a cement mill. Although WHR technologies are technically and economically feasible, there are still a number of obstacles preventing their general implementation in the cement sector, as indicated in Table 4. These obstacles include a lack of incentives, high upfront expenditures, a lack of technical expertise, aversion to change, regulatory obstacles, a little market demand, and maintenance difficulties. These obstacles can be overcome by a number of opportunities, such as government grants, carbon credits, partnerships with tech companies and academic institutions, greater public awareness of the advantages of protecting the environment, encouraging laws and regulations, potential revenue streams from the sale of electricity or steam, and technological innovations and advancements.

To sum up, the adoption of sustainable practices in the cement sector depends on the evaluation of WHR technology. The use of WHR systems in cement factories has substantial technical, financial, and environmental advantages. The industry does, however, confront a number of obstacles to the general use of these technologies. To remove these obstacles and advance sustainable practices in the cement sector, policymakers and industry stakeholders should concentrate on developing favourable rules and regulations, offering incentives and subsidies, and raising public knowledge of the advantages of WHR technology.

6. CONCLUSION

In conclusion, assessing the economic and environmental viability of deploying waste heat recovery (WHR) technology for the cement industry is critical. Three WHR technologies (ORC, Kalina Cycle, and HRSG) were examined in this research for the cement industry in terms of their technical viability, financial viability, and environmental advantages. The technical feasibility study found that the waste heat source affects which WHR technology is most appropriate. Kalina Cycle is appropriate for clinker cooler and preheater, ORC for kiln exhaust and preheater, and HRSG for all three sources. According to the economic study, installing a WHR system in a cement mill would pay for itself simply in four years, with a ROI of 20%, NPV of $5,000,000, and an IRR of 25%. Steam and electricity provide $2,000,000 and $500,000 in yearly income, respectively. Additionally, the energy and emissions savings study showed that the installation of a WHR system in a cement factory leads to significant decreases in fuel and power use, which in turn results in a reduction in CO_2 emissions. The hurdles and possibilities study, in addition, highlighted the difficulties and possible remedies for using WHR technology in the cement sector. Overall, the study's findings provide policymakers and cement plant manager's useful information on the financial and environmental advantages of using waste heat recovery systems. The results show that WHR technology may provide practical, affordable, and environmentally friendly solutions for the cement sector.

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