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OPTIMIZATION OF THERMAL ENERGY CONSUMPTION IN CEMENT PLANT

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Abstract: This study centers on breaking down the waste heat produced by the cooling of a high-temperature gas profluent from a rotating kiln in a Koderma cement plant. The point is to decide its true capacity for either drying wet natural substance (limestone) or creating power utilizing a Natural Rankine Cycle (ORC). Aspen in addition to V.10 programming is used to perform material, energy, and exergy balances for consistent state conditions. The investigation incorporates an exergo-financial assessment in view of the net present worth (NPV) of the speculation. A responsiveness examination is led by changing the power source temperatures of the hot gases and taking into account different working liquids for the ORC. The outcomes uncover that the most ideal choice is to produce power involving an ORC with Cyclo-Pentane as the functioning liquid. This option accomplishes a greatest power result of 3.77 MW, with a warm productivity of 15.96% and an exergy proficiency of 37.52%. The relating NPV is 0.37 MUSD under economic situations of power and fuel costs. Then again, none of the drying units analyzed in the review yield a positive NPV and are thusly not monetarily reasonable. Be that as it may, the most noteworthy dampness decrease in the solids stream is accomplished when the gases are cooled to a temperature of 120 °C, with a decrease of 5.67%. The chance of incorporating a drying unit following the ORC to additional cool down the gases is likewise examined. In any case, no huge improvement is noticed contrasted with utilizing the ORC alone. At long last, the review investigates the consideration of an inside heat exchanger to upgrade the presentation of the ORC. The recovered cycle setup outflanks the basic ORC, conveying an organization result of 4.1 MW, NPV of 0.42 MUSD, a pace of return of 15.58%, and a recompense season of 6.07 years. This addresses a 8.75% expansion in work yield and 13.51% better financial execution contrasted with the basic ORC setup.

Keywords: Cement production, Clinker, Kiln system, Waste heat recovery, Carbon dioxide emissions

1. INTRODUCTION

The act of getting heat created as a side-effect of modern exercises and utilizing it to deliver power or intensity up different cycles is known as waste intensity recuperation (WHR). As one of the top modern energy shoppers, the concrete business presents a sizable chance for WHR. The heat delivered during the assembling of clinker, the essential fixing in concrete, can be caught in the concrete business utilizing WHR. The calcination of limestone and other unrefined components at high temperatures expected for the assembling of clinker creates a sizable measure of waste intensity.

The concrete business approaches various WHR advances, for example, preheater and cooler frameworks, natural Rankine cycle, and Kalina cycle frameworks. Preheater and cooler systems, which are used to warm up the raw materials and cool the clinker, respectively, recover heat from the cement kiln's exhaust gases. Electricity is produced using the waste heat using ORC and Kalina cycle systems. Cement factories can gain from implementing WHR in a number of ways, including decreased energy use, a decrease in greenhouse gas emissions, and increased profitability. WHR can also assist cement companies in adhering to the increasingly strict environmental laws.
By and large, heat recuperation is a significant innovation for the concrete business and has the ability to significantly aid the sector's attempts to increase energy efficiency and lessen its environmental effect.

1.1. CEMENT

The most well-known building material being used today is concrete. To make concrete, concrete should be joined with water and a total like sand or rock. For the entire absolute people, more than three tons of cement are conveyed year, making it the most consistently involved made perfectly on the planet. Around the world, concrete is involved two times as frequently as any remaining interconnected building materials like wood, steel, plastic and aluminum. None of these various materials can supplant concrete concerning reasonableness, cost, or execution for most applications. Concrete is preferred as a design material because of its sensible gathering costs, ability to be made locally using expeditiously open raw parts, malleability, and uncommon compressive strength. Concrete gives the substantial blend cohesiveness, strength, low penetrability, and phenomenal toughness
Rankine cycle is used in concrete kiln heat recovery performance system. In this thermodynamic cycle, the motive power source (evaporator) converts the liquid working fluid into high pressure steam (power station steam), which passes through the turbine generator to provide electricity. This is the reason for normal nuclear power plants. Condensate from the condenser is returned to the evaporator feedwater siphon to complete a circuit that converts the low-pressure steam released from the turbogenerator back to its liquid state. A waste heat recovery system consists of a turbine, generator, condenser, working fluid cooling system, and a strength exchanger or strength recovery steam generator that transfers heat from the exhaust gas to the internal working fluid. Depending on the service fluid used, there are three major waste strength recovery energy generation advances available (Gibbon 2013, EPA 2012, CII 2009).

Steam Rankine Cycle (SRC)

Water fills in as the functioning liquid in the most famous Rankine cycle strategy for squander heat recuperation power age. This structure incorporates making steam in a waste force evaporator, which then, drives a steam turbine. One of the most settled and most flexible power age structures by and by being utilized is the steam turbine. In the steam heat recovery steam cycle, the functioning liquid (water) is first siphoned to high voltage prior to entering the heat recovery evaporator, as displayed in Figure 1. The hot exhaust from the cycle splits water into high-pressure steam, which expands and cools down to load a turbine and produce mechanical energy to drive a generator. The expanded smoke becomes a denser, lower pressure liquid and returns to the feed water siphon and boiler. The low pressure steam is then sent to the condenser under vacuum conditions. Known as the steam cycle, most waste strength recovery systems used in concrete processing plants often exhibit attendant qualities:

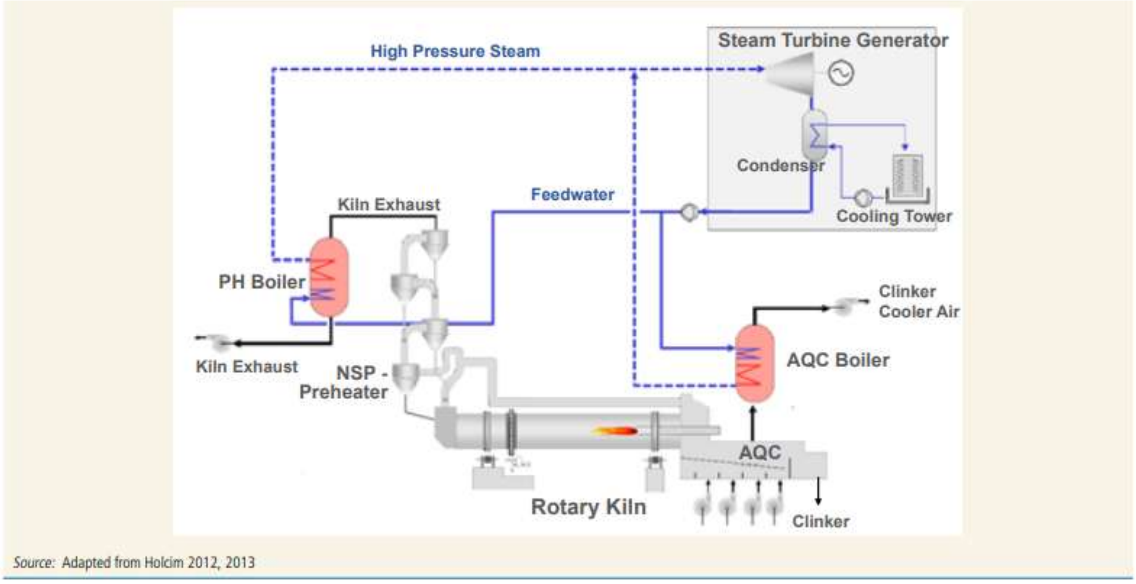

Figure 1: NSP Cement Kiln Waste Heat Recovery System

- Where the source heat temperature surpasses 300 °C (570 °F), the most common and economically preferred materials are those used in the cement industry.
- Widely accessible from a number of sources;
- Based on tested technology;
- Generally easy to use
- On a per-kW basis, generally less expensive to install than alternative Rankine cycle systems.
- For ideal activity, heat dissipation should occur at higher temperatures (>260°C (500°F) or higher). — Aging efficiency drops significantly at low temperatures, and steam conditions with low voltage and temperature can result in slightly thicker steam from the turbine. , can melt the sharp edges of the turbine.
- Subject to applicable regulations, in most cases heat is recovered from the focal point of the flue flow of an air cooler to raise the flue gas temperature to a satisfactory level for the framework; at the cost of not recovering some of the vessel's discard strength
- Usually requires a water-cooled condenser. Air-cooled condenser can be used, but the higher vacuum pressure in the condenser will lower the grade.
- As a rule, enormous ovens and frameworks with little water content in the natural substances function admirably together (higher waste gas temperatures subsequently)

Waste heat recovery power generation system in the cement manufacturing process

Introduction of Steam Cycle Waste Heat Recovery Energy Framework in Concrete Industry is driven by Japanese Organization. At Sumitomo Osaka Concrete, Kawasaki Weighty Ventures (KHI) introduced the principal squander heat recuperation framework in 1980. Starting around 1982, the 15 MW first significant business frameworks have been running at the Kumagaya industrial facility of Taiheiyo Concrete. In 1998, China set up its most memorable framework in a joint effort with a Japanese supplier. More than 700 units were showing in China to 2012 because of government arrangements and Clean Improvement System (CDM) motivators (OneStone Exploration, 2013). Asia is currently the most dynamic market, with Chinese organizations or joint ventures being the main suppliers. Leading manufacturer of waste strength recovery systems using conventional steam cycle innovation presents second generation system with enhanced efficiency and higher supercritical steam limits, capable of delivering up to 45 kWh/t clinker doing.

1.2. Power generation potential from recoverable waste heat

The amount of waste intensity that might be recuperated from a NSP furnace relies upon various factors, including the accompanying:

- How much overabundance air in the furnace; how much air penetration;
- Number and adequacy of preheaters/feed stages.
- Placement of clinker cooler frame ;
- The dampness content of the unrefined substance feed (which decides the intensity prerequisite for the oven and how much preheater exhaust required for drying);

1.3. Objectives of the study

- To analyse the potential use of waste heat obtained from the cooling of a high-temperature gas effluent in a cement plant.
- To Evaluate the feasibility of using the waste heat for either drying wet raw material (limestone) or generating electricity through an Organic Rankine Cycle (ORC).

2. LITERATURE REVIEW

Mirko et al. (2011) gave a purposeful procedure to recognizing and creating waste heat recovery and reuse in modern zones with a few units. The technique at first lays out the types of waste heat that are accessible and their true capacity for reuse while representing the detachments between different plants. The most extreme practicable waste heat recovery for the modern still up in the air by settling an engaged enhancement issue as a simple straight program.

The pyro processing unit of the cement factory was the subject of a thermal energy audit examination by Kabir et al. (2010), which revealed that 95.48% of the unit's total energy input originates from burning fuel. Fuel usage and energy expenditures are crucial for clinker manufacturing's energy management. The kiln exhaust gases and the kiln shell are the primary drivers of nuclear power misfortunes, representing 27.9% and 10.84%, individually. The unit's 41% thermal efficiency is so low that using thermal energy-saving techniques should be seriously considered. Thus, emphasis is placed on the energy audit as a tool for locating possible areas for energy savings.

This "waste to heat" method is thermodynamically better than the flow practice of changing over flammable gas with a high energy content into vent gas at incredibly high temperatures and afterward utilizing it to heat water for space heating, as per Augustine et al's. (2007) research on locale heating systems. This procedure offers a useful method for heating homes and different designs. The proposed plan includes a high-and low-temperature heating system configuration as a component of a coordinated (specialized and institutional) reasonable plan approach for a more vigorous plan.

Soylemez (2003) played out a thermo economic improvement concentrate on heat siphons in drying systems with waste heat recovery and distributed a simple mathematical technique to find the best working boundaries for heat siphons with helper heating that are utilized in drying applications.

Soylemez (2005) fostered a straightforward strategy to lay out the ideal working settings for heat siphons with helper heating utilized in drying applications. The proper working temperatures and ideal part estimates for the heat siphon driven drying system are distinguished to acquire the least life cycle cost. The legitimacy of the enhancement detailing is examined. While developing heat siphon systems for dryers, near this ideal position should be considered.
Ogulata (2004) suggested the use of convection-type drying machines, in which heat and mass transfers occur when hot drying air comes into contact with moist textile materials, in order to dramatically minimize energy consumption during the drying process of textiles.
The energy balance of the roasting process at the coffee roasting factory where Monte et al. conducted their 2003 case study supported the possibility of heat recovery from a high temperature source.
Junhong et al. (2003) played out an examination on a waste heat recovery system that utilizations truck fumes gas to heat bitumen utilized in the activity utilizing heat move oil as the functioning liquid while going to an area for street fix.
The best three cases had genuine, worldwide heat recovery efficiencies somewhere in the range of 60 and 70% for units with a 80% ostensible proficiency, as per Roulet et al. (2001), who directed a hypothetical examination of genuine energy recovery with air taking care of units and introduced the consequences of estimations on 13 modern units. In the three most pessimistic scenario situations, the general productivity was generally 10%. In these conditions, the heat recovery system wastes more energy than it does.

3. MATERIAL AND METHODS

The components for heat recovery in a cement plant are depicted, alongside the models used to extend the general presentation of the Natural Rankine Cycle (ORC) for creating energy utilizing different working liquids. Here is a rundown of the central issues examined in every subsection:

3.1. The Organic Rankine Cycle for the production of power

- The Natural Rankine Cycle (ORC) is viewed as great for recuperating waste heat in business settings.
- Alkanes are practical working fluids for high-temperature exhausts, while refrigerants are used in lower temperature applications.
- Four unmistakable working liquids (Pentane, Cyclo-Pentane, R134a, and R1234yf) are surveyed in a straightforward nonexclusive ORC setup.
- Equations are provided to calculate the exergy rate of each stream and the total amount of pumping work.

$$\dot{X}_i = \dot{m}_f[(h_i - h_0) - T_0(S_i - S_0)] \qquad (3.1)$$

- Different execution pointers are analyzed, including warm Carnot proficiency, warm productivity, exergetic effectiveness, exergy obliteration factor, energy proficiency, volumetric stream proportion, and size boundary of the turbine.

3.2. Drying unit for limestone

- A drying unit is proposed as an alternative for heat recovery from combustion gases.
- A direct contact rotary dryer is used to reduce the water content of the wet raw material (limestone) until the depleted stream is 10 B C over the dew point.
- Equations are provided for the energy and exergy balance of the drying unit components, including the heat exchanger and the dryer.

$$\dot{Q}_{in} = \dot{m}_{air}(h_{dry} - h_{fresh}), \qquad (3.16)$$

$$\dot{m}_{air} = \dot{m}_{hs}(h_{hs,in} - h_{hs,out})/(h_{dry} - h_{fresh}). \qquad (3.17)$$

$$\dot{I}_{HK} = (\dot{X}_{hs,in} - \dot{X}_{hs,out}) - (\dot{X}_{dry} - \dot{X}_{fresh}). \qquad (3.18)$$

3.3. Models of exergoeconomic costs:

- An exergo-financial examination is led to evaluate the waste heat recovery choices in the cement plant.
- The expense rates for heat, work, approaching and leaving streams, and complete capital venture and activity and support costs are thought of.
- Conditions are given to work out the expense rates utilizing the typical unit cost and the exergy pace of each stream.

$$\sum \dot{C}_e + \dot{C}_w = \sum \dot{C}_i + \dot{C}_q + \dot{Z}_t, \qquad (3.22)$$

- The capital venture costs are annualized utilizing the capital recovery factor (CRF)
- The financial pointers incorporate the expense rates for power age and dry strong stream, exergy obliterated esteemed as fuel, and the exergoeconomic factor.

4. RESULT AND DISCUSSION

The evaluation of heat recovery options in terms of energy, performance, and expenses was conducted using the methods described earlier. To get a complete comprehension of the cement plant's heat recovery capacities, a responsiveness study was performed by differing the result temperature of the hot gases from the pre-molding tower. The pivotal factors for the drying unit and natural Rankine cycles (ORCs) at various result temperatures (120 OC, 150 OC, 180 OC, and 210 OC) individually. These tables provide detailed information on the performance parameters relevant to each scenario. To summarize the information related to the overall energy utilization, Figure 2 provides an overview of the energy destruction for each component, considering all the alternatives. This figure offers insights into the distribution of energy losses throughout the system. Besides the fundamental expense pointers for the choices with a positive net present worth (NPV). These indicators help assess the economic viability of the various options. Analyzing the ORCs and drying units separately initially allows for a more practical and easier assessment before reaching a consensus on the economic basis for the heat recovery system. By examining the performance parameters, energy utilization, and cost indicators, the evaluation provides a comprehensive understanding of the potential benefits and drawbacks of each heat recovery option. This analysis aids in determining the most suitable and economically viable approach for the cement plant's heat recovery system.

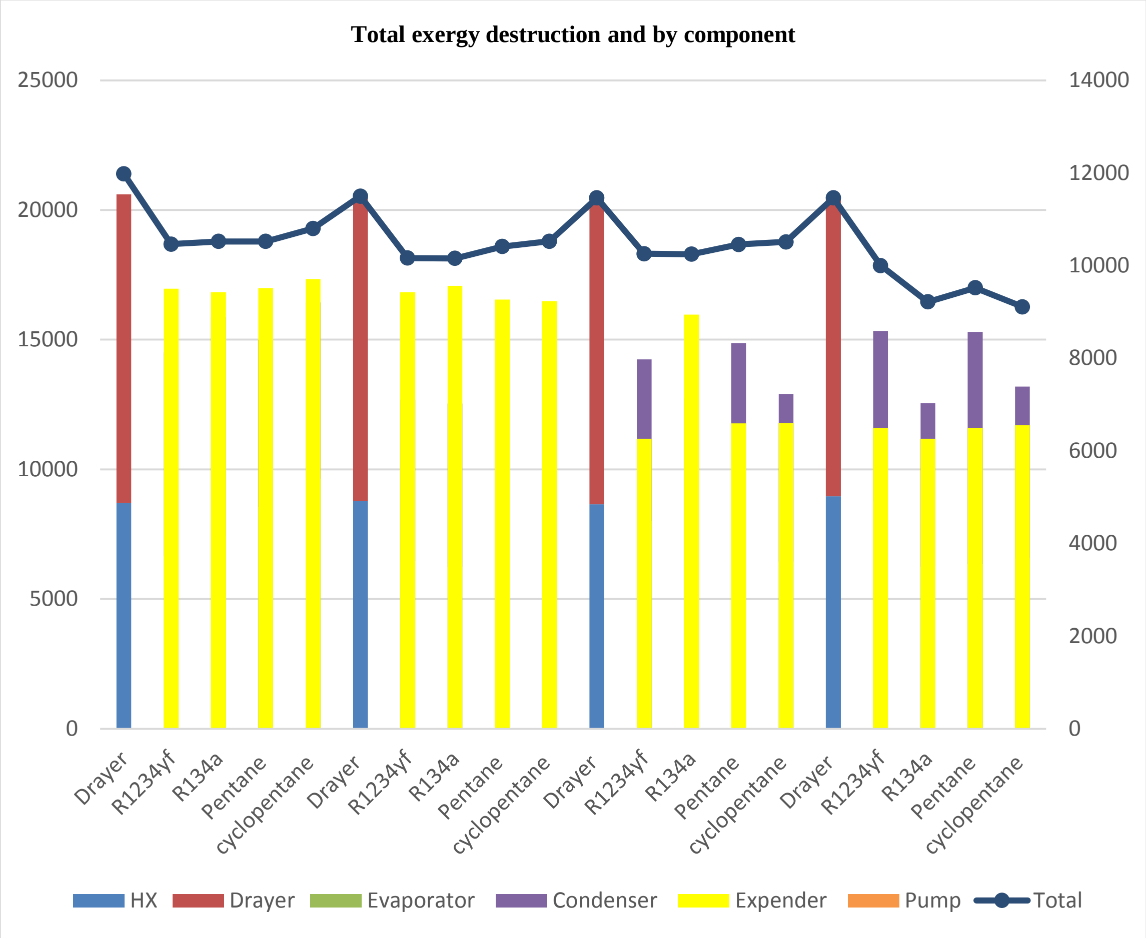

Figure 2: Total exergy destruction and by component

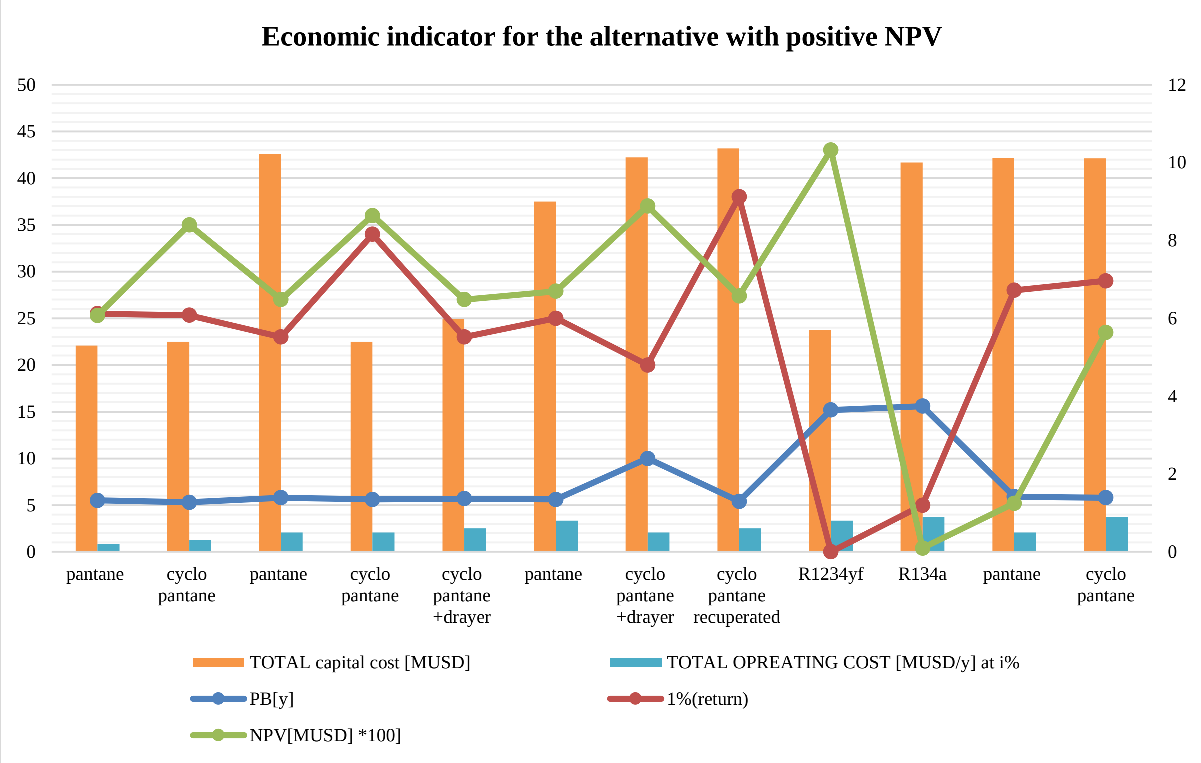

Figure 3: Economic indicator for the alternative with positive NPV

4.1. ORCs:

- Cyclo-Pentane shows the best exhibition concerning warm and exergetic effectiveness, as well as generally speaking exergy annihilation.
- The evaporator consumes the most energy (64.3%), trailed by the condenser (29.2%), expander (5.6%), and siphon (0.85%).
- The ORC operating with cyclo-pentene at a hot gas outlet temperature of T = 210 OC achieves the highest energetic efficiency of 40.54%.
- However, the highest network production of 3.77 MW is obtained at the base scenario temperature of T = 180 OC.
- The exergy obliteration factor (EDF) uncovers that lower values show better system execution and Cyclo-Pentane as the functioning liquid yields the most minimal EDF esteem.
- The volumetric development proportion (VFR) and size boundary (SP) are higher for alkanes than for refrigerants, with R1234yf playing out the best under the given circumstances.

4.2. Drying unit:

- The performance of the drying system is influenced by the absence of moisture, with lower temperatures resulting in less heat used for water evaporation.
- The thermal efficiency of the drying unit is highest at T = 150 OC.
- The rate of water evaporation is highest at T = 120 OC, and the minimal moisture content of solids is reached at this temperature.
- The drying unit incurs the highest costs in terms of exergy generated and lost, which increase as the hot gases' temperature decreases.

4.3. Costs:

- Cyclo-Pentane exhibits the lowest cost of exergy destruction, consistent with its lower exergy destruction in the system.
- The cost per unit of producing electricity is lowest at T = 150 OC.
- The exergo-economic factor (fk) reaches its peak at T = 210 OC.
- Drying units show negative net present values (NPV) due to the lower cost of saved fuel compared to electricity.
- The ORC with cyclo-pentane at T = 180 OC yields the highest NPV value, and considering unlimited capital investment, the option with the highest NPV is the ORC operating at T = 210 OC.
- The addition of a drying unit after the ORCs is not financially viable, but there may be non-measurable advantages such as increasing grinding capacity.

4.4. Complexity and modifications:

- More complex versions of the ORC can be considered, such as incorporating consecutive expansion or multiple preheating steps in the evaporator.
- The transition from a simple ORC to a more complex configuration should be supported by economic and thermodynamic performance.
- The inclusion of an internal heat exchanger (IHE) in a recuperated ORC system improves efficiency and decreases the necessary area for heat exchange.
- A recuperated ORC with Cyclo-Pentane at T = 180 OC achieves an NPV of 0.42 million dollars, a return of 15.58%, and a payback period of 6.07 years, while producing 4.1 MW of power.

5. CONCLUSION

All in all, the review researched the expected use of waste heat from the cooling system of a high-temperature gas pro-fluent in a Colombian cement plant. The goal was to decide its attainability for drying wet unrefined substance or producing power utilizing a Natural Rankine Cycle (ORC). The examination utilized material, energy, and exergy balances, as well as reproductions in Aspen In addition to programming. The outcomes demonstrated that using the waste heat for power age through an ORC ended up being the most practical choice. The best-performing design accomplished a greatest power result of 3.77 MW with a warm productivity of 15.96% and an exergy proficiency of 37.52%. Cyclo-Pentane was recognized as the ideal working liquid. Be that as it may, the drying units for wet natural substance didn't yield positive net present qualities (NPV) and were considered financially impractical. A resulting examination of setting a drying unit after the ORC system likewise showed no significant improvement over utilizing the ORC alone. To upgrade the ORC system's presentation, the review investigated the consideration of an inward heat exchanger, which brought about a recovered cycle beating the less complex setup. The better ORC design accomplished 4.1 MW of organization with a NPV of 0.42 MUSD, a pace of return of 15.58%, and a restitution season of 6.07 years. This addressed a critical improvement in both work yield and monetary execution contrasted with the straightforward ORC system.

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