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“Exploration & Optimization of Waste Heat Recovery In Tunnel Kiln Furnace Using Shell & Tube Heat Exchanger – A Review”

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Abstract

This review explores the potential of waste heat recovery (WHR) in tunnel kiln furnaces through the implementation of shell and tube heat exchangers. Tunnel kiln furnaces are extensively utilized in various industries, including ceramics, cement, and metallurgy, for the continuous firing of products at high temperatures. However, a significant portion of the energy input is lost as waste heat through the flue gases discharged from these furnaces. This review investigates the feasibility and effectiveness of employing shell and tube heat exchangers to recover this waste heat and utilize it for various applications, such as preheating combustion air, water heating, or electricity generation. The review examines various aspects including the operating principles of shell and tube heat exchangers, design considerations, heat transfer mechanisms, materials selection, and case studies highlighting successful implementations of WHR systems in tunnel kiln furnaces. Additionally, challenges and limitations associated with WHR systems are discussed, along with potential solutions and future research directions to enhance the efficiency and viability of waste heat recovery in tunnel kiln furnaces. Overall, this review provides valuable insights for researchers, engineers, and industry stakeholders interested in implementing WHR systems to improve energy efficiency and reduce environmental impact in tunnel kiln furnace operations.

Keywords: Waste heat recovery, Waste Heat Recycling, Waste Heat Stream, STHE, Process Furnace, and Technology Advances.

Introduction

In the pursuit of sustainable industrial practices, the recovery and efficient utilization of waste heat represent paramount significance. Among various industrial processes, the tunnel kiln furnace stands as a notable consumer of energy, where significant amounts of heat are often lost as waste. However, the integration of waste heat recovery systems, particularly employing Shell & Tube Heat Exchangers (STHE), presents a promising avenue to mitigate such losses and enhance overall energy efficiency.

This review embarks on a comprehensive exploration of the state-of-the-art techniques and optimization strategies concerning waste heat recovery in tunnel kiln furnaces. By delving into existing literature, this review aims to elucidate the fundamental principles, technological advancements, challenges, and opportunities associated with the utilization of STHE systems for waste heat recovery in tunnel kiln operations. The significance of this considerable point is underscored by the dual imperatives of reducing energy consumption and minimizing environmental impact within the industrial sector. By harnessing previously dissipated thermal energy, not only can operational costs be mitigated, but also greenhouse gas emissions and reliance on finite energy resources can be curtailed.

Furthermore, this review seeks to elucidate the multifaceted considerations involved in the optimization of STHE-based waste heat recovery systems. From thermal efficiency enhancements to economic viability and operational feasibility, a holistic approach is imperative to realize the full potential of such endeavours. Through a synthesis of empirical findings, theoretical frameworks, and practical insights, this review focused to offer a comprehensive understanding of the challenges and opportunities inherent in the exploration and optimization of waste heat recovery in tunnel kiln furnaces utilizing Shell & Tube Heat Exchangers. Moreover, it aims to delineate pathways for future research and development points aimed at fostering sustainable industrial practices and mitigating the adverse impacts of climate change.

Using an additional heat exchanger with potential of heat recycling to enhance the efficiency of pneumatic conveying systems in the graphite manufacturing industry. The coefficient of performance (COP) improves by up to 75.2%, with downtime reduced by 75%, leading to a 23.7% increase in the availability of pneumatic conveying. Additionally, there is a reduction in the cost of steel pipe material by up to 66.67% and labor cost by 90%. The effectiveness of the heat exchanger is found to be 63.51%, with a heat transfer rate of 16.907 KW [1]. The present article delves into advancements in the field of heat exchangers, focusing particularly on design and optimization. It provides concise yet informative details about existing constraints before delving into the discussion on advancements. Financial and operational constraints affecting heat exchanger performance are analyzed; making it easier to identify barriers to development. The primary focus of the study is on three main advancements: phase change material cooling technology, twisted heat exchangers, and micro plate heat exchangers. A comparison between these innovations and traditional heat exchanger technology reveals specific advantages. These advancements show improvements in efficiency and reduced power consumption. By observing the specific design configurations, environmentally friendly and economically viable changes in the heat exchanger field are identified [2, 17, 18].

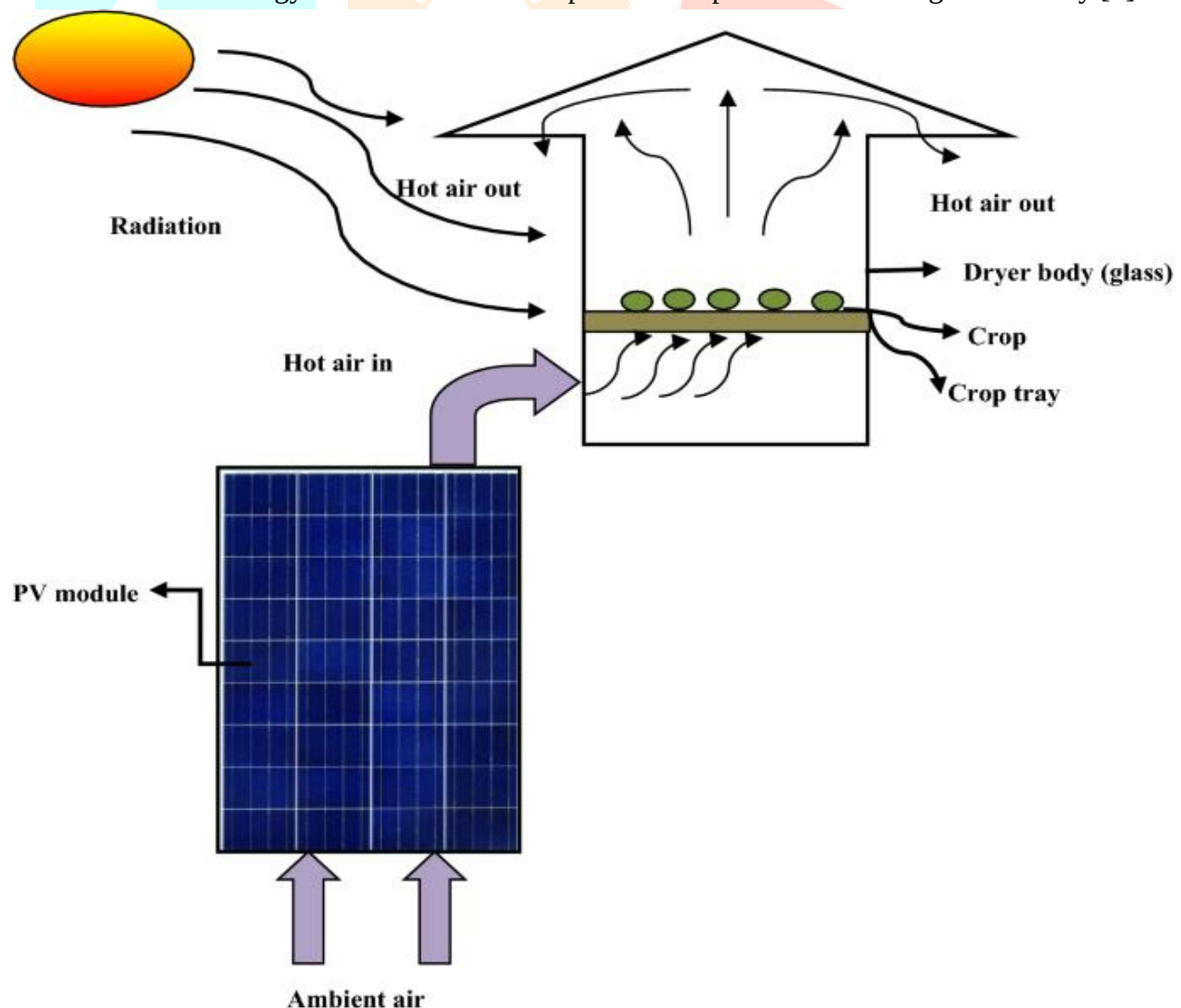
Recent advancements have focused on enhancing heat exchangers in terms of design, analysis, and optimization. Many of these improvements aim to make heat exchangers more flexible and scalable, while also boosting their efficiency and effectiveness. These advancements involve developing better materials, employing advanced mathematical models to enhance current designs, and exploring new applications for modern computer-aided design systems [3]. Engineers utilize mathematical models to examine the geometry and performance of heat exchangers under various conditions. Additionally, designers are

increasingly utilizing waste heat from industrial processes and renewable energy sources such as solar power to improve heat exchanger efficiency [4].

Literature Survey-

The primary criterion in designing a waste heat recovery system is selecting the appropriate heat exchanger under optimal conditions. In this study, the goal is to capture heat from exhaust gas and store it in a storage tank. This can be achieved either by placing the heat exchanger coil surface inside the storage tank where the storage material is present, allowing exhaust gas to pass through the coil, or by using a separate heat exchanger. In the latter case, a heat transfer fluid (HTF) is circulated to extract heat from the exhaust gas and transfer it to the storage medium in the Thermal Energy Storage (TES) tank. The storage fluid itself can serve as the heat transfer fluid, or a separate one can be used to transfer heat from the exhaust gas to the storage medium. [5]. A new heat recovery exchanger is suggested to capture heat loss from the kiln shell. A multi-objective optimization model is developed to balance heat transfer rates and design parameters. The optimal design parameters for the new heat recovery exchanger are determined. Economic analyses for a practical heat recovery system are outlined [6].

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Greenhouse dryer integrated with PV/T air collector [3]

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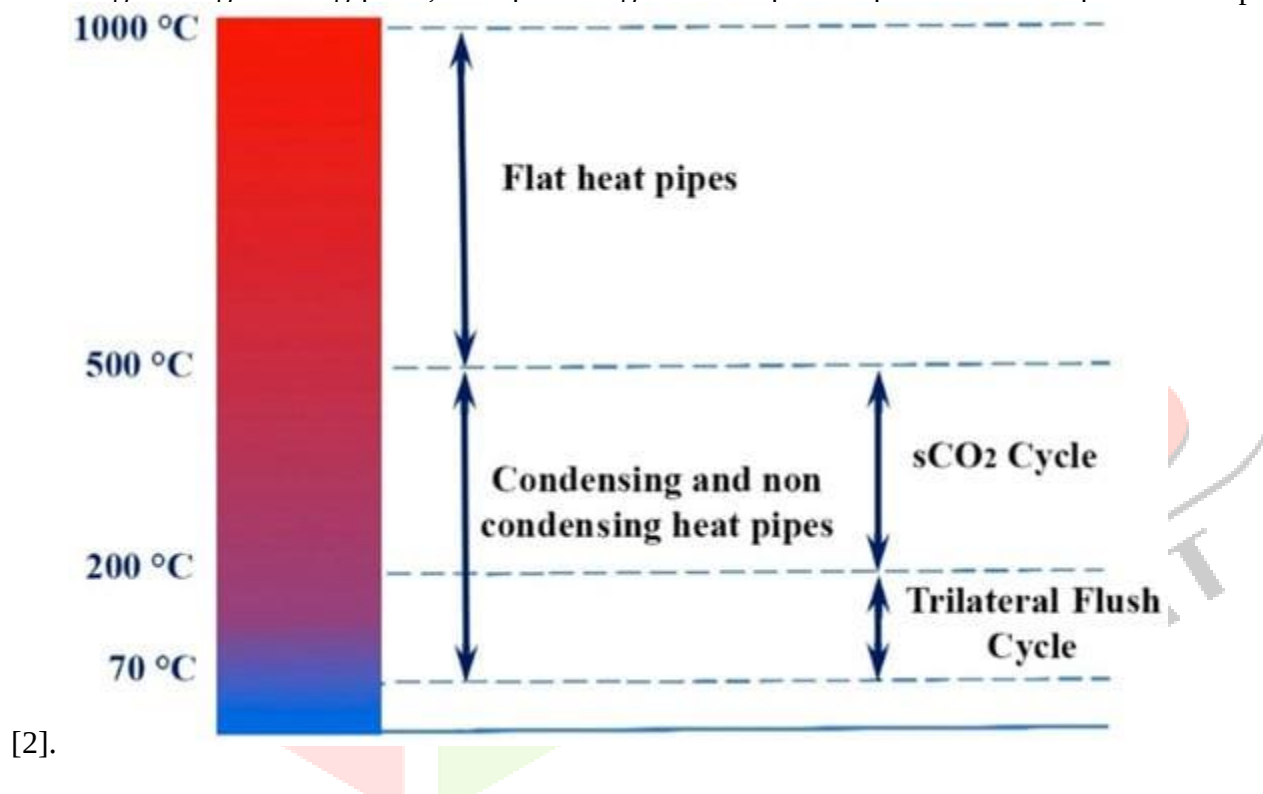


Figure 1. Heat recovery range and technologies in I-ThERM [4]

Quantity of waste heat in the exhaust gas

The quantity of waste heat present in exhaust gas primarily relies on factors such as its mass flow rate and enthalpy, as outlined in the following equation [7]

$$\dot{Q}_{ex} = [\dot{m} h(t)]_{ex} = \dot{m}_{ex} \sum_i (x_i h_i(t))_{ex}$$

where, $\dot{Q}_{ex}$ represents the rate at which the exhaust gas waste heat is lost (kJ/s); $\dot{m}_{ex}$ represents the flow rate of the exhaust gas (kg/s); $h(t)$ is the exhaust gas enthalpy as a function of temperature (t); x_i is the mass fraction of the exhaust gas species, and $h_i(t)$ is the enthalpy of each species in the exhaust gas as a function of temperature (t).

In order for heat transfer and subsequent recovery to occur, it is imperative that the temperature of the waste heat (WH) source surpasses that of the WH sink. The extent of the temperature differential between the heat source and sink, denoted as ΔT , holds significant sway over the quality of waste heat. Consequently, ΔT directly impacts the rate at which heat is transferred per unit surface area of the recovery apparatus. This factor plays a pivotal role in determining the most suitable type of Waste Heat Recovery (WHR) technology to deploy for specific applications[8,9].

Waste heat recovery classification, barriers, and possible solutions-

Waste Heat Recovery (WHR) encompasses four primary domains: energy recycling within processes, WHR for on-site processes beyond the immediate scope, installations for Combined Heat and Power (CHP) aimed at electricity generation, and systems dedicated to district heating [20]. Nonetheless, each domain presents its unique set of challenges. Therefore, researchers are keen on systematically devising cost-effective and environmentally sustainable methodologies to optimize WHR from diverse waste heat (WH) sources, employing various approaches to bolster industrial output. A myriad of WH sources exist, with some categorized as Low-Grade Waste Heat (LGWH), including flue gas, variable cooling water temperatures, and exhaust steam, among others[10]. In industrial processes, High-Grade Waste Heat (HGWH) is reclaimed post-recovery, either for internal reuse within the same industry or for cross-industrial purposes. Subsequent to reuse, HGWH undergoes degradation to LGWH; often, WH below 200°C is discharged into the environment without harnessing its potential [11]. LGWH encompasses liquid or exhaust steam below 100°C, flue gas below 200°C, and other medium to high-temperature waste heat sources that may not be fully recoverable due to dispersed heat sources and the high cost of recovery. Among various industrial sectors such as cement, ceramics, aluminium, chemicals, glass, pulp and paper, food and beverage, among others, the iron and steel industry stands out as the largest consumer of heat energy, exhibiting considerable potential for recovering Low-Grade Waste Heat (LGWH). Nonetheless, obstacles and constraints associated with the adoption of specific Waste Heat Recovery (WHR) technologies can be broadly categorized as technical, commercial, and logistical [12]. the primary barriers, as outlined by the US Department of Energy [13]. Include: (i) application constraints, which are often dictated by temperature thresholds, specific processes involved, and the composition of the Waste Heat Stream (WHS); (ii) limitations stemming from the inaccessibility of certain heat sources and challenges related to their transportability; and (iii) the overarching concern of costs associated with implementing WHR solutions. An additional significant challenge hindering the advancement and adoption of industrial Waste Heat Recovery (WHR) systems, particularly for power generation and other industrial operations, is the dearth of extensive experience and pertinent knowledge regarding the identification, design, and operation of diverse industrial facilities harbouring potential Waste Heat (WH) resources[14]. Internally harnessing waste heat serves to enhance energy efficiency within industrial processes, whereas external Waste Heat Recovery (WHR) facilitates meeting the energy demands of auxiliary services and industrial operations, particularly those reliant on Low-Grade Waste Heat (LGWH). Consequently, it is imperative to establish a clear objective for WHR initiatives. This entails optimizing internal heat recovery to bolster the energy efficiency of core industrial processes while simultaneously evaluating the WHR potential for external utilization, with a keen focus on realizing economic benefits. Oyedepo and Fakeye [16] have proposed several potential remedies to address the challenges associated with the development and application of Waste Heat Recovery (WHR) technologies, outlined as follows: Augmenting relevant research endeavours focused on advancing WHR technologies and their utilization. Offering incentives such as grants, soft loans, etc., to foster and bolster the implementation of WHR technologies. Initiating global awareness programs to underscore the significance and advantages of WHR systems. Formulating favourable policies conducive to enforcing internationally recognized practices aimed at optimizing energy

utilization in both the power and industrial sectors. Facilitating the transfer of technology from developed nations to developing ones.

Conclusion-

In present scenario tunnel kiln furnace are using in various sectors of manufacturing industries for processing of baking stage of a product, and the tunnel kiln furnace are used in graphite manufacturing industries to process re-baking stage of electrodes for maximum calcification to achieve higher carbon percent which will convert in graphite structure from amorphous structure. This process has been under specified time under certain temperature control situation using scada. In this process heat is a main source of processing and controlled by using of heat exchangers and furnace facilities, but there is a certain design parameters limitation to examine the ongoing advancements in heat exchangers worldwide. To assess how these advancements are influencing the design and level of optimization of heat exchangers examine the potential challenges associated with these advancements, to explore and obtained optimum solutions that can broaden the future applications of these advancements in heat exchangers by using waste heat recovery and waste heat recycling method in heat exchanger by designing of reheating of preheated air for maximum utilization of resources and process optimization and production enhancement.

Future Scope-Through the integration of waste heat recovery systems employing heat exchangers, industrial sectors can diminish energy usage, decrease operational expenditures, and mitigate greenhouse gas emissions; thereby fostering economic and environmental sustainability concurrently. WHR has a scope in reheating process of air for combustion reaction in specified condition and operation such advancement would be beneficial in EHS consideration at globe.

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