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# WASTE HEAT RECOVERY IN INJECTION MOLDING MACHINES

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**Abstract**- Waste heat management is increasingly crucial in contemporary industrial operations, driven by the imperative to enhance energy efficiency and promote environmental sustainability. This research investigates the utilization of waste heat in a plastic plant, focusing on three thermal cycles: Lithium Bromide Absorption (LBA), Ammonia Water Absorption (AWA), and Organic Rankine Cycle (ORC). By using the ASPEN PLUS program, three models corresponding to the three selected thermal cycles were created. The study rigorously evaluates the performance of each cycle in terms of temperature output and Coefficient Of performance (COP) or efficiency. The results reveal that both the LBA and AWA cycles demonstrate promising alignment with the desired temperature output for cooling applications in industrial applications, specifically plastic plants. However, upon thorough analysis of efficiency metrics, the LBA cycle emerges as the leading option. This finding underscores the significant potential of the LBA cycle for effectively managing waste heat in comparable industrial environments. By addressing critical considerations of temperature output and efficiency, the utilization of the LBA cycle offers a comprehensive solution to waste heat management challenges in industrial operations. This research contributes valuable insights to the field and underscores the importance of exploring advanced thermal cycles for sustainable energy utilization. This multidimensional approach underscores the significance of integrating sustainability considerations into waste heat management practices, paving the way for more efficient and environmentally responsible industrial operations. Future research endeavors could further investigate optimization strategies and explore the practical implementation of the LBA cycle in industrial applications, fostering continued advancements in waste heat management practices.

**Keywords:** Waste Heat Utilization, Lithium Bromide Absorption Cycle, Ammonia-Water Absorption Cycle, Organic Rankine Cycle, Energy Efficiency.

## 1. INTRODUCTION

In the context of sustainable development and the preservation of energy resources, the consumption of efficient energy has become more crucial. One of the foremost industrial issues currently is the substantial quantity of waste heat produced through diverse production processes [1]. Using waste heat leads to significant energy conservation and significantly helps to decrease carbon emissions. Injection molding is a prominent industrial process characterized by generating substantial amounts of heat, often dissipating without use. This phenomenon offers a promising prospect for the recovery of waste heat [2-3].

Injection molding is a pivotal process within the manufacturing industry, serving to produce a diverse range of plastic parts, spanning from small components to the expansive panels [4]. The process involves melting plastic granules and injecting them into molds at high pressures. This process results in the generation of large amounts of thermal energy, particularly inside the machines such as heaters, motors, and hydraulic systems [5]. A significant amount of thermal energy is often dissipated into the surrounding environment, resulting in inefficient energy use and elevated operating expenses [6].

Moreover, it is crucial to emphasize the significant environmental consequences associated with the inefficiency of the systems [7-9]. Waste Heat Recovery (WHR) systems are designed to collect the leftover heat generated during industrial operations and transform it into a form of energy that can be utilized [10]. The recuperated energy might be used for diverse purposes [11]. The use of WHR in injection molding machines offers potential economic advantages via the reduction of energy expenses and contributes to the attainment of sustainability objectives by mitigating the injection molding industry's total carbon emissions [12-14].

Nevertheless, implementing WHR equipment in the systems of injection molding presents some obstacles. The efficiency of these systems is determined by several factors, including the regularity of waste heat production, the temperature gradients associated with the process, and the extent to which they may be integrated with pre-existing equipment [15-17]. To effectively tackle these problems, it is essential to possess a sufficient comprehension of the injection molding process and the complexities associated with WHR systems.

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The primary objective of this research is to investigate and assess the viability of WHR systems in injection molding machines to optimize energy efficiency and mitigate environmental consequences at a plastic plant. Through an in-depth exploration of the complex mechanisms involved in the production and dispersion of heat in the context of molding processes. Our objective is to develop a highly effective WHR plan specifically designed for these machines. This study contributes to the scientific discussion on industrial energy efficiency by providing practical and feasible ideas that manufacturers can readily implement. This transformation would be characterized by adopting sustainable and cost-effective operational practices, which might serve as a model for other sectors.

## 2. LITERATURE REVIEW

The investigation and advancement of WHR in injection molding machines constitute a significant field of scientific inquiry, with the primary objective of enhancing energy efficiency and mitigating environmental consequences. Various methodologies have been examined to solve this problem. One such method involves using variotherm injection molding or Rapid Heat Cycle Molding (RHCM), as proposed by [18]. This approach aims to mitigate imperfections in polymer injection products and minimize the need for further post-processing operations such as spraying and coating. An alternative methodology involves ultrasonic injection molding [19]. Ultrasonic injection molding has the advantage of reduced energy consumption during the polymer melting process.

In addition, the mold configuration may also contribute to the WHR process. According to [20], the integration of venting into the mold design and adjusting operating conditions can mitigate waste creation and enhance process efficiency. Furthermore, topology optimization and finite element techniques in mold design have been shown to preserve mechanical stability and effectively enhance heat transfer efficiency [21]. Several research has concentrated on expediting the mold cavity's heating process using infrared, water steam heating, or induction heating techniques [22]. The energy recovery systems for the electric motor drive system in injection molding machines have also been investigated [23]. Simulation analysis has been employed to evaluate the impact of these systems on energy conservation, hence facilitating a reduction in energy consumption and enhancement of overall efficiency.

In recent years, a growing activity of research has explored the possibility of waste heat use in several sectors, demonstrating notable progress in this field. Table 1 offers a detailed summary of many investigations undertaken in this field. [17] conducted a study whereby they used a mathematical model to examine the usage of waste heat from electrical gas turbine generators. The investigation conducted by the researchers demonstrated a significant improvement of efficiency, with a notable increase of 4.62% compared to a power cycle operating independently.

Similarly, [24] focused on integrating waste heat into the absorption cycle for cooling and refrigeration applications. He demonstrated an improvement of coefficient of performance in the absorption-compression combination cycle designed for vehicles and generators compared to the standalone compressor cycle. In an alternative direction, [25] proposed to use a Flat Heat Pipe Exchanger (FHPE) system. This research emphasizes the significant potential of WHR and its crucial role in improving energy efficiency, decreasing expenses, and promoting sustainable practices in diverse sectors. The cumulative results of this research highlight the significant opportunities and obstacles within the field of WHR. The progressions in techniques and the wide range of approaches facilitate the development of future systems that are more sustainable and efficient.

Table 1. Overview of studies on waste heat utilization and their key results

| Ref. | Objective | Methodology | Key Results |
|---|---|---|---|
| [17] | Utilization of waste heat from electrical gas turbine generators | A mathematical model for technical (thermal) and economic (cost) analyses | Exergy efficiency enhanced by 4.62% compared to stand-alone power cycle |
| [24] | Use of waste heat with absorption cycle in cooling-refrigeration | Absorption-compression combined cycle for vehicles and generators | Enhanced coefficient of performance compared to compressor cycle |
| [25] | FHPE system for heat recovery | Experimental and theoretical investigation in the lab and industrial plant | Agreement between practical and theoretical results |
| [26] | Organic Rankine cycle in cement plants | Parametric analysis of water-steam and organic Rankine cycles | Water steam technology is more effective than ORC at exhaust gas temperatures > 310 °C |
| [27] | ORC with different working fluids | Simulation with REFPROP software | R-32 was the best working fluid choice |

## 3. METHODOLOGY

The research initiates with a historical analysis that provides a comprehensive examination of the injection process, charting its development and emphasizing its crucial significance in modern production. This study's primary focus is investigating waste heat generated by injection molding machines. The aim is to get a comprehensive knowledge of this heat's possible uses and determine the practical advantages of its utilization. This study notably investigates the absorption cycle, explicitly analyzing its two variants: Lithium Bromide (LiBr) and Ammonia Water (AW).

Additionally, it studies the Organic Rankine Cycle (ORC). By using the functionalities of the ASPEN PLUS software, comprehensive models of these systems are developed and subjected to meticulous simulations. The accuracy of the simulations is ensured by including customized input parameters. After the completion of the simulations, a comprehensive analysis is conducted to understand the outcomes, with particular emphasis on each system's heat capacities and efficiency.

The research concludes by using the collected data and providing suggestions, namely identifying the most effective methods for using the waste heat generated during injection molding. Figure 1 shows the study methodology flowchart. ASPEN PLUS is a software tool used for process modeling and simulation. When the user establishes connections between the components based on temperature, pressure, or any other relevant characteristic, it will provide a comprehensive model of a complicated process.

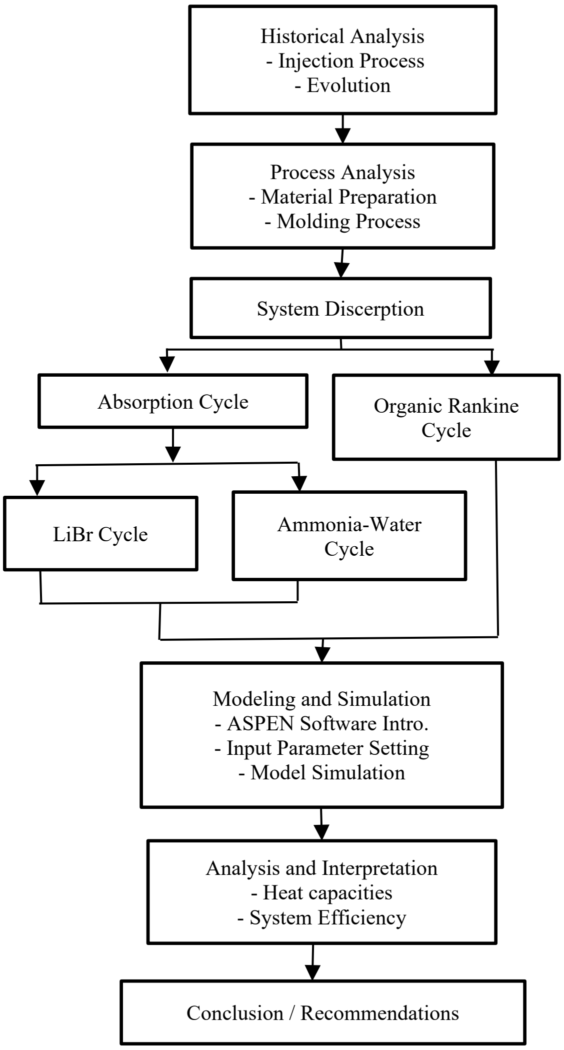


Figure 1. Study methodology flowchart

### 3.1. Historical Analysis

The injection process has played a pivotal role in the manufacturing sector. It has undergone significant advancements, from its first crude designs in the late 19th century to the highly complex mechanisms used today. The injection molding method has experienced several alterations since its invention in 1872 by the Hyatt brothers. The industry was transformed by significant innovations, including the creation of the screw injection machine by James Watson Hendry in 1946 and the subsequent development of the gas-assisted injection molding technology in the 1970s.

### 3.2. Process Analysis

Plastic injection production entails a series of sequential procedures. Initially, the tanks are filled with raw material. Subsequently, the material is transferred from the tanks to a separate tank equipped with a drier, where they undergo heating to decrease moisture content. This drying process typically spans around nine hours. Additionally, the material is conveyed into the NETSTAL machine using the screw mechanism for molding, extraction. This process occurs at elevated temperatures, achieved by heating the refrigerant using the chiller or cooling tower. Subsequently, the product is transported by a conveyor system after extraction by an automated machine and subsequent placement into boxes. The cooling process in the injection machine encompasses three distinct inputs. Firstly, there is input to the mold during the injection process, where the cooling process assumes utmost significance in ensuring the production of defect-free products by facilitating effective heat transfer between the material and mold. Secondly, input to the Programmable Logic Controller (PLC) control system incorporates a heat exchanger to mitigate potential risks. Lastly, there is input to the hydraulic system, which serves as the central control unit for the injection process. The temperature range obtained throughout the process varies from 46 °C to 50 °C, contingent upon the quantity of machines used. However, the temperature inside the mold itself remains at a relatively lower level of around 15 °C. To maintain this lower temperature, the use of a chiller or cooling tower is necessary, which results in supplementary expenses related to consumption, operation, and maintenance.

### 3.3. System Description and Objective

This research investigates the complex procedure of using the thermal energy produced by injection molding machines. The inception of absorption refrigeration may be traced back to the use of ammonia-water mixtures, which later evolved into water-lithium bromide systems throughout the mid-20th century. The primary objective of this study is to explore the potential use of waste heat produced during injection molding processes for generating electricity in absorption cooling systems. The investigation will specifically utilize lithium bromide and ammonia water variants of absorption cooling cycles.

The LBA cycle is notable for using water as a refrigerant and lithium bromide as an absorbent. The complex procedure involves many steps, such as heating, condensation, and evaporation. The generator, absorber, condenser, and evaporator are integral components that collaborate to facilitate the best performance and efficiency of the cycle. One notable characteristic of this cycle is the imperative need for a rectification column after the generating phase that jointly guarantees the system's effectiveness. Furthermore, the ORC is comprehensively explored. The ORC has emerged as a notable alternative to the conventional steam cycle due to its ability to effectively harness waste heat from various sources. The system utilizes refrigerant, particularly R134a, to convert waste heat into valuable energy.

As seen in Figure 2, the investigation has a threefold nature. The first focus of this study is the examination of the absorption cycle that utilizes ammonia water, Furthermore, the focus is on the ORC. Finally, an examination is conducted on the absorption cycle that employs a combination of Lithium Bromide (LiBr) and water.

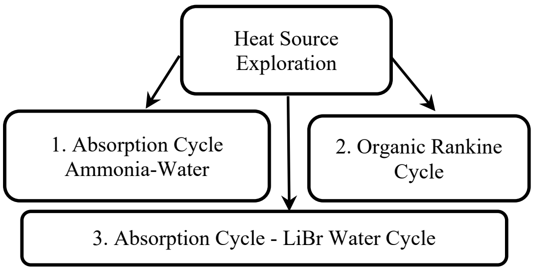


Figure 2. Waste heat investment

## 3.4. Modeling and Simulation

### 3.4.1. Input Parameters

The input parameters of the cycle may be classified into four separate categories. Firstly, the parameters associated with the heat source: an initial temperature $T_i$ of 50 °C, a final temperature $T_o$ of 15 °C, and a mass flow rate $\dot{m}$ of 1 kg/s. Table 2 shows the input parameters specifically for the LBA and AWA cycles, representing the second and third categories. Both cycles exhibit similar temperature settings for the generator, condenser, and evaporator. However, there are noticeable differences in the pressure settings for specific components. For instance, the evaporator and absorber pressures in the AWA cycle are distinctly lower than those in the LBA cycle. Despite these variations, the mass flow rate remains consistent at 40,000 kg/hr for both cycles.

Table 2. Input parameters for the LB and AW absorption cycles

| Component | LBA Cycle | AWA Cycle |
|---|---|---|
| $T_g$ | 50 °C | 50 °C |
| $P_g$ | 5 bar | 5 bar |
| $T_c$ | 20 °C | 20 °C |
| $P_c$ | 5 bar | 5 bar |
| $T_e$ | 30 °C | 30 °C |
| $P_e$ | 1 bar | 0.3 bar |
| $P_a$ | 1 bar | 0.3 bar |
| $P_p$ | 5 bar | 5 bar |
| $\dot{m}$ | 40,000 kg/hr | 40,000 kg/hr |

Table 3. ORC Input Parameters

| Component | Value |
|---|---|
| $T_c$ | 15 °C |
| $P_c$ | 1 bar |
| $T_e$ | 50 °C |
| $A_e$ | 2 sqm |
| $P_p$ | 2 bar |
| $P_{dp}$ | 1 bar |
| $\dot{m}$ | 3600 kg/hr |

Finally, The ORC, as shown in Table 3, delineates the critical input parameters vital for efficient operation. The condenser operates at a temperature and pressure of 15 °C and 1 bar, respectively, while the evaporator is set at a higher temperature of 50 °C. Additionally, the evaporator is characterized by a surface area, $A_e$ of 2 square meters. The system also features a pump pressure, $A_p$ set at 2 bars and a drop pressure, $P_{dp}$ of 1 bar. Notably, the mass flow rate for the ORC is maintained at 3,600 kg/hr.

### 3.4.2. Model Simulation

Using the ASPEN PLUS program, a complete study was performed on the waste heat source in a tri-cyclic system originating from the injection machine with a constant heat flow. This analysis resulted in the identification of two main benefits. The primary function of this system is to assist in removing heat from components while simultaneously calculating the Coefficient of Performance (COP) or the inherent efficiency of the cycle. For the LB absorption cycle context, the input parameters stated in Table 2 were integrated. Figure 3 and Table 4 are the visual representation of the outcomes that resulted from this integration. Figure 4 illustrates the outcomes of applying the input parameters of the absorption cycle AW model. Table 5 contains temperature, pressure, mass flow rate and volume flow rate at specific points within the model shown in Figure 4. The results of applying the input parameters from Table 3 to the model of the OR cycle are presented in Figure 5.

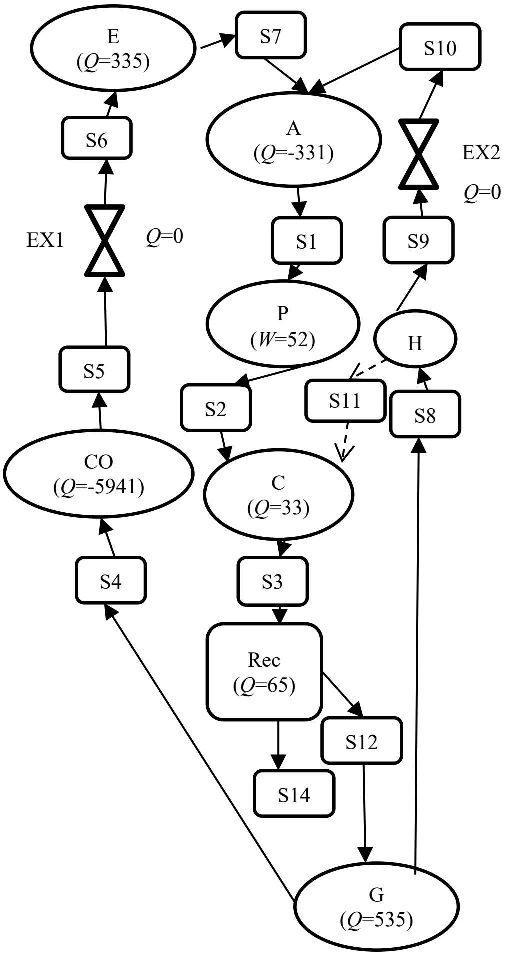


Figure 3. Model of Lithium Bromide ($Q$: Duty (kW), $W$: Power (kW), A: Absorber, E: Evaporator, P: Pump, EX: Ex valve, CO: Condenser C: Cold, H: Hot, G: Generator, Rec: Rectifier, S: Sensor)

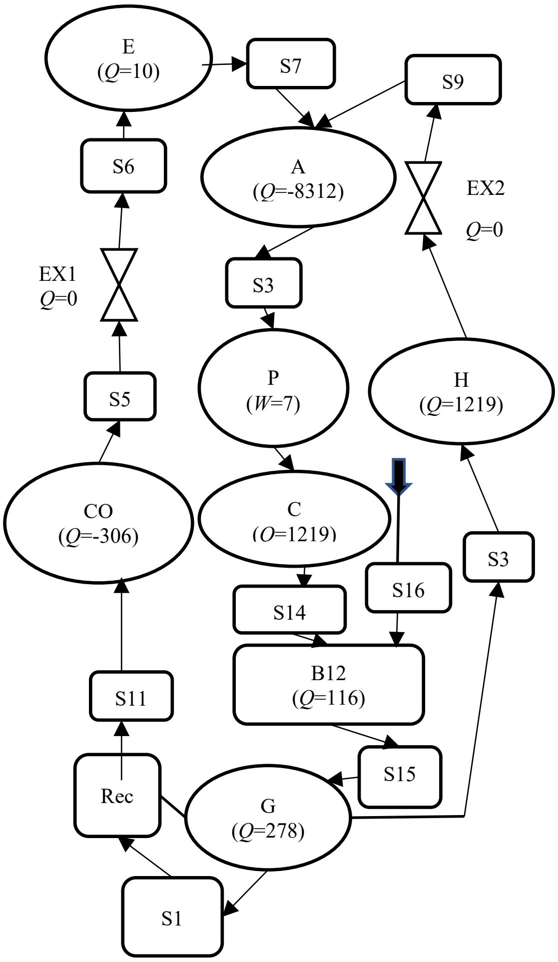


Figure 4. Model of Ammonia-Water ($Q$: Duty (kW), $W$: Power (kW), A: Absorber, E: Evaporator, P: Pump, EX: Ex valve, CO: Condenser, C: Cold, H: Hot, G: Generator)

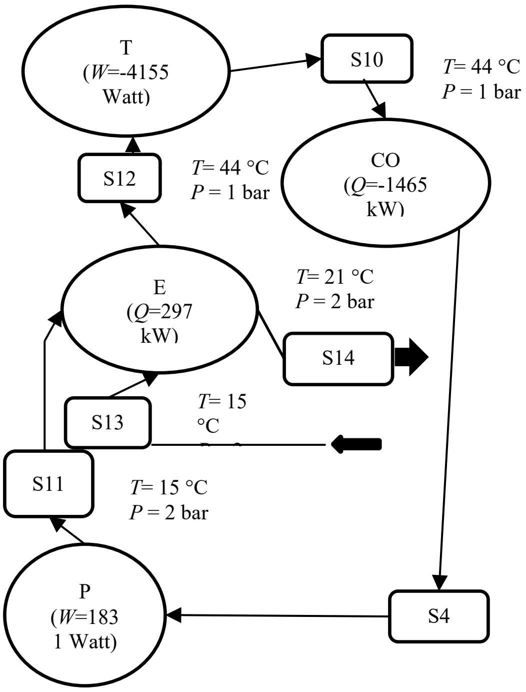


Figure 5. Model of Organic Rankine Cycle (P: Pump, T: Turbine, E: Evaporator, CO: Condenser, S: Sensor)

Table 4. Sensor data of Lithium Bromide

| Sensor | Temperature (°C) | Pressure (bar) | Vapor Fraction |
|---|---|---|---|
| S1 | 6 | 7 | 0 |
| S2 | 6 | 29 | 0 |
| S3 | 9 | 29 | 0 |
| S4 | 50 | 29 | 1 |
| S5 | 40 | 29 | 0 |
| S6 | 5 | 7 | 0.06 |
| S7 | 20 | 7 | 0 |
| S8 | 50 | 29 | 0 |
| S9 | 40 | 29 | 0 |
| S10 | 25 | 7 | 0.02 |
| S12 | 49 | 40 | 0.63 |
| S14 | 14 | 29 | 0 |

Table 5. Sensor data of Ammonia-Water

| Sensor | Temperature (°C) | Pressure (bar) | Mass flow rate (kg/hr) | Volume flow rate (cum/hr) |
|---|---|---|---|---|
| S3 | –42 | 0 | 40000 | 51 |
| S5 | 30 | 5 | 13146 | 3674 |
| S6 | 5 | 0 | 13146 | 59232 |
| S7 | 6 | 0 | 13146 | 59530 |
| S9 | –13 | 0 | 26854 | 13886 |
| S11 | 50 | 5 | 13146 | 4196 |
| S12 | 50 | 5 | 26854 | 36 |
| S14 | –20 | 5 | 40000 | 52 |
| S15 | 49 | 5 | 40000 | 3846 |
| S16 | 50 | 5 | 40000 | 3923 |
| S17 | –18 | 5 | 13146 | 4196 |

### 3.4.3. Verification and Validation

Osta-Omar and Micallef [28], conducted a numerical investigation on the analysis of LBA cycle. The authors specifically focus on analyzing the COP of the temperature differential inside the generator. The generator receives temperature input within the range of 65 to 90 °C while maintaining a constant evaporator temperature of 10 °C, absorber temperature of 30 °C, and condenser temperature of 35 °C. Subsequently, the input reference parameter from the study about the model of the LBA cycle was implemented using ASPEN PLUS. Figure 6 present a comparative analysis of the COP values for the LBA cycle. This comparison is drawn between reference values and those obtained from the ASPEN PLUS simulations at different generator temperatures $T_g$. As observed, the COP values are closely following the reference, with an average error margin of 3.66%.

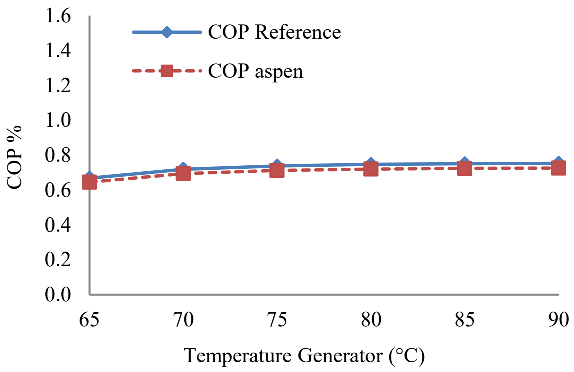


Figure 6. Lithium bromide COP verifications

Oni and Taiwo [29], conducted a mathematical analysis of the COP for an AW absorption cycle in a solar thermal system context. The investigation focused on the impact of varying temperatures inside the generator, fixed evaporator, absorber, and condenser. The temperature supplied to the generator falls within the range of 388 K to 343 K. The evaporator temperature remains constant at 267 K, while the absorber and condenser temperatures are set at 303 K. Subsequently, the reference parameter from the study of the application of the AWA cycle model was included in ASPEN PLUS. Figure 7 delve into a side-by-side comparison of the COP values for the AWA cycle. This juxtaposition is established between reference values and those obtained from ASPEN PLUS using various generator temperatures ($Tg$). The ASPEN-derived COP values demonstrate commendable consistency with the reference, registering an average error of just 3.07%.

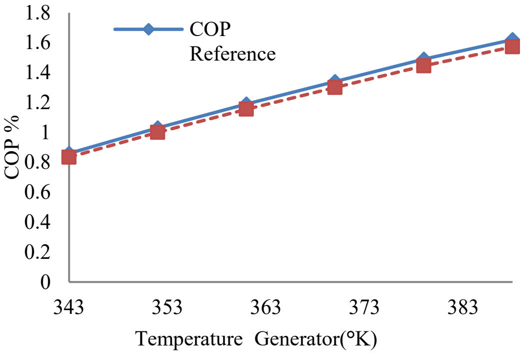


Figure 7. Ammonia-water COP verifications

Kilic and Ipek [30], analyzed the efficiency of the system in the OR cycle using several refrigerants, including R134a. The analysis was performed using the Engineering Equation Solver software. The temperature of the waste heat diesel engine's input to the evaporator ranges from 80 to 100 °C, while the condenser temperature remains constant at 35 °C. Subsequently, the reference parameter from the research was used as an input for the OR cycle model in ASPEN PLUS. The outcomes of this application are shown in Figure 8 with a range of generator temperatures $T_g$. The results from the ASPEN PLUS simulations align closely with the reference data, evidencing an average deviation of 5.09%. This small margin of error accentuates the reliability of the simulations, emphasizing the importance of continuous validation in simulation studies to ensure the robustness and accuracy of the results.

## 4. RESULTS ANALYSIS

From the data generated by the ASPEN PLUS model, one noteworthy aspect concerns the temperature at the interface between the heat exchanger and the generator during the system's cycle: The LBA cycle is about 14 °C, the AWA cycle produces an exit temperature in the vicinity of -18 °C, whereas the ORC exhibits an exit temperature of around 21 °C. It is important to acknowledge that these temperatures are measured under the condition of maintaining the internal system temperature at roughly 50 °C.

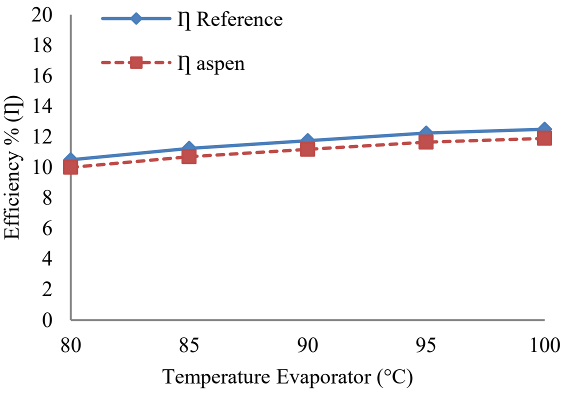
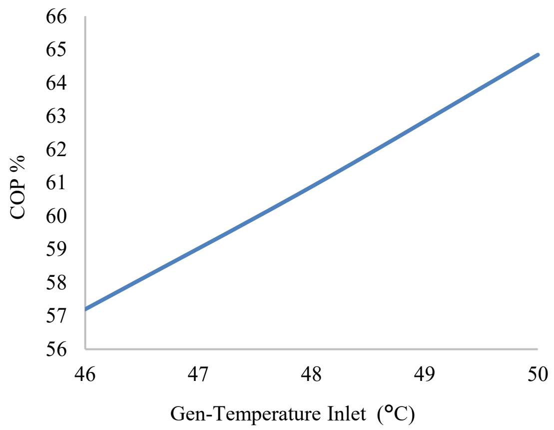


Figure 8. Organic Rankine cycle efficiency verifications

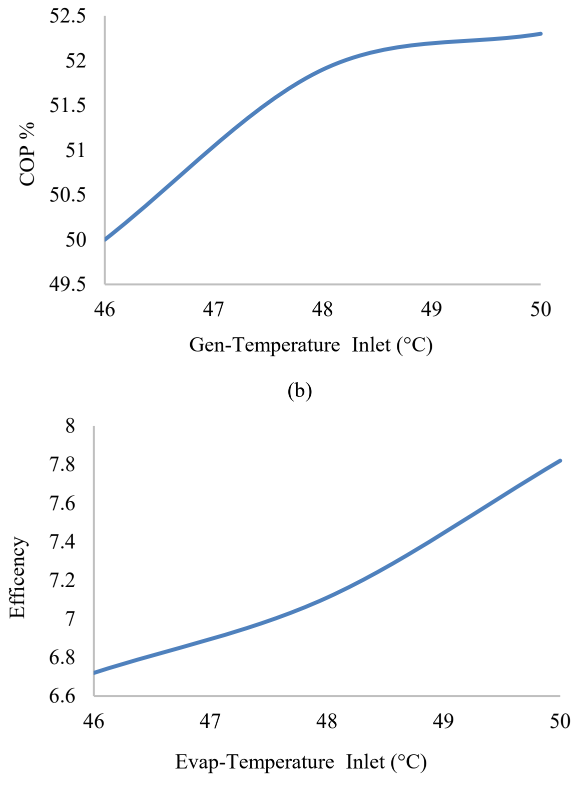
### 4.1. The Efficiency / COP of the Cycles

The efficiency/COP output results for the cycles are provided by the ASPEN PLUS results in this research. Figure 9a illustrates the distribution of the COP in the absorption cycle of LB water, with variations in the input temperature inside the generator. It can be shown that as the temperature within the generator rises, there is a corresponding increase in the COP output. The temperature range inside the generator spans from 46 °C to 50 °C, while the COP ranges from 57.2 to a maximum of 64.84%. The experimental setup included maintaining the evaporator temperature at 30 °C and the condenser temperature at 20 °C.

The COP distribution of the AWA cycle is shown in Figure 9b. It is seen that an increase in the generator temperature leads to a corresponding rise in the COP value. The temperature range inside the generator spans from 46 °C to 50 °C, while the corresponding COP ranges from 50 to a maximum of 52.3 %. The experimental conditions included maintaining both evaporator and condenser temperatures at 30 °C. The efficiency distribution of the ORC-R134a is shown in Figure 9c, illustrating the relationship between the input temperature inside the evaporator and the efficiency. It is seen that as the temperature within the evaporator rises, the efficiency of the system also increases. The temperature ranges inside the evaporator span from 46 °C to 50 °C, while the output efficiencies vary between 6.72 and a maximum of 7.82%. The used temperature of the condenser is 25 °C.



(a)



(b)

(c)

Figure 9. (a) COP for the lithium bromide absorption cycle, (b) COP for the ammonia-water absorption cycle, (c) Efficiency for the ORC-R134a

## 5. DISCUSSION

In the conducted investigation, it was observed that the temperature outputs of the LB and AW absorption cycles had a strong resemblance to the targeted 15 °C, making them suitable for cooling applications. This observation is consistent with the results of [24], who reported improved performance in cooling systems that use waste heat through absorption cycles. Nevertheless, the OR cycle, as highlighted by [26], demonstrated a temperature output of 21 °C, which makes it less compatible with the operational needs. The level of efficiency, which is of great importance, revealed that the OR cycle fell behind the absorption cycles. This divergence may be attributed to the basic operational differences between these two systems. This result is consistent with the results of [27] and other researchers who have extensively examined the complexities of efficiency in different cycles, particularly the OR cycle.

Table 6, shows a comparative study of the selected cycles, it is evident that the LB and AW absorption cycles nearly match the target temperature output of 15 °C. This is consistent with the results of [24] on the enhanced efficiency of cooling systems that include waste heat through absorption cycles. The OR cycle, operating at a temperature of 21 °C, exhibits deviations from the optimum behavior. This observation aligns with the results of [26], who have previously emphasized the effectiveness of the OR cycle in other applications, but not specifically in the context of this study. The comparative efficiency of the OR cycle falls below that of absorption cycles, mostly due to inherent operational disparities. The aforementioned statement aligns with the research conducted by [27], which explored the intricacies of efficiency throughout different cycles. Based on the analysis, it can be concluded that the LBA cycle is the most favorable method for implementation in the plastic plant based on injection molding machines.

Table 6. Comparison of results

| | AWA | LBA | ORC- R134a |
|---|---|---|---|
| Temperature output (°C) | –18 | 14 | 21 |
| COP/efficiency | 52.3 | 64.84 | 7.82 |

It is important to note that the heterogeneity in waste heat outputs across various industrial applications might potentially affect the generalizability of the results. This study provides a comprehensive analysis of only three cycles only, facilitating a more nuanced comprehension of waste heat usage in a particular industrial application.

## 6. CONCLUSION

The current investigation undertook a comprehensive examination of waste heat use in the particular application of the plastic industry. At the core of this undertaking lay the examination of three distinct thermal cycles, namely the LB absorption cycle, the AW absorption cycle, and the OR cycle. The ASPEN PLUS program was used to conduct this study, which included simulating waste heat sources and thoroughly analyzing the key factors associated with these cycles.

Several significant conclusions were identified based on the collected data. Lithium bromide and ammonia-water absorption cycles closely aligned with the desired cooling temperature of 15 °C for industrial applications. However, the ammonia-water cycle posed some safety concerns owing to the use of ammonia as a refrigerant, necessitating the implementation of rigorous safety standards. Although the organic Rankine cycle has been shown the limitations in terms of temperature production. In terms of efficiency, it has been shown that absorption cycles, namely the lithium bromide cycle, exhibit superior performance compared to the organic Rankine cycle. This result aligns with previous research and emphasizes the potential of absorption cycles in effectively managing waste heat.

## NOMENCLATURES

### 1. Acronyms

| | |
|---|---|
| LBA | Lithium Bromide Absorption |
| AWA | Ammonia-Water Absorption |
| ORC | Organic Rankine cycle |
| WHR | Waste heat Recovery |
| RHCM | Rapid Heat Cycle Molding |
| FHPE | Flat Heat Pipe Exchanger |
| COP | Coefficient of Performance |
| LiBr | Lithium Bromide |
| AW | Ammonia Water |

## 2. Symbols / Parameters

$T_i$: The initial temperature (°C)
$T_o$: The Final temperature (°C)
$\dot{m}$: Flow rate (kg/s or kg/hr)
$A_e$: Surface area (m$^2$)
$T_g$: Generator temperature (°C)
$T_c$: Condenser temperature (°C)
$T_e$: Evaporator temperature (°C)
$P_g$: Generator pressure (bar)
$P_c$: Condenser pressure (bar)
$P_e$: Condenser pressure (bar)
$P_p$: Pump Pressure (bar)
$P_a$: Absorber pressure (bar)
$P_{dp}$: Drop pressure (bar)

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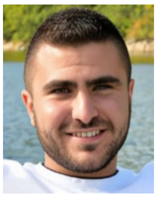

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