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Performance Evaluation and Optimization of Chiller Systems: A Data-Driven Approach to Enhancing Energy Efficiency

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Abstract: Chiller systems account for a significant portion of energy consumption in industrial and commercial HVAC operations, often exceeding 50% of total power usage. However, inefficiencies such as elevated condenser pressure, inadequate heat transfer, and excessive compressor workload contribute to increased energy demand. This study presents a comprehensive performance evaluation of water-cooled centrifugal chiller systems based on 30 operational test scenarios. Key efficiency indicators—including Coefficient of Performance (COP), Specific Energy Consumption (SEC), and isentropic efficiency—were analyzed to identify performance gaps. The results revealed COP values ranging from 1.92 to 4.07, with an average between 2.8 and 3.2, indicating suboptimal performance relative to industry benchmarks (COP > 4). SEC values between 1.07 and 1.25 kW/ton further highlight opportunities for energy optimization. High condenser pressure (>7.5 barg) and negative subcooling (-4.1 K to 0 K) were identified as major contributors to inefficiency. The study emphasizes that optimizing water flow rates and maintaining proper heat exchanger conditions can significantly improve system performance. Unlike previous research relying on AI or IoT-based diagnostics, this work adopts a practical, data-driven approach, offering actionable insights for facility managers seeking to enhance energy efficiency and operational reliability.

Keywords: Water-Cooled Centrifugal Chiller; Coefficient of Performance (COP); Specific Energy Consumption (SEC); Superheat; Subcooling; Isentropic Efficiency; Energy Optimization

1. Introduction

Chiller systems play a pivotal role in industrial and commercial facilities, accounting for a substantial portion of total energy consumption in building operations. With rising energy costs and increasingly stringent sustainability targets, optimizing the performance and efficiency of chiller systems has become a critical priority for facility managers and engineers. The efficiency of a chiller system is commonly evaluated using the Coefficient of Performance (COP), which measures the ratio of cooling output to energy input [1]. Achieving and maintaining high COP values, however, requires continuous monitoring and adjustment of operational parameters [2].

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Chiller performance is influenced by several factors, including refrigerant pressure, heat exchanger cleanliness, evaporator and condenser temperatures, and compressor workload [3]. Dalibard et al. [4] emphasize that routine maintenance practices—such as descaling condensers—can significantly enhance energy efficiency by improving heat transfer and reducing energy losses. Their findings indicate that chiller efficiency deteriorates over time due to fouling and scaling, which impede heat exchange and increase compressor workload [5,6].

Yu et al. [7] highlight the integration of modern technologies as a means to improve chiller performance. Their research demonstrates that the use of advanced refrigerants and high-efficiency compressors can reduce energy consumption by up to 20% compared to conventional systems [8]. These innovations, when combined with optimized control strategies, offer substantial potential for energy savings [9].

Recent developments in chiller technology—such as IoT-based monitoring, AI-driven diagnostics, and high-efficiency refrigerants—have shown promising results in energy optimization [2,3]. Nevertheless, real-world implementation remains limited due to cost constraints and the need for specialized technical expertise, underscoring the importance of practical, data-driven optimization strategies as explored in this study.

Yamamoto et al. [10] advocate for real-time performance monitoring and predictive maintenance using supervisory control systems to mitigate condenser fouling. Their study illustrates how IoT-enabled data collection and analysis can facilitate early detection of inefficiencies, thereby preventing costly downtime and equipment failure [11]. Similarly, Liu et al. [12] demonstrate that solar-driven chillers equipped with advanced control algorithms can achieve energy reductions of 30–40% [13].

Alyousef and Bukshaisha [14] investigate the impact of chilled water supply temperatures on chiller efficiency. Their findings suggest that maintaining lower water temperatures reduces compressor workload, thereby improving system performance [15].

Lee et al. [16] underscore the value of failure trend analysis in developing reliable maintenance strategies. Their research shows that predictive maintenance can enhance chiller reliability by up to 25% [17]. Wang et al. [18] further discuss how innovative condenser coil designs improve COP by enhancing heat rejection efficiency and lowering power consumption.

Energy storage technologies have also emerged as viable solutions for improving chiller efficiency. Al Quabeh et al. [19] examine the integration of thermal energy storage with district cooling systems, reporting energy savings of up to 15% in tropical climates. Suamir et al. [20] highlight the environmental benefits of water-cooled chiller plants equipped with advanced monitoring systems.

Other studies emphasize the role of advanced control algorithms in optimizing chiller performance under varying load conditions [21]. Putri et al. [22] argue that aging assessments and life-cycle management are essential to prevent performance degradation, which can increase energy consumption by as much as 30% [23,24].

This study aims to conduct a comprehensive performance analysis of chiller systems using real-time operational data to identify key factors affecting efficiency. By evaluating critical parameters such as refrigerant pressure, superheat, subcooling, and isentropic efficiency, the research seeks to develop actionable strategies for optimizing chiller performance and minimizing energy consumption. The findings contribute to the existing body of literature by addressing operational challenges and offering practical solutions for long-term efficiency improvement.

While previous studies have explored chiller performance through experimental and theoretical models [1,4], there remains a gap in real-time operational data analysis for practical optimization in commercial settings. This study addresses that gap by evaluating the impact of various operational conditions on chiller efficiency and proposing data-driven strategies to enhance energy performance and reduce operational costs.

2. Methods

This study employs a comprehensive methodological approach to analyze the performance of chiller systems, focusing on key parameters that influence efficiency. The methodology consists of data collection, computational analysis, and comparative evaluation against established benchmarks. The primary objective is to identify operational inefficiencies and propose targeted strategies for optimization.

2.1. Data Collection

Operational data from the chiller system were collected over 30 test cycles to ensure robustness and reliability of the analysis. Key variables recorded include:

- Evaporator inlet and outlet temperatures (Tei and Teo, in °K)
- Refrigerant pressures at the evaporator and condenser (Pe and Pc, in kPa)
- Compressor workload (W, in kW)
- Suction and discharge temperatures (Tsuc and Tdis, in °K)
- Liquid line temperatures (Tll, in °K)
- Flow rates of chilled water (L/s, in liters per second)

These variables were measured using calibrated sensors and data acquisition systems integrated into the chiller's operational setup. Data consistency was ensured by cross-validating sensor readings with manual measurements during periodic inspections.

2.2. Computational Analysis

The collected data were analyzed using the following computational models:

2.2.1. Coefficient of Performance (COP)

The efficiency of the chiller system was evaluated using:

$$\mathrm{COP} = \frac{Q_{\text{evaporator}}}{W_{\text{compresor}}} \tag{1}$$

where $Q_{\text{evaporator}}$ is calculated based on the temperature difference ($\Delta T = T_{ei} - T_{eo}$) and flow rate of chilled water.

2.2.2. Superheat and Subcooling Evaluation

Superheat ($T_{\text{superheat}}$) was determined as:

$$T_{\text{superheat}} = T_{\text{suc}} - T_{\text{saturation, evaporator}} \tag{2}$$

Subcooling ($T_{\text{subcooling}}$) was calculated as:

$$T_{\text{subcooling}} = T_{\text{saturation, condenser}} - T_{\text{ll}} \tag{3}$$

2.2.3. Isentropic Efficiency of the Compressor

The isentropic efficiency ($\eta_{\text{isentropic}}$) was determined using:

$$\eta_{\text{isentropic}} = \frac{\text{Ideal Temperature Rise}}{\text{Actual Temperature Rise}} \tag{4}$$

This metric evaluates the compressor's performance in converting input energy into useful work.

2.2.4. Specific Energy Consumption (SEC)

Energy efficiency was further analyzed using SEC, calculated as:

$$\mathrm{SEC} = \frac{W_{\mathrm{compresor}}}{Q_{\mathrm{evaporator}}} \tag{5}$$

This metric provides insights into energy consumption per ton of cooling delivered.

2.3. Data Validation and Statistical Analysis

The dataset was validated to identify and eliminate outliers. Statistical tools, including correlation analysis, were employed to examine the relationships between variables such as temperature differences, flow rates, and COP. Regression models were used to predict trends and assess the impact of specific variables on energy efficiency.

2.4. Comparative Evaluation

The results were compared against industry benchmarks and previous studies to contextualize the findings. Key metrics, such as COP and SEC, were evaluated against the optimal ranges specified in the literature to determine the chiller's performance under various operating conditions.

2.5. Strategy Development

Based on the results, targeted strategies for optimizing chiller performance were proposed. These strategies include:

- Regular maintenance practices, such as descaling and coil cleaning.
- Optimization of operational parameters, such as refrigerant charge and water flow rates.
- Implementation of predictive maintenance techniques using IoT-based monitoring.

This methodical approach ensures that the findings are both reliable and actionable, providing a solid foundation for enhancing the performance and efficiency of chiller systems.

3. Results and Discussion

Present results clearly and concisely, focusing on the most significant findings of your study. In the Discussion, interpret these results in light of their implications and relevance. Compare and contrast your findings with those of prior studies to position your work within the existing body of knowledge. If possible, highlight how your results support, refine, or challenge established understandings in the field.

3.1. Coefficient of Performance (COP) Analysis

The calculation of COP across 30 test cycles revealed significant variations in chiller efficiency. The results showed an average COP of **3.45,** with values ranging from **2.9** to **4.1.** These fluctuations indicate that the chiller operates below optimal efficiency during certain periods, suggesting the presence of operational inefficiencies or mechanical limitations.

For COP calculation for the test data is:

$$\mathrm{COP} = \frac{Q_{\mathrm{evaporator}}}{W_{\mathrm{compresor}}}$$

Where:

- $Q_{evaporator}$: Capacity cooling counted with:

$$Q_{\mathrm{evaporator}} = \dot{m} \cdot c_p \cdot \Delta T,$$
$$\Delta T = Tei - Teo$$

- $\boldsymbol{m}$: Water flow rate in kg/s (calculated from L/s data).
  $C_{p:}$ Capacity hot specific water = 4.186 kJ/ kg·K.
- $W_{compressor:}$ Compressor input power in kW (shown in the table).

COP Calculation for Test 1

Test Data 1:

- T_{ei} = 8.70°C = 281.85 K
- T_{eo} = 6.10°C = 279.25 K
- flow rate = 90.17 L/s
- $W_{compressor}$ = 300 kW

Steps:
Conversion L/s to kg/s:
Since the density of water = 1 kg/L, then:

$\dot{m}$=90.17 L/s = 90.17 kg/s

Count ΔT (difference temperature):
$$\Delta T = T_{\mathrm{ei}} - T_{\mathrm{eo}} = 281{,}85 - 279{,}25 = 2{,}6\,\mathrm{K}$$

Count $Q_{\mathrm{evaporator:}}$
$$Q_{\mathrm{evaporator}} = \dot{m} \cdot c_p \cdot \Delta T$$

Substitution mark:
$$Q_{\mathrm{evaporator}} = 90{,}17 \cdot 4{,}186 \cdot 2{,}6$$
$$Q_{\mathrm{evaporator}} = 981{,}85\,\mathrm{kW}$$

Count COP:
$$\mathrm{COP} = \frac{Q_{\mathrm{evaporator}}}{W_{\mathrm{compresor}}}$$

Substitution mark:

$$\mathrm{COP} = \frac{981{,}85}{300} = 3{,}27$$

Based on the COP calculations from 30 test scenarios, the chiller system demonstrates suboptimal energy efficiency. COP values range from 1.92 to 4.07, with average values between 2.8 and 3.2. Generally, efficient cooling systems exhibit COP values above 4; thus, the observed performance falls below industry benchmarks. These findings indicate the presence of operational inefficiencies that may lead to increased energy consumption.

In the test with the highest COP (4.07 in Test 3), the chilled water flow rate reached 106.54 L/s, enabling maximum cooling capacity. Conversely, the lowest COP (1.92 in Test 6) was recorded at a reduced flow rate of 50.39 L/s, resulting in diminished cooling capacity (Q_evaporator) due to suboptimal heat transfer.

The fluctuation in COP values across tests suggests several contributing factors to the reduced chiller performance:

- Suboptimal Water Flow Rate Low COP values frequently occurred when the chilled water flow rate through the evaporator was below the optimal design threshold, reducing heat transfer efficiency.
- Scaling or Fouling in Heat Exchangers The presence of scaling or fouling on the evaporator or condenser surfaces can hinder heat exchange, preventing a significant drop in evaporator outlet temperature (TEO) and resulting in a reduced temperature differential (ΔT).
- Fluctuating Load Conditions Under partial load conditions, the compressor may not operate at peak efficiency, leading to higher energy consumption relative to the cooling capacity produced.
- Refrigerant Pressure Instability Pressure fluctuations due to refrigerant leakage or improper charging can disrupt the cooling cycle. Additionally, compressor inefficiencies may further increase power consumption.

To address these issues and improve COP values, several corrective measures are recommended:

- Optimize Water Flow Rate Adjust flow settings to align with the chiller's design specifications, ensuring efficient heat transfer.
- Routine Cleaning of Heat Exchangers Periodic maintenance of the evaporator and condenser is essential to prevent fouling and maintain optimal thermal performance.
- Refrigerant Pressure Monitoring Continuous monitoring of refrigerant pressure helps maintain cycle stability and prevents performance degradation.
- Preventive Compressor Maintenance Scheduled inspections and servicing can reduce mechanical losses and improve energy efficiency.
- Implementation of Variable Speed Drives (VSDs) VSDs allow the compressor speed to adapt to cooling demand, enhancing system efficiency under varying load conditions.

By implementing these strategies, the chiller system's performance can be significantly improved, approaching the recommended efficiency standards for water-cooled centrifugal chillers.

Key Insight: Regular descaling and evaporator maintenance can mitigate the drop in COP, as also suggested by Wang and Li (2021).

3.2. Superheat and Subcooling Analysis

Ideal superheat indicates that all refrigerant has changed become steam in the evaporator before enter to compressor. If the superheat value is too low, there is risk refrigerant liquid enter to compressor, which can damage compressor. On the other hand, if the superheat is too high, evaporator is not works optimally because lack refrigerant For absorb hot.

For ideal subcooling shows that refrigerant has fully changed become liquid in the condenser before enter to valve expansion. Subcooling values that are too high low can indicates existence bubble steam in refrigerant, which interferes with the cooling process. Conversely, subcooling is too tall can become sign pressure high condenser or condition suboptimal refrigerant.

Superheat and subcooling calculations can be use formula following:

$$\text{Superheat} = T_{suc} - T_{\text{saturasi evaporator}}$$

$$\text{Subcooling} = T_{\text{saturasi kondensor}} - T_{ll}$$

This parameter used for evaluate condition refrigerant in the evaporator and condenser. The data used covering suction (T_{suc})temperature, evaporator pressure, (P_e) *liquid line* temperature (T_{ll}), and condenser pressure (P_c).

Calculation For testing 1:
Calculating Superheat
Formula:
$\text{Superheat} = T_{\text{suc}} - T_{\text{saturation evaporator}}$

Substitution mark:
$\text{Superheat} = 277{,}45 - 272{,}15$
$\text{Superheat} = 5{,}3\ K$

Calculating Subcooling
Formula:
$\text{Subcooling} = T_{\text{saturasi kondensor}} - T_{\text{dis}}$

Substitution mark:

$\text{Subcooling} = -4{,}1\ \text{K}$

Superheat **=** 5.3 K → This value show that the refrigerant in the evaporator has experience warmup excessive after evaporate perfect, which is still in condition reasonable.

The superheat values ranged from 5.2 K to 5.5 K, indicating that the refrigerant undergoes sufficient vaporization and warming after exiting the evaporator. These values remain within the acceptable range for chiller systems, suggesting that the evaporator is effectively absorbing heat from the chilled water. The consistency of superheat values across tests confirms that no liquid refrigerant is entering the compressor, thereby minimizing the risk of mechanical damage due to slugging. This reflects a well-functioning evaporator with stable thermal performance.

In contrast, the **subcooling values varied between –4.1 K and 0 K**, with several tests—such as **Test 1 and Test 8**—showing negative values. A negative subcooling value implies that the refrigerant has not fully condensed into liquid before exiting the condenser. This condition is typically caused by:

- **Fouling or scaling** on condenser surfaces, which obstruct heat transfer.
- **Low cooling water flow rates**, reducing heat rejection capacity.
- **Elevated condenser pressure**, which may result from poor heat dissipation.

These issues lead to incomplete condensation, allowing vapor bubbles to remain in the liquid line. As a result, the refrigerant entering the expansion valve is not fully liquid, which significantly reduces cooling capacity. Additionally, the compressor must work harder to compensate for the thermal imbalance, increasing power consumption and reducing overall system efficiency. If left unaddressed, these conditions may accelerate wear and shorten the operational lifespan of key chiller components.

Overall, the evaporator performance is satisfactory, as evidenced by stable superheat values. However, the condenser performance requires immediate attention. Low or negative subcooling values are strong indicators of condenser inefficiencies, likely stemming from poor cooling water quality, suboptimal flow rates, or thermal obstructions due to fouling.

To restore optimal system performance and improve energy efficiency, the following corrective actions are recommended:

- 🧼 Routine cleaning of condenser surfaces to remove fouling and scaling
- 💧 Monitoring and optimizing cooling water flow rates to ensure adequate heat rejection.
- 📊 Periodic inspection of condenser pressure to detect and resolve abnormal pressure conditions.

By implementing these measures, the subcooling values can be restored to the optimal range of 3–7 K, enhancing the condenser's heat rejection capability and improving the overall efficiency of the chiller system.

3.3. Isentropic Efficiency of the Compressor

Efficiency isentropic compressor ($\eta_{\text{isentropik}}$) used for evaluate how much effective compressor increase pressure and temperature refrigerant during the compression process. Efficiency isentropic compressor counted for evaluate performance in increase pressure and temperature refrigerant. The formula used:

$$\eta_{\text{isentropic}} = \frac{\text{Ideal Temperature Rise}}{\text{Actual Temperature Rise}}$$

Ascension Ideal Temperature counted use enthalpy at condition pressure certain.. Ascension Temperature Current measured based on discharge (T_{dis}temperature) and suction T_{suc}. DataT_{dis} andT_{suc} on table 1. used for evaluate reliability compressor.

Table 1. Data T_{dis} and T_{suc}

Test	T_{suc}		T_{dis}	
	°C	K	°C	K
1	4.30	277.45	34.10	307.25
2	4.30	277.45	34.10	307.25
3	4.30	277.45	34.20	307.35
4	4.30	277.45	34.20	307.35
5	4.20	277.35	34.10	307.25
6	4.30	277.45	34.10	307.25
7	4.30	277.45	34.10	307.25
8	4.20	277.35	34.00	307.15
9	4.30	277.45	34.00	307.15
10	4.30	277.45	34.00	307.15
11	4.30	277.45	34.00	307.15
12	4.30	277.45	34.00	307.15
13	4.30	277.45	34.00	307.15
14	4.50	277.65	34.00	307.15
15	4.30	277.45	34.10	307.25
16	4.30	277.45	34.10	307.25
17	4.30	277.45	34.30	307.45
18	4.50	277.65	34.50	307.65
19	4.30	277.45	34.30	307.45
20	4.30	277.45	34.30	307.45
21	4.30	277.45	34.50	307.65
22	4.50	277.65	34.20	307.35

Test	T_{suc}		T_{dis}	
	°C	K	°C	K
23	4.50	277.65	34.30	307.45
24	4.30	277.45	34.30	307.45
25	4.50	277.65	34.50	307.65
26	4.30	277.45	34.30	307.45
27	4.30	277.45	34.30	307.45
28	4.2	277.35	34.2	307.35
29	4.3	277.45	34.3	307.45
30	4.3	277.45	34.3	307.45

Calculation Steps

Ascension Temperature Current

Ascension temperature current is difference between discharge temperature (T_dis) and suction temperature (T_suc):

$$\Delta T_{\text{actual}} = T_{\text{dis}} - T_{\text{suc}}$$

Ascension Ideal Temperature

Ascension ideal temperature calculated with consider enthalpy at condition pressure certain. For compression isentropic, formula general used is:

$$\Delta T_{\text{ideal}} = T_{\text{suc}} \left(\left(\frac{P_{\text{dis}}}{P_{\text{suc}}} \right)^{\frac{\gamma-1}{\gamma}} - 1 \right)$$

T_{suc} : Suction temperature in Kelvin
P_{dis} and P_{suc} : Discharge and suction pressure
Γ : Ratio specific hot (usually 1.33 for refrigerant)

For simplification analysis beginning, focus we are at temperature actual (ΔT_{aktual}) with assumption increase ideal temperature obtained in a way theoretical. The assumption of ΔT_ideal = 25 K for isentropic efficiency calculations is based on industry best practices and previous studies [7], which define this range as optimal for centrifugal chillers operating under standard conditions.

Example Calculation for Test 1

Test Data 1:

T_{suc} = 277.45 K
T_{dis} = 307.25 K

Ascension Temperature Current (ΔT_{aktual}):
$\Delta T_{\text{aktual}} = T_{\text{dis}} - T_{\text{suc}}$
$\Delta T_{\text{aktual}} = 307{,}25 - 277{,}45 = 29{,}8$ K
Efficiency Isentropic ($\eta_{\text{isentropik}}$):

Assumed Ascension Ideal Temperature is 25 K (assumption) theoretical from calculation enthalpy):

$$\eta_{\text{isentropic}} = \frac{\Delta T_{\text{ideal}}}{\Delta T_{\text{aktual}}}$$

$$\eta_{\text{isentropic}} = \frac{25}{29{,}8} = 0{,}838\ (83{,}8\%)$$

Based on the calculated isentropic efficiency using suction temperature (T_{suc}) and discharge temperature (T_{dis}) data, the efficiency values ranged from **83% to 90%**, indicating that the compressor operates within a **moderately efficient range**, though not yet fully optimized.

- **Higher efficiencies (≈90%)**, observed in **Tests 18, 21, and 25**, suggest that the compressor operates near ideal conditions, with minimal energy loss during compression.
- **Lower efficiencies (≈83%)**, found in **Tests 1–5**, may indicate mechanical degradation, refrigerant imbalance, or suboptimal operating conditions.

The actual temperature increase (ΔT_{actual}) varied between **29.7 K and 30.2 K**, showing relatively stable thermal behavior across tests. However, lower discharge temperatures in early tests may point to energy losses or inefficiencies in the compression cycle.

3.4. Refrigerant Pressure Analysis

Refrigerant pressure analysis is essential for evaluating the thermal balance and operational integrity of a chiller system. By examining the low-side pressure (PRE) and high-side pressure (PRC) across 30 test cycles, insights can be drawn regarding the efficiency of heat transfer in the evaporator and condenser, as well as the overall stability of the refrigeration cycle.

Calculation Difference Pressure for Test 1:

- Pressure side low (PRE) = 248.3 kPa
- Pressure side height (PRC) = 753.2 kPa

$$\Delta P = PRC - PRE$$
$$\Delta P = 753{,}2 - 248{,}3 = 504{,}9\ kPa$$

This pressure differential falls within the acceptable range for typical refrigeration systems, indicating that the cycle is functioning within operational limits.

Performance Trends Across 30 Tests

- **Evaporator Pressure (PRE)**: Stable between **2.47 to 2.49 barg** (~247–249 kPa), suggesting consistent refrigerant evaporation and effective heat absorption from the cooling water.
- **Condenser Pressure (PRC)**: Fluctuated between **749 kPa and 761 kPa**, with peak values reaching **7.61 barg**, indicating potential thermal stress or condenser inefficiencies.

The stability of the low-side pressure confirms that the evaporator is operating effectively, with minimal flow disturbances. However, elevated high-side pressures in several tests suggest thermal imbalance, likely caused by:

- Fouling or scaling on condenser surfaces
- Poor cooling water quality
- Inadequate cooling water flow rates

These conditions hinder heat rejection, causing pressure buildup in the condenser. If unchecked, this can degrade chiller performance, increase energy consumption, and reduce system efficiency.

The observed pressure differentials ranging from **500 to 512 kPa** are within acceptable limits but indicate a **thermal imbalance** when correlated with rising condenser pressures. This imbalance forces the compressor to operate under higher load conditions, reducing isentropic efficiency and increasing power demand.

These findings are consistent with research by **Mittal et al. (2017)**, which highlights that elevated condenser pressures—often due to fouling or poor heat rejection—correlate with reduced Coefficient of Performance (COP) and overall system efficiency.

To restore thermal balance and enhance chiller performance, the following corrective actions are advised:

- 🧼 **Routine cleaning of condenser surfaces** to remove fouling and scaling
- 💧 **Optimization of cooling water flow rates** to improve heat rejection
- 📊 **Periodic monitoring of condenser pressure** to detect early signs of inefficiency

By stabilizing condenser pressures and maintaining a healthy pressure differential, the chiller system can operate more efficiently, reduce compressor workload, and extend component lifespan.

3.5. Specific Energy Consumption (SEC) Analysis

Consumption Energy Specific (SEC) is used For evaluate efficiency energy internal chiller system produce capacity cooling per unit of power consumed by the compressor. Consumption energy specific counted For evaluate efficiency energy per ton of cooling:

$$\mathrm{SEC} = \frac{W_{\mathrm{compresor}}}{Q_{\mathrm{evaporator}}}$$

Data $\boldsymbol{W}, \boldsymbol{T_{ei}}, T_{eo}$ and test data used for calculation This. SEC results are compared with standard efficiency for determine performance relatively system.

Calculation For Test 1

It is known from Test 1 data:

- Compressor power ($\boldsymbol{W}_{\mathrm{compressor}}$) = 300 kW
- Cooling water flow rate ($\boldsymbol{m}$) = 90.17 L/s
- Temperature entering the evaporator ($\boldsymbol{T}_{\mathrm{ei}}$) = 281.85 K
- Temperature exiting the evaporator ($\boldsymbol{T}_{\mathrm{eo}}$) = 279.25 K
- Capacity hot specific water (cp) = 4.186 kJ/ kg·K

Count Capacity Cooling ($\boldsymbol{Q}_{\mathrm{evaporator}}$)

Formula:

$$Q_{\mathrm{evaporator}} = \dot{m} \cdot c_p \cdot (T_{ei} - T_{eo})$$

Where:

- $\boldsymbol{M}^{\cdot}$ in kg/s (1 L/s ≈ 1 kg/s because water density ≈ 1 kg/L)
- $\boldsymbol{Cp}$ = 4.186 kJ/ kg·K

Substitution mark:

$$Q_{\mathrm{evaporator}} = 90{,}17 \cdot 4{,}186 \cdot (281{,}85 - 279{,}25)$$
$$Q_{\mathrm{evaporator}} = 90{,}17 \cdot 4{,}186 \cdot 2{,}6$$
$$Q_{\mathrm{evaporator}} = 981{,}83\ \mathrm{kW}$$

Count Consumption Energy Specific (SEC)
Formula:

$$\text{SEC} = \frac{W_{\text{compresor}}}{Q_{\text{evaporator}}/3{,}517}$$

Conversion kW to ton of refrigeration (1 ton refrigeration = 3,517 kW).
Substitution mark:

$$\text{SEC} = \frac{300}{981{,}83/3{,}517}$$

Count mark denominator:

$$Q_{\text{evaporator}}\ (\text{ton}) = \frac{981{,}83}{3{,}517} = 279{,}2\ \text{ton}$$

Substitution return:

$$\text{SEC} = \frac{300}{279{,}2} = 1{,}07\ \text{kW/ton}$$

Calculation Results
- Capacity Cooling ($Q_{\text{evaporator}}$) = 981.83 kW
- Consumption Energy Specific (SEC) = 1.07 kW/ton

SEC value as big as 1.07 kW/ton show that performance energy the chiller system in Test 1 is still Enough efficient. As benchmark, good SEC value for chiller range between 0.6 to 1.2 kW/ton, depending on the load operational and conditions environment. With mark this, system still work in range reasonable efficiency. However, it is necessary Keep going monitored for ensure optimal performance, especially under heavy loads operational tall or condition changing environment.

Specific Energy Consumption (SEC) was calculated to evaluate the energy efficiency of the chiller in kW per ton of cooling. The average SEC was 0.82 kW/ton, within the acceptable range of 0.6 to 1.0 kW/ton.

However, tests with **higher compressor workloads (above 75 kW)** showed SEC values exceeding **0.95 kW/ton,** indicating suboptimal energy performance. Conversely, lower workloads (below 70 kW) resulted in SEC values closer to 0.75 kW/ton.

- **Primary Finding:** Compressor workload directly influences SEC, with excessive loads leading to higher energy consumption. These findings align with **Deng et al. (2023),** who emphasized the role of workload management in optimizing chiller performance.
- **Mitigation Strategy:** Balancing the chiller load by redistributing cooling demand across multiple units can prevent overloading and reduce SEC, contributing to long-term energy savings.

4. Conclusions

This study aimed to evaluate the performance of a water-cooled centrifugal chiller system based on refrigerant pressure, compressor efficiency, superheat and subcooling values, and specific energy consumption (SEC).

The findings indicate that condenser pressures frequently exceed the 7.5 barg threshold, suggesting inefficiencies in heat rejection. The compressor exhibits isentropic efficiency between 83–90%, though early fluctuations point to potential mechanical degradation. Superheat values remain within the optimal range (5.2–5.5 K), while negative subcooling values (–4.1 to 0 K) reflect incomplete condensation, which can impair cooling capacity. SEC values range from 1.07 to 1.25 kW/ton, indicating moderate energy performance below optimal standards.

In conclusion, targeted improvements in condenser performance, compressor maintenance, and cooling water flow control are essential to enhance energy efficiency and ensure long-term operational reliability.

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Conflict of Interest

The authors declare no conflict of interest related to the publication of this study.

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