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Performance Optimization of Power Plant Waste Heat Using H2O-LiBr Absorption Refrigerant System

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ABSTRACT

This paper examines the use of waste energy in a 3x1 MW Gas Engine Power Plant (GEPP) on Bawean Island, Indonesia. The feasibility method uses water-lithium bromide (H_2O-LiBr) technology as absorption refrigeration technology. In addition, bananas are also used for cold storage to overcome waste energy utilization. The cold storage is placed in the 300 m^3 area with a 100 kg load capacity for a banana with a temperature of 5°C, 85% humidity, 24 hours of operation, 1292 W cooling load, and 371 TR. This system is used because it utilizes a cheap energy source that dissipates heat from gas and has no ecological hazards, such as ozone layer depletion and global warming. The exhaust gas temperature is 500°C. Moreover, cooling loads for cold storage, which are used with thermodynamic models, and consistent fluid properties, performance, and size of cold storage were also investigated. The results obtained show that higher cold storage output comes from internal factors as compared to external factors. In addition, the absorption refrigerant with Tevaporation is 5°C, capacity 403 TR and $Q_{absorption}$ is 984 kW, $Q_{generator}$ is 1066 kW, $Q_{evaporation}$ is 1411 kW, $Q_{condenser}$ is 1493 kW, with an absorption coefficient of performance (COP) of 1.32 and power consumption of 158,25 kW. Furthermore, after calculations, analysis, and field experiments, it shows that the internal factor of the cooling load is higher than the external factor sourced from bananas in the cold storage. This phenomenon occurs probably due to the product being refrigerated, following the soar cooling capacity. Thus, the waste energy in PLTGU 3x1 MW has tried to be utilized by the refrigerant absorption system.

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1. INTRODUCTION

Most industrial power plants exploit waste heat and have significant problems with increasing energy demand due to environmental problems [1–3]. LiBr absorption refrigerant cooling systems are a potential application in residential and commercial buildings [4]. The water absorption system can also use a refrigerant and an H_2O-LiBr solution as an absorbent. The refrigerant pair is potential because it is non-flammable, non-toxic and has no associated environmental hazards such as ODP (Ozone Depletion Potential) or GWP (Global Warming Potential) [4]. However, performance drops rapidly as ambient temperature increases [5].

Therefore, to overcome this problem, the use of H_2O-LiBr solutions tends to crystallize at high ambient temperatures [6, 7]. Cold storage is a room designed with certain temperature conditions and is used to store various types of products to maintain their freshness. Cold storage has several types known chilled room, freezer room, blast freezer, and blast chiller [8]. The condition in the cooling room is 1°C – 7°C and used to store fresh food ingredients such as vegetables and fruits that can last no more than 60 days [9, 10].

In addition, the freezer room has a temperature condition in the range of -15°C to -20°C, which is used to store meat, milk, and cheese. The blast freezer can be used to quickly cool raw materials, such as frozen or processed foods. This blast freezer's temperature achievement is generally targeted at -20°C to -35°C [11–13].

This study was conducted at the 3x1 MW Gas Engine Power Plant located on Bawean Island. The exhaust gas is obtained from the 3x1 MW Gas Engine Power Plant (GEPP) as heat energy sourced from the cold storage chilled room, which stores vegetables, fruits, and other foodstuffs that can last no more than 60 days. Cold storage uses LiBr absorption refrigeration, where the output temperature is 5°C with 85% humidity [14, 15]. Furthermore, to take advantage of the refrigerant absorption performance system; coefficient parameters, performance coefficient, and cooling capacity are discussed in this paper.

2. RESEARCH METHODOLOGY

This research is conducted by measuring the exhaust gas of a gas engine 3×1 MW, while the properties for absorption refrigeration and finding the model in the market have been analyzed. Cold storage using absorption refrigeration at cooled temperature has been investigated. This cold storage system is subjected to vegetables and fruit, suitable for the condition of exhaust gas from gas engine 3x1 MW applied on Bawean Island. The illustration of the absorption refrigerant system application is shown in **Figure 1**.

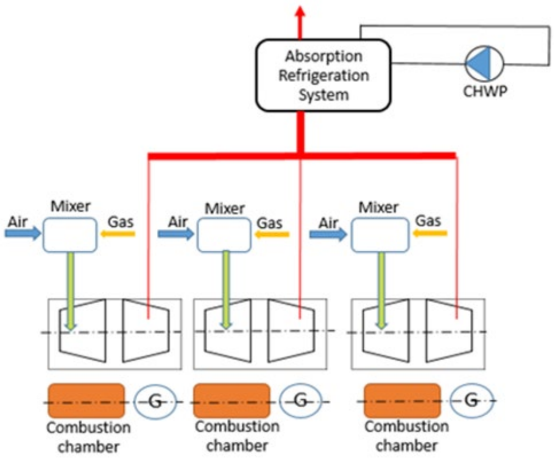

Figure 1. Installation of absorption refrigeration system

The exhaust heat measures the refrigerant absorption in LiBr and plans for cold storage calculation data from a 3×1 MW gas engine power plant. The raw data are the specification of the 3×1 MW gas engine (**Table 1**), exhaust gas temperature, jacket water temperature, Cos Phi (**Table 2),** specification of the broad X chiller (**Table 3** and **Table 4**).

Table 1. Specification of gas engine

Specification	Gas Engine 1 (M1)
Model	JGS 320 GS-N.L
Maximum Continuous Rating	1067 kW
Fuel Type	Natural Gas
Maximum Electrical Efficiency	40.2 %
Frequency	50 Hz
RPM	1500/2250 RPM

Table 2. Temperature of exhaust gas, jacket water and Cos Phi of machine gas

Day/Time		Gas Engine 1		
		$T_{Exhaust}$	Jacket Water	Cos Phi
Time	03:00	538.5	84.1	0.936
Monday	05:00	539.10	84.1	0.932
	08:00	533.30	83.2	0.934
	11:00	533.20	83.7	0.932
	14:00	533.3	84	0.934
	17:00	533.6	83.3	0.934
	20:00	546.9	84.7	0.937
	23:00	537.25	83.4	0.936
Time	03:00	537.55	83.8	0.933
Sunday	05:00	537.95	84.1	0.933
	08:00	529.65	83.7	0.931
	11:00	529.65	83.4	0.936
	14:00	536.2	84.1	0.935
	17:00	525.75	82.7	0.932
	20:00	545.60	85	0.932
	23:00	542.15	84.1	0.933

Table 3. Specification of absorption refrigerant

Model	BROAD X BE75
Cooling Capacity	872 kW
Rate Exhaust Temperature	500°C / 160°C
COP_{abs}	1.41
Lithium Bromide solution	52%
Rated Condensate Temperature	95°C
Rated Chilled Temperature	7°C / 14°C
Rated Cooling Temperature	37°C / 30°C
Lowest Permitted Outlet Temperature	5°C
Energy Source	Waste Heat from Exhaust Gas

Table 4. Unit specification of absorption refrigerant BROAD X BE75

Chilled Water		Exhaust Source	
T_{Outlet}	7°C	$T_{Outlet\ Exhaust}$	170°C
T_{Inlet}	12°C	$T_{Inlet\ Exhaust}$	500°C
Flow rate	67.2 ltr/sec	Flow rate	40 kg/h
Cooling Water		**Diluted Solution**	
T_{Outlet}	32°C	T_{Inlet}	90°C
T_{Inlet}	27°C	T_{Outlet}	41°C
Flow rate	71.1 ltr/sec	Flow rate	10.3 ltr/sec

The next data investigation is materials for cold storage design. The raw data is cold storage material specifications for the wall, roof, and floor layer, as shown in **Table 5** and **Table 6**.

Table 5. Plan specification of cold storage

	Specification
Dimension	10 m × 10 m × 3 m
Room Temperature	5 – 8 °C
Temperature Evaporator	5°C
Cooled Product	Banana
Quantity	100 kg
Room Insulation	PU with 75 mm
Outside Temperature	28°C
Temperature product before cooling	14°C
Operation Hour	24 hour
Labor	1 Person
Lamp	40 Watt

Table 6. Material used for wall, roof and floor layer cold storage

Material	Width (m)	Thermal Conductivity (W/m^2K)
Wall Layer Cold Storage		
Color bond steel	0.0005	31.2
Polyutethan	0.075	0.046
Color bond steel	0.0005	31.2
Roof Layer		
Color bond steel	0.0005	31.2
Polyutethan	0.075	0.046
Color bond steel	0.0005	31.2
Floor Layer		
Color bond steel	0.0005	31.2
Polyutethan	0.075	0.046
Color bond steel	0.0005	31.2

The analysis of LiBr absorption refrigeration and plan for cold storage can be done using MATLAB, such as cooling capacity COP_{abs}, the heat of each unit, power consumption, and power specifically. In addition, for cold storage analysis are cooling load through the walls of the room; through the roof of the room; through the floor of the room; through the infiltration of the room; from the product to be cooled; from the labor and from the equipment lamp. The absorption refrigerant is calculated using Eq. 1 to Eq. 18:

Absorption Refrigerant

- Heat Balance

$$Q_{gen} + Q_{evap} = Q_{ab} + Q_{con} \quad (1)$$

$$Q_{evap} = \dot{m} \times c_p \times \Delta T_{Chilled\ Water} \quad (2)$$

$$Q_{ab} = \dot{m} \times c_p \times \Delta T_{Diluted\ Solution} \quad (3)$$

$$Q_{con} = \dot{m} \times c_p \times \Delta T_{Cooling\ Water} \quad (4)$$

- Coefficient of Performance (COP)

$$COP = Q_{evap}/Q_{gen} \quad (5)$$

$$Cooling\ Capacity = Q_{evap}/3.5 \quad (6)$$

- Power Specific

$$Tr/Kw = P_{consumption}/Cool\ Capacity \quad (7)$$

Plan Cold Storage

$$Q_{wall} = A \times U \times \Delta T\ (T_{surr} - T_{cold\ storage}) \quad (8)$$

$$Q_{roof} = A_{roof} \times U \times \Delta T\ (T_{surr} - T_{cold\ storage}) \quad (9)$$

$$Q_{floor} = A_{floor} \times U \times \Delta T\ (T_{surr} - T_{coldstorage}) \quad (10)$$

$$Q_i = V_{storage} \times (x_i) \times (q_i)/24\ hours \quad (11)$$

$$Q_1 = m \times C_o \times \Delta T\ (T_{surr} - T_{freeze}) \quad (12)$$

$$Q_2 = m \times C_l \quad (13)$$

$$Q_3 = m \times C_u \times \Delta T\ (T_{freez} - T_{coldstorage}) \quad (14)$$

$$Q_c = Q_1 + Q_2 + Q_3 \quad (15)$$

$$Q_{sensible} = N \times SHG \times CLF \quad (16)$$

Then, to find the Qlatent of labour is by the following equations:

$$Q_{latent} = N \times LHG \quad (17)$$

$$Q_{latent\_Lamp} = N \times P_{lamp} \times BF \times CLF \times SF \quad (18)$$

where h is specific enthalpy (kJ/kg), m is the mass flow rate (kg/s), P is pressure (kPa), T is the temperature (^oC), Q is the heat transfer rate (kW), C is LiBr mass concentration (%), COP is the Coefficient of Performance. In addition, the nomenclature of subscription for gen is generator, con is the condenser, eva is the evaporator, ab is the adiabatic absorber, sub 1 is weak solution sub-cooler, sub 2 is intermediate solution sub-cooler and sub 3 is strong solution sub-cooler.

3. RESULTS AND DISCUSSION

The analytical results for power consumption of absorption refrigerant and the output of absorption refrigerant are shown in **Table 7** and **Table 8**, respectively. Cooling loads through the walls of the room (referred to **Table 5**) are shown the convection heat transfer coefficient f_i = 9.24 W/m^2K and f_o = 22.4 W/m^2K. Cooling loads through the roof of the room (referred to **Table 5**) are obtained f_i = 9.24 W/m^2K and f_o = 22.4 W/m^2K. Cooling loads through the floor of the room (referred to **Table 5**) are obtained f_i = 9.24 W/m^2K. Cooling loads through infiltration of the room are obtained from the conditions of volume cold storage = 300 m^2, operation hour = 24 hour, air exchange (x_i) 14 /day, heat gain (q_i) = 28°C = 28 $kcal/m^3$.

Table 7. Power Consumption of Absorption Refrigerant

Power Consumption			
Source : BZHE 125 Abs. Chiller			
	Qty	***Power* [kW]**	***Total Power* [kW]**
Chilled Water Pump (CHWP)	1	75	75
Cooling Water Pump (CWP)	1	55	55
Motor Fan Cooling Tower	4	5.5	22
Solution Pump	1	5.5	5.5
Refrigerant Pump	1	0.75	0.75
Total			158.25

Table 8. Output of Absorption Refrigerant

Heat Balance	
Q_{ab}	984.1650 kW
Q_{evap}	1.4112e+03 kW
Q_{gen}	1.0661e+03 kW
Q_{con}	1.4931e+03 kW
COP	1.32
Power Consumption	158.25 kW
Cooling Capacity	403 TR
Power Specific	0.3925 kW

Cooling loads from the product to be cooled is 100 kg banana has resulted in the product before entering cold storage at a temperature of 14^oC, the room temperature of cold storage of 5–8^oC. The final evaporation temperature is 5^oC. The cooling process is carried out for 24 hours, at freezing point of -1.2^oC ; C_o = 0.92 kcal/kg^oC; Cu = 0.47 kcal/kg^oC; Cl = 71 kcal/kg^oC. Cooling loads sourced from people is analyzed from the conditions of SHG = 80 W (referred to the table heat gain); CLF = 0.49 (referred to the table of cooling load factor), N is labor quantity, LHG =140 W (referred to the table of heat gain). However, the cooling load sourced from equipment light is analyzed by heat from humans, the internal factor is the heat source from the lamp, i.e. latent heat, which is the amount of latent heat obtained from the lights.

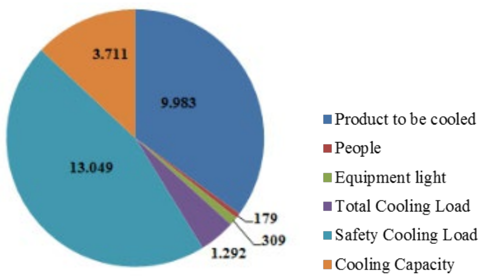

Figure 2. Graph of the utilization of banana cold storage from internal factor cooling source

The analytical results are clearly shown that the internal factor is higher than the external factor of cooling load sourced for banana cold storage. These phenomena can be occurred due to the product being cooled, following the cooling capacity is very high. It is correlated with the following graphs as shown in **Figure 2** and **Figure 3**.

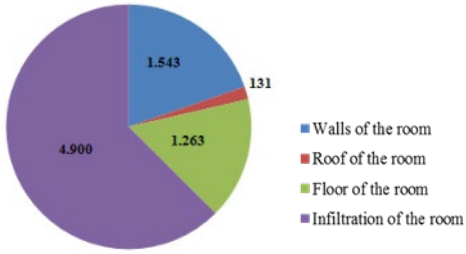

Figure 3. Graph of the utilization of banana cold storage from external factor cooling source

To validate the LiBr-H_2O absorption refrigerant system, these results have been compared with data available from works of literature [16–19]. **Figure 4** shows a graph of the average of COP for each material used for the absorption refrigerant system, compared with other works. The lowest and the highest averages of COP are 0.773 and 2.459, which were obtained from NH_3-H_2O and NH_3-$LiNO_3$ absorption refrigerant systems, respectively [16]. In addition, the average COP has resulted from 0.8133 to 1.325 using H_2O-LiBr [17–24]. Certainly, although the material used is the same and the results from references [17] to [19] are close to the results calculated in this study, the tools and conditions used are different. These can cause differences in results. However, through this discussion, it has been proven that the process of an absorption refrigerant system is stated to be effective in achieving optimum power consumption as energy savings.

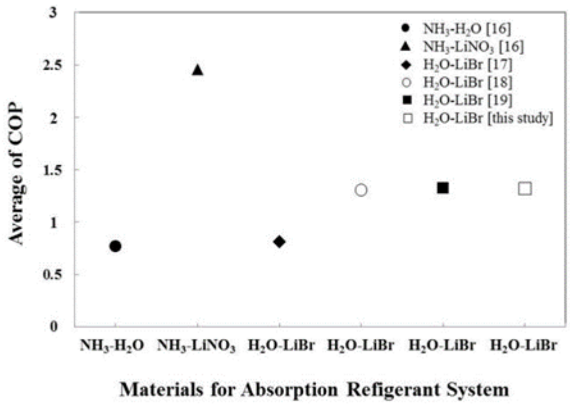

Figure 4. Graph of the average of COP v.s. materials for the absorption refrigerant system compared with other references [16-18]

Furthermore, another cooling system, such as solar-powered vapor absorption refrigeration (SVAR), has been discussed by Somesh et al., in his report, who concluded that the absorption refrigeration system can produce various temperatures for cooling and air conditioning by adopting renewable energy sources [25]. This technology can not only serve the demands for air conditioning applications but also does not meet the requirements for energy conservation and climate protection [25]. Poor COP and low solar collector efficiency essentially hinder the commercialization of this system from prototyping to the final product [25]. However, further research is required to increase heat and mass transfer and to improve system performance.

4. CONCLUSIONS

The utilization of exhaust energy by the H_2O-LiBr absorption refrigerant system has been investigated in this research. The summaries are as follows:

a. Waste heat from a 3×1 MW exhaust gas engine with a temperature of 500°C is suitable for cold storage using an absorption refrigerant system for vegetables and fruits.

b. The weight of a banana which is able to cool with a cold storage system is 100 kg at 5°C temperature, 85% humidity, 24-hour operation, with a total cooling load factor of 1.2920 x e^{03} W and cooling capacity of 371 TR.

c. Absorption refrigerant system can be used effectively for cold storage, with $T_{evaporation}$ of 5°C, the cooling capacity of 403 TR, $Q_{absorption}$ = 984.1650 kW, $Q_{generator}$ = 1066 kW, $Q_{evaporation}$ = 1411 kW, $Q_{condenser}$ =1493 kW, with the COP of 1.32 and power consumption of 158.25 kW.

d. By calculation, analysis, and field experimenting, the internal factor of cooling load is higher than the external factor sourced from banana cold storage. This phenomenon occurs due to the product being cooled, following the soaring cooling capacity. Thus, the exhaust energy in the 3×1 MW gas engine power plant is successfully utilized by the absorption refrigerant system.

REFERENCES

Acciaro, M. G. (2014). Energy management in seaports: A new role for port authorities. *Energy Policy, 71*, 4-12.

Auh, P. (1977). Survey of absorption cooling technology in solar applications. *In Brookhaven National Lab. Report, no. BNL-50704, Upton, NY, USA*, 1977.

Belman-Flores, J. L.-M. (2017). Thermal simulation of the fresh food compartment in a domestic refrigerator. *Energies, 10*(1), 128.

Boopathi Raja, V. &. (2012). A Review and New Design Options to Minimize the Capital and Operational Cost of Single Effect Solar Absorption Cooling System for Residential Use. *Emerging Trends in Science, Engineering and Technology*, 3–18.

Chaiwong, S. (2016). Effect of impact and vibration on quality and damage in the British strawberries. *Doctoral dissertation, University of Essex*, 2016.

Dudita, M. D.-F. (2017). Closed Sorption Seasonal Thermal Energy Storage with Aqueous Sodium Hydroxide. *In Conference on Sustainable Energy, Springer*, 239–246.

Ellabban, O. A.-R. (2014). Renewable energy resources: Current status, future prospects and their enabling technology. *Renewable and Sustainable Energy Reviews, 39*, 748–764.

Florides, G. K. (2003). Design and construction of a LiBr–water absorption machine. *Energy Conversion and Management, 44*(15), 2483–2508.

Fuller, R. (2000). Storing frozen food: cold store equipment and maintenance. In Managing Frozen Foods. *Woodhead Publishing Series in Food Science, Technology and Nutrition*, 213–232.

Hang, Y. &. (2010). Design and Analysis of an Integrated Solar Absorption Cooling and Heating System at Purdue University. *In Energy Sustainability, 43956*, 225–230.

Iranmanesh, A. &. (2012). Thermodynamic modelling of a double-effect LiBr-H2O absorption refrigeration cycle. *Heat and Mass Transfer, 48*(12), 2113–2123.

Jiang, L. W. (2000). Transient temperature performance of an integrated micro-thermal system. *Journal of Micromechanics and Microengineering, 10*(3), 466.

Kovacı, T. &. (2018). Energy and exergy analysis of a double-effect LiBr-H2O ab-sorption refrigeration system. *International Journal of Energy and Environment, 9*(1), 37–48.

Lansing, F. (1980). A two-dimensional finite difference solution for the transient thermal behavior of a tubular solar collector. *Solar Energy International Progress, 42*, 328–350.

Lefebvre, E. F. (2015). Lithium bromide crystallization in water applied to an inter-seasonal heat storage process. *Chemical Engineering Science, 133*, 2-8.

Mahlia, T. S. (2014). A review of available methods and development on energy storage; technology update. *Renewable and Sustainable Energy Reviews, 33*, 532–545.

Manu, S. C. (2018). Effect of Cooling Water on the Perfor-mance of Lithium Bromide–Water (LiBr–H2O) Absorption Based Heat Pump. *In IOP Conference Series, Materials Science and Engineering,, 376*(1), 012007.

Neetoo, H. &. (2015). Influence of Growth Temperatures of S almonella and Storage Temperatures of Alfalfa Seeds on Heat Inactivation of the Pathogen during Heat Treatment. *Journal of Food Processing and Preservation, 39*(6), 1992–2000.

Ren, J. Q. (2019). Thermodynamic evaluation of LiCl-H2O and LiBr-H2O absorption refrigeration systems based on a novel model and algorithm. *Energies, 12*(15), 3037.

Somesh, S. S. (2019). A Comprehensive Review on LiBr–H2O Based Solar-Powered Vapour Absorption Refrigeration System. *Advances in Interdisciplinary Engineering*, 343–352.

Sutikno, J. P. (2018). Utilization of Solar Energy for Air Conditioning System. *In EDP Sciences, MATEC Web of Conferences, 156*, 03040.

Tershak, A. F. (1989). Apparatus for controlling a refrigerator in low ambient temperature conditions. *Whirlpool Corp, U.S. Patent no. 4, 834*(4), 169.

Van Hattem, D. &. (1981). Description and performance of an active solar cooling system using a LiBr-H2O absorption machine. *Energy and Buildings, 3*(2), 169–196.

Wang, K. A. (2011). State-of-the-art review on crys-tallization control technologies for water/LiBr absorption heat pumps. *International Journal of Refrigeration, 34*(6), 1325-1337.

Worsfold, D. (1997). Food safety behaviour in the home. *British Food Journal, 99*(3), 97–104.