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Design of Dry Cooling Tower using Solar Energy for MMR

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1. Introduction

Most of world power plant traditionally use the cooling with water, and the types of cooling system are different from each other. The 85% of cooling system are once-through cooling system and closed cycle wet cooling system. However, many countries are trying to reduce the water requirement due to the water shortage and water pollution. Dry cooling system is investigated for water saving advantage. There are two dry cooling system which are direct and indirect cooling system. In direct type, turbine exhaust is directly cooled by air-cooled condenser. In indirect system, turbine steam is cooled by recirculating intermediate cooling water loop, then the loop is cooled by air-cooled heat exchanger in cooling tower. In this paper, the purpose is to remove MMR waste heat, 24 MWth by using newly designed tower. The possibility of enhancing cooling performance by solar energy is analyzed. [1]

2. Methods

In the paper, the cooling tower of 24 MWt heat removal capacity is introduced. The purpose of designing tower is to cool CO_2 with mass flux of 97kg/s from 148.6ºC to 45ºC in 11MPa. The first design looks like typical wet cooling tower in Fig.1. The design uses the natural draft flow by the difference of air density between tower and ambient air. Second design is solar tower which has the glass roof collector in bottom side of cooling tower in Fig. 2.

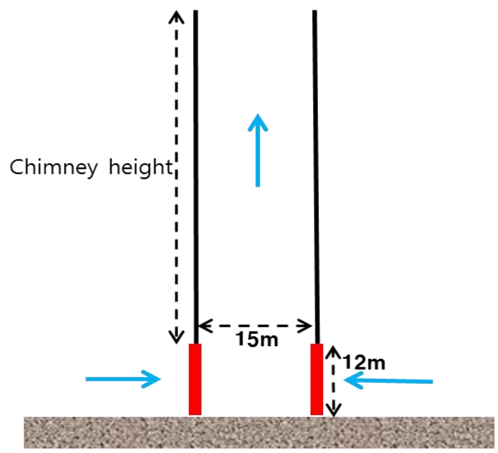


Fig. 1. Simple cooling tower

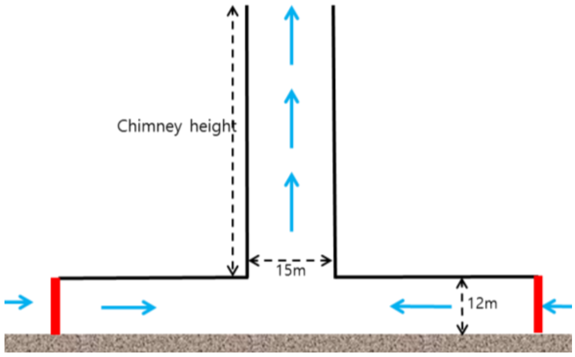


Fig. 2 Solar cooling tower using solar energy

To optimize the cooling tower, the diameter of chimney and height of heat exchanger was assumed in Tab.1.The basic dimensions of two tower and information of tube inside (CO_2) are in Table 1.

Table 1. Basic Cooling tower configuration

Tower diameter (D_{chim})	15 m
Heat exchanger height	12 m
Ambient air temperature(T_1)	25 °C
Tube inside pressure	110 bar
Inlet CO_2 temperature(T_{hin})	148.6 °C
Outlet CO_2 temperature(T_{hout})	45 °C

The heat exchanger is in the bottom of chimney and ambient air cool down the hot CO_2. The heat exchanger is at entrance part of collector and arranged as triangular pitch banks of finned tubes. Heat exchanger consist of finned long tube where heated CO_2 flow through.

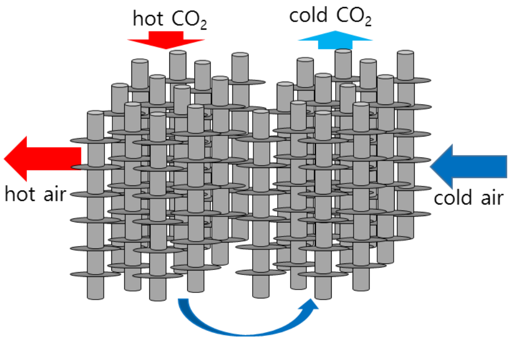


Fig.3. Desing of heat exchanger

The calculation of required chimney height is shown in Fig. 4. First, mass flow rate of air is assumed. When the design of chimney and tube number of heat exchanger are confirmed, the outlet air temperature of HX is calculated. As the number of finned tube was changed, required chimney height is calculated from

MATLAB calculation in Fig.4. Then, the mass flux is calculated using equation (3). To match the pressure difference and pressure drop, the chimney height is calculated using iteration.

$$\dot{Q}_{hx} = UA\Delta T_{ln} = 24 \ \ MWth \quad (1)$$
$$\frac{1}{UA} = \frac{1}{\eta_{fin}A_c h_c} + \frac{ln(D_{out}/D_{in})}{2\pi k_{al}L} + \frac{1}{A_h h_h} \quad (2)$$
$$\dot{Q}_{air} = \dot{m}_a(h_{out} - h_{in}) = 24 \ \ MWth \quad (3)$$
$$\frac{1}{2}\rho v^2 = \Delta\rho g H - \Delta P_{drop} \quad (4)$$

where U is overall heat transfer coefficient, A is heat transfer area in HX. The log mean temperature difference (ΔT_{ln}) is used in heat exchanger. The density difference of chimney makes the natural air flow into chimney. But there are pressure drops by the heat exchanger, friction of chimney wall and inlet & outlet form loss, etc. From equation (3), overall air velocity configuration is obtained.

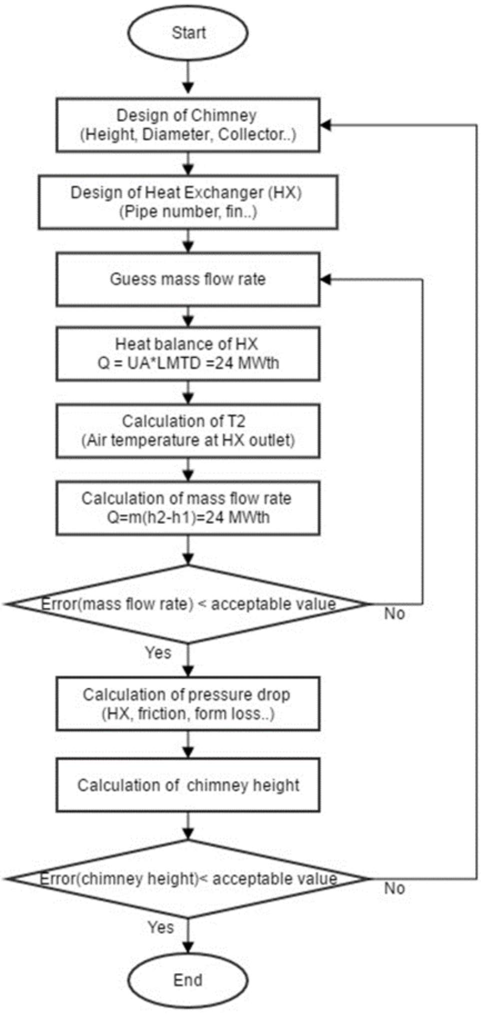


Fig. 4. Calculation flow chart

3. Result

3.1 Simple Cooling Tower

When the tower diameter is 15 m and the height of heat exchanger is 12m, the required chimney height was calculated in simple chimney with finned-tube HX. As the number of HX finned tube increased, the chimney height decreased.

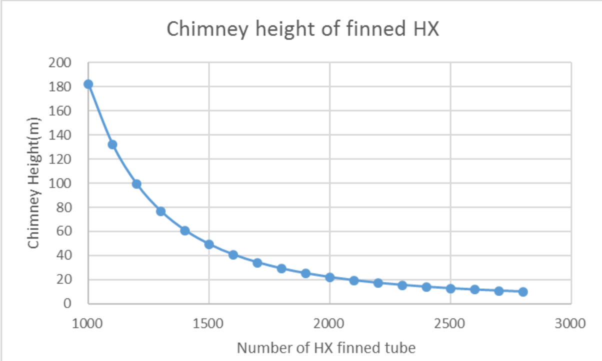
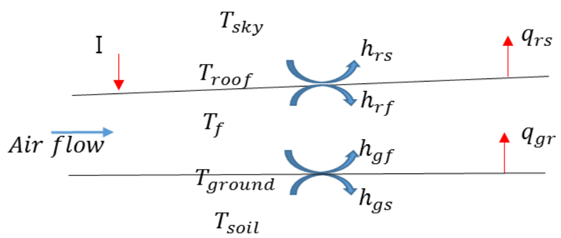


Fig. 4. Required chimney height for simple cooling tower

3.2 Cooling Tower using Solar Energy

The air in collector is heated by the solar energy and the air temperature increase toward center of tower in Fig.2. It makes the inner air density lower, then this phenomenon makes pressure difference between tower and ambient air. Heat exchanger is located in small part and the remainder entrance was blocked from ambient air to increase inlet air velocity. The air temperature profile in collector is obtained by following analysis. The solar radiation is assumed 800 W/m^2.



$$I\alpha_r + q_{gr} = h_{rs}(T_r - T_s) + h_{rf}(T_r - T_f) + q_{rs} \quad (5)$$
$$h_{rf}(T_r - T_f) + h_{gf}(T_g - T_f) = \frac{\dot{m}C_p}{2\pi r}\frac{dT_f}{dr} \quad (6)$$
$$\mathrm{I}\tau_r\alpha_g = \mathrm{h_{gf}}(\mathrm{T_g} - \mathrm{T_f}) + \mathrm{h_{gs}}(\mathrm{T_g} - \mathrm{T_{soil}}) + \mathrm{h_{qgr}}(\mathrm{T_g} - \mathrm{T_r}) \quad (7)$$

where I is global solar radiation, α is absorption coefficient, τ is transmission coefficient and h is convective heat transfer coefficient and q is radiative heat flux.

Finally, tower height was calculated by changing collector radius to meet the purpose of removing 24 MW heat. Fig. 6 show required chimney height for solar cooling tower. The required tower height of solar cooling tower decreased as collector radius increased according to the number of finned tube. When the collector radius is 200 m with number of 1,000 finned tube, the tower height is decreased from 182 m to 118m. As the collector radius increased, the chimney height decreased and approached to some height. However, there are some disadvantage of large collector, which are high cost for collector and maintenance.

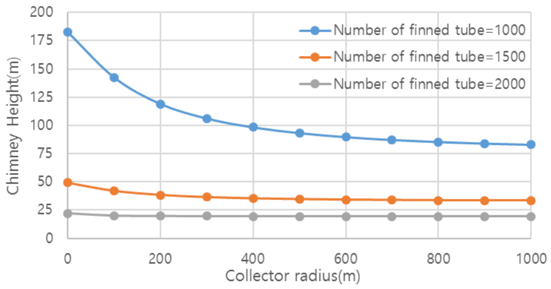


Fig. 6. Required chimney height for solar cooling tower

3.3 Cost analysis for solar cooling tower

In fig. 6, the chimney height decreased as collector radius increased according to the number of finned tube. Therefore, the optimization of solar cooling tower needed to obtain the high efficient dimension. Several cost models for solar chimney was available in Tab.2. [5]

Table 2. Cost of solar cooling tower [5]

Chimney cost	$/m^3	1,232
Collector cost	$/m^2	11
Tube	$/m	4
Finned tube	$/m	10

From the cost of chimney, collector, tube etc., total cost of solar cooling tower is calculated in Fig. 7. The cost decreased as the collector radius increased small because the chimney height decreased by the collector. However, the cost become higher at large collector because the cost of collector increased exponentially. Therefore, we can choose the optimized dimension of solar cooling tower.

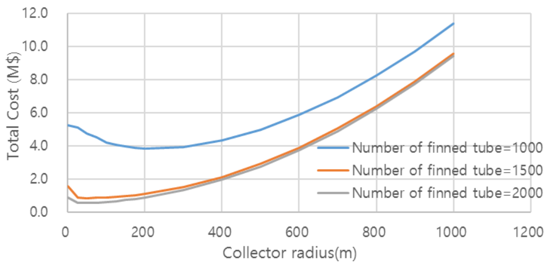


Fig. 7. Total cost for solar cooling tower

3. Conclusion

The simple cooling tower and solar cooling tower are presented and two design should meet the purpose of removing MMR waste heat, 24 MW. In simple cooling tower, as the number of finned tube increase, the required chimney height decreased. In solar cooling tower, as the collector radius increased, the required chimney height is decreased. To optimized the solar cooling tower, the cost analysis was conducted to find low cost tower. To analyze solar cooling tower further, consideration of solar energy performance at night should be analyzed.

ACKNOWLEDGMENTS

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