# Design of Dry Cooling Tower for Waste Heat Removal of SMART using Solar Energy

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# Contents

# *Introduction*

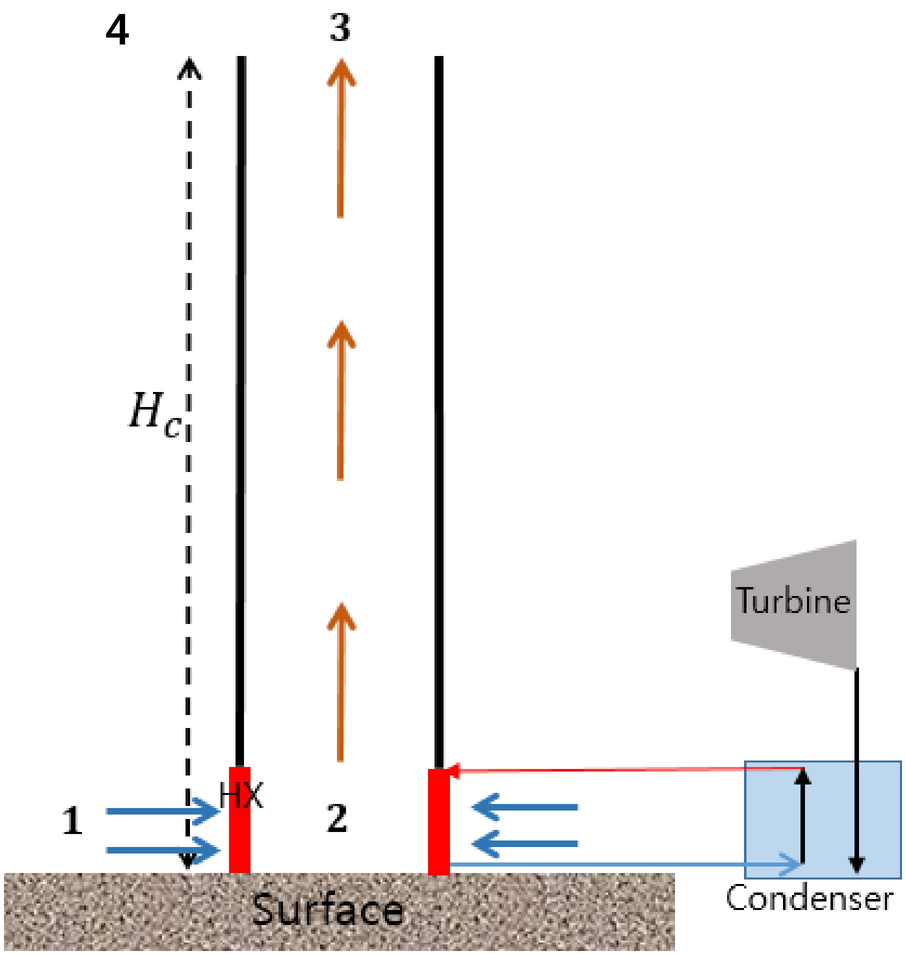
- Dry cooling using solar energy

1) Reducing water requirement for cooling heat of power plant
2) Indirect cooling tower using natural draft with no water
3) Solar energy make more natural draft by heat up air flow in system

- Purpose

1) Removing waste heat of SMART ($200MW_{th}$)
2) Feasibility study of solar chimney using solar energy

# Design of Simple Chimney



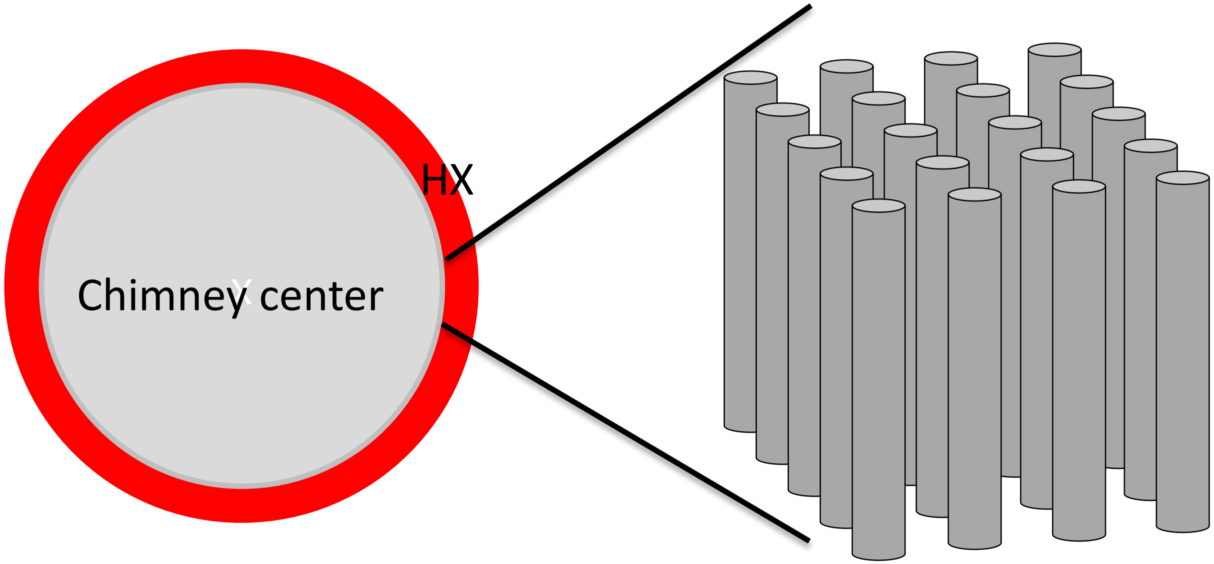

- Fixed parameter

| | |
|---|---|
| Tower diameter ($D_{chim}$) | 70 $m$ |
| Heat exchanger height | 20 $m$ |
| Ambient air temperature ($T_1$) | 35 ℃ |
| Inlet water temperature ($T_{hin}$) | 60 ℃ |
| Outlet water temperature ($T_{hout}$) | 50 ℃ |
| Total heat transfer area of HX($A$) | 200,000 $m^2$ |

- Assumption

1) The ideal gas law
2) Steady state condition
3) Only buoyancy force in chimney
4) No heat loss in chimney wall
5) Constant solar irradiation

# Heat Exchanger Configuration

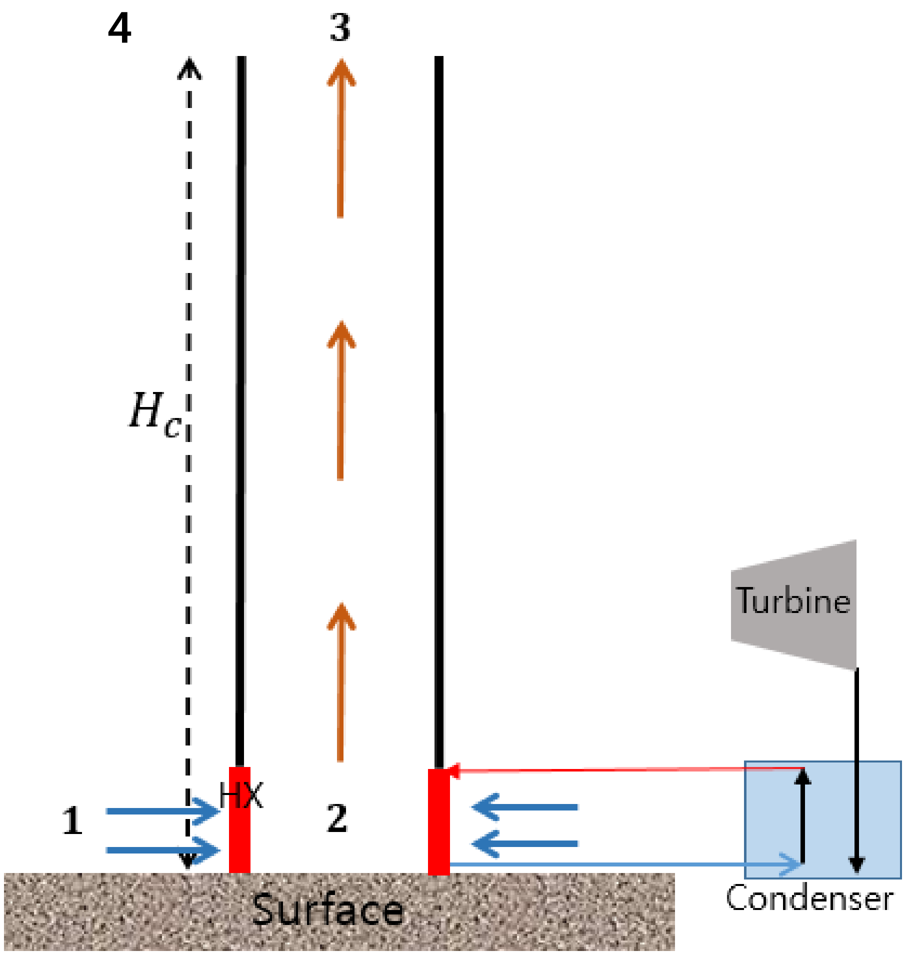



Chimney top view

P=10cm
D=5cm

| | |
|---|---|
| Total heat transfer area of HX($A$) | 200,000 $m^2$ |

# Analysis of Simple Chimney(1)




- Bernoulli's equation

$$P_1 + \frac{1}{2}\rho_1 v_1^2 + \rho_1 g h_1 = P_2 + \frac{1}{2}\rho_2 v_2^2 + \rho_2 g h_2 + \Delta P_{loss}$$

- Heat exchanger

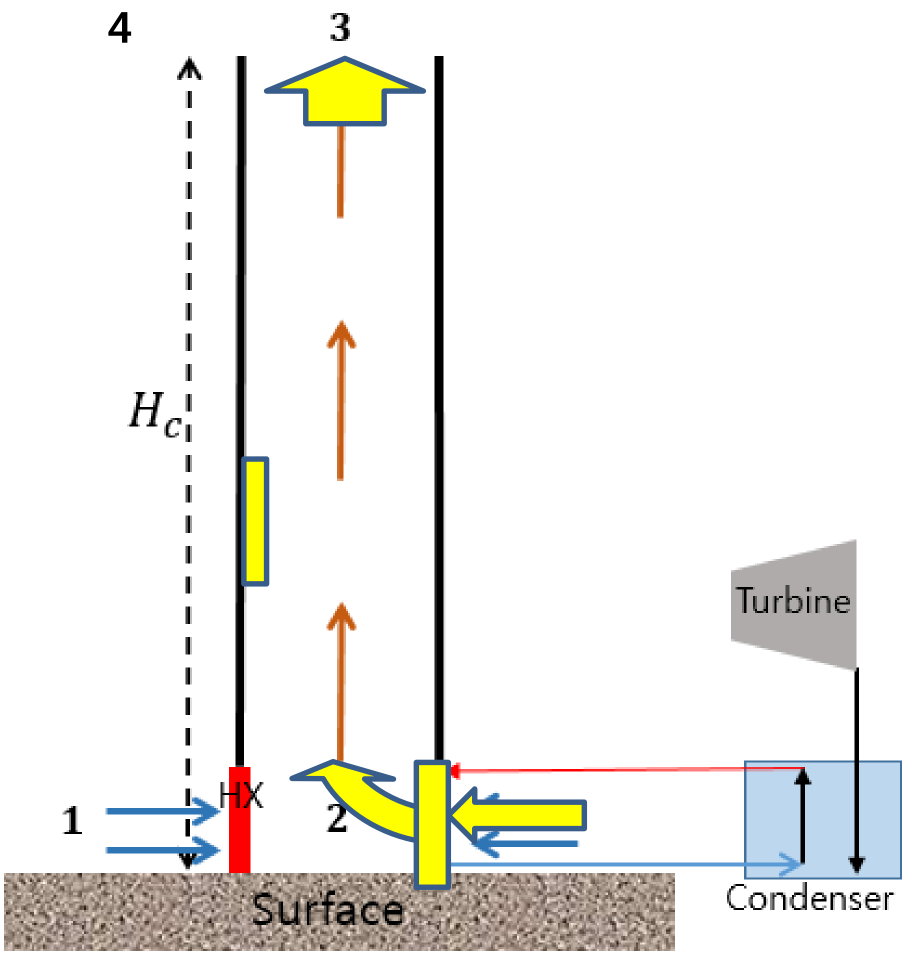
$$UA\Delta T_{ln} = \dot{m}_a C_{p.a}(T_2 - T_1) = 200 \text{ MWth}$$

- Driving Pressure

$$\frac{1}{2}\rho_3 v_3^2 = \int_0^{H_c} (\rho_{out} - \rho_{in}) g dz - \Delta P_{form} - \Delta P_{hx} - \Delta P_{friction}$$

$$\dot{M}_{air} = \rho_3 A_{chim} V_3 = constant$$

# Analysis of Simple Chimney(2)




- Pressure drop

$$\Delta P_{k,1} = K_{in}\frac{\rho_1}{2}V_1^2$$

$$\Delta P_{hx} = K_{hx}\frac{\rho_{hx}}{2}(2V_{hx}^2)$$

$$\Delta P_{k,2} = K\frac{\rho_2}{2}V_2^2$$

$$\Delta P_{f,chim} = f\frac{H}{D}\frac{\rho}{2}V_{chim}^2$$

$$\Delta P_{k,3} = K_{out}\frac{\rho_3}{2}V_3^2$$

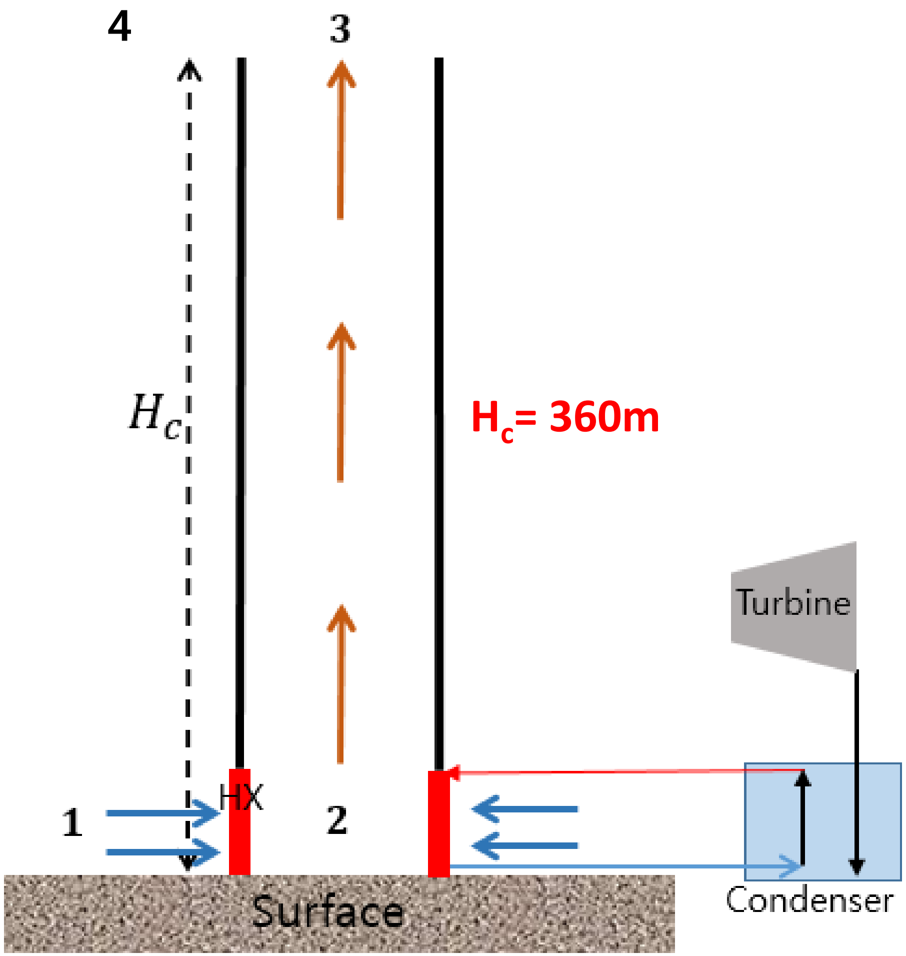
- T,P by height

$$P_4 = P_1\left(1 - \frac{g}{C_p T_\infty}H_c\right)^{\frac{C_p}{R}}$$

$T_4 = T_1 - 0.0065H_c$ (environmental lapse rate($\gamma_\infty$) = 0.0065K/m)

$T_3 = T_2 - 0.0098H_c$( dry adiabatic lapse rate($\gamma$) = 0.0098K/m)

# Result of Simple Chimney




- Temperature, Pressure

| | | | |
|---|---|---|---|
| $T_1$ | 35 ℃ | $P_1$ | 100.186 $kPa$ |
| $T_2$ | 43.6 ℃ | $P_2$ | 100.09 $kPa$ |
| $T_3$ | 40.1 ℃ | $P_3$ | 96.28 $kPa$ |
| $T_4$ | *32.7* ℃ | $P_4$ | *97.54 kPa* |

- Air velocity, Density

| | | | |
|---|---|---|---|
| $v_1$ | 4.6 $m/s$ | $\rho_1$ | 1.13 $kg/m^3$ |
| $v_2$ | 4.8 $m/s$ | $\rho_2$ | 1.09 $kg/m^3$ |
| $v_3$ | 5.6$m/s$ | $\rho_3$ | 1.07 $kg/m^3$ |

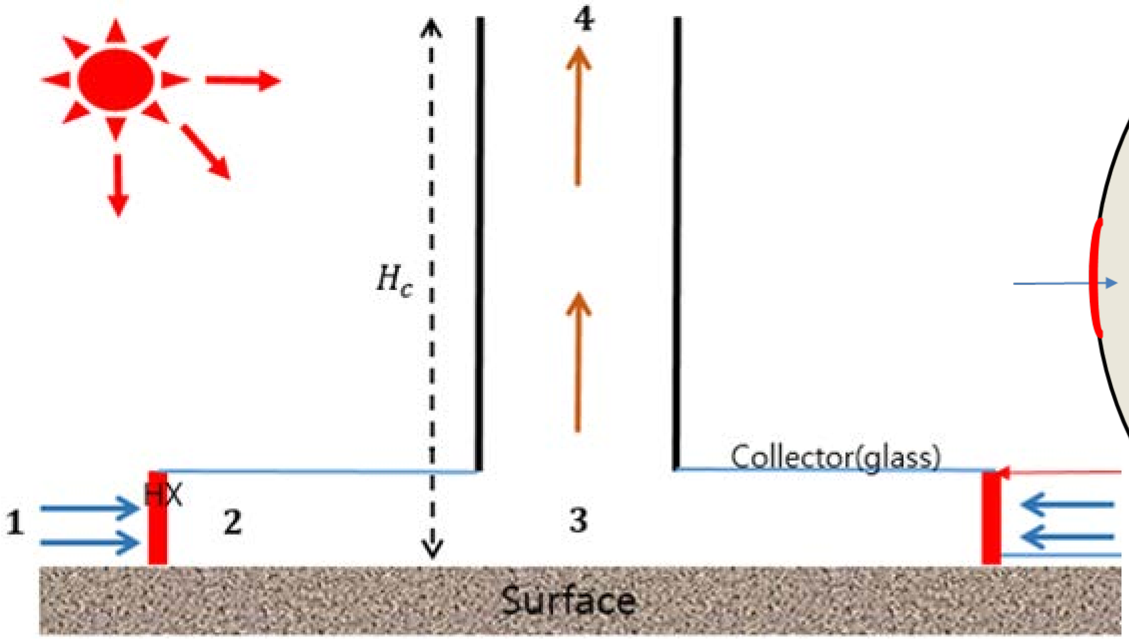
- Mass flow rate = 23180 kg/s
- Pressure difference, pressure drop

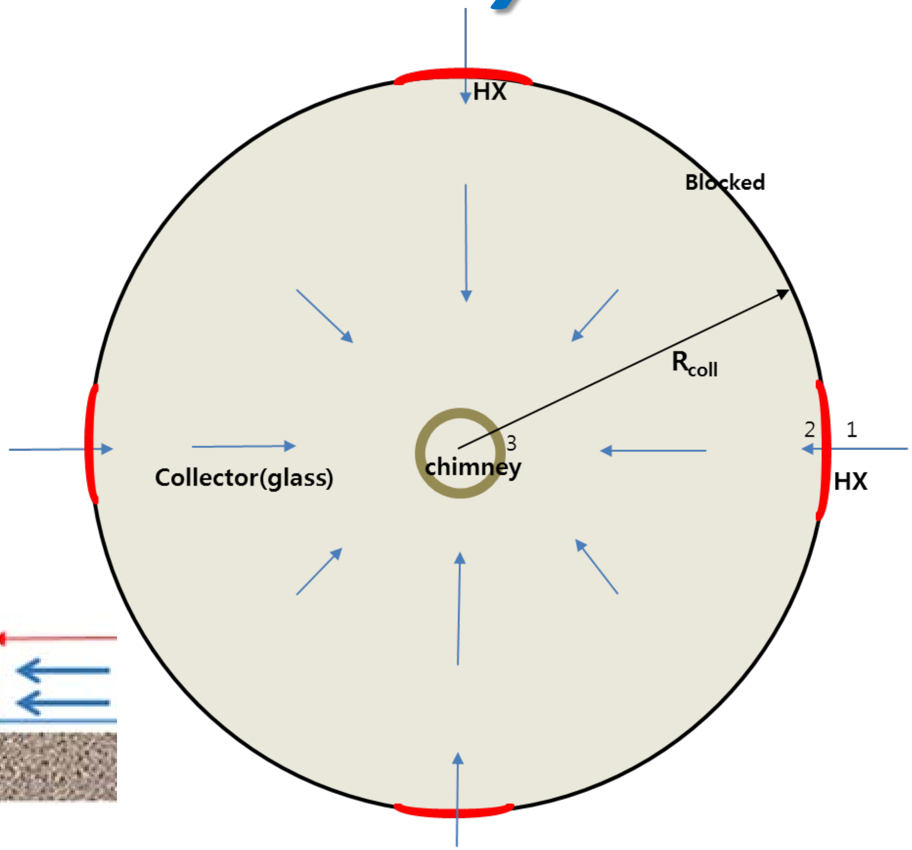
Total driving pressure: 127.95 Pa

Total pressure drop: 111.01 Pa

| | |
|---|---|
| $\Delta P_{k,1}$ | 12.3 $Pa$ |
| $\Delta P_{hx}$ | 74.6 $Pa$ |
| $\Delta P_{k,2}$ | *6.3 Pa* |
| $\Delta P_{f,chim}$ | *0.9 Pa* |
| $\Delta P_{k,3}$ | 16.9 $Pa$ |

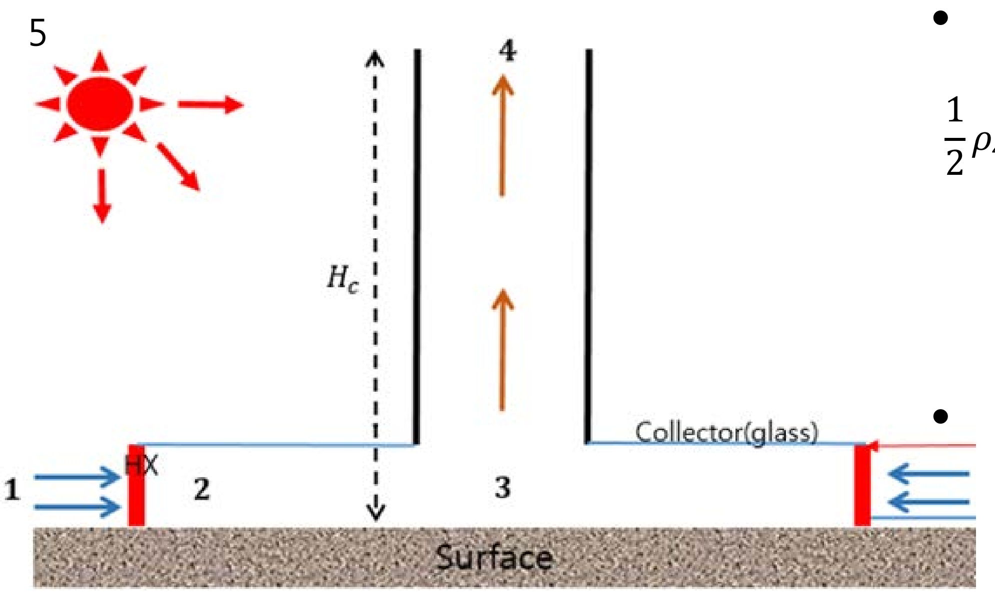
# Design of Solar Chimney




- HX at specific 4 side of round collector
- Constant solar radiation(I) = 1,000 $W/m^2$

# Analysis of Solar Chimney(1)




- Heat exchanger

$$UA\Delta T_{ln} = \dot{m}_a C_{p.a}(T_2 - T_1) = 200\text{MWth}$$

- Driving pressure

$$\frac{1}{2}\rho_4 v_4^2 = \int_0^{H_c} (\rho_{out} - \rho_{in}) g dz - \Delta \text{P}_{form} - \Delta \text{P}_{hx} - \Delta \text{P}_{friction}$$

$$\dot{M}_{air} = \rho_4 A_{chim} V_4 = constant$$

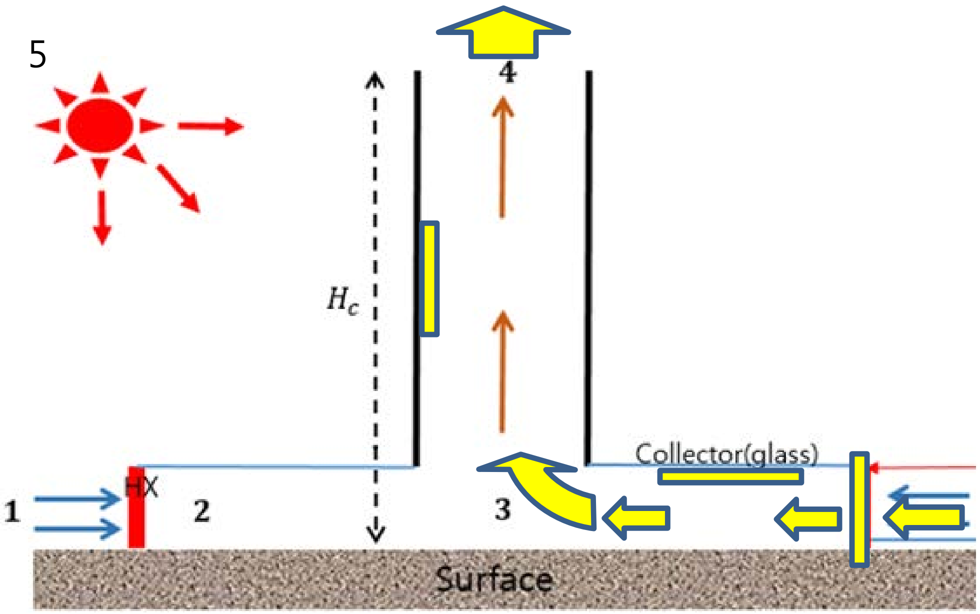
- Collector

$$T_3 = T_2 + \frac{\alpha I}{\frac{\dot{m}_a C_p}{A_r} + U} \quad [1]$$

| | |
|---|---|
| Collector absorption coefficient, $\alpha$ | 0.65 |
| Global solar irradiation, $I(W/m^2)$ | 1,000 |
| Collector loss coefficient, $U(W/m^2K)$ | 15 |

[1] Chitsomboon T, 2013.

# Analysis of Solar Chimney(2)




- Pressure drop

$$\Delta P_{k,1} = K_{in}\frac{\rho_1}{2}V_1^2$$

$$\Delta P_{hx} = K_{hx}\frac{\rho_{hx}}{2}(2V_{hx}^2)$$

$$\Delta P_{k,2} = K_{out}\frac{\rho_2}{2}V_2^2$$

$$\Delta P_{f,collector} = f * \frac{R_{coll}}{H_{coll}} * \frac{\rho}{2} * V_{coll}^2$$

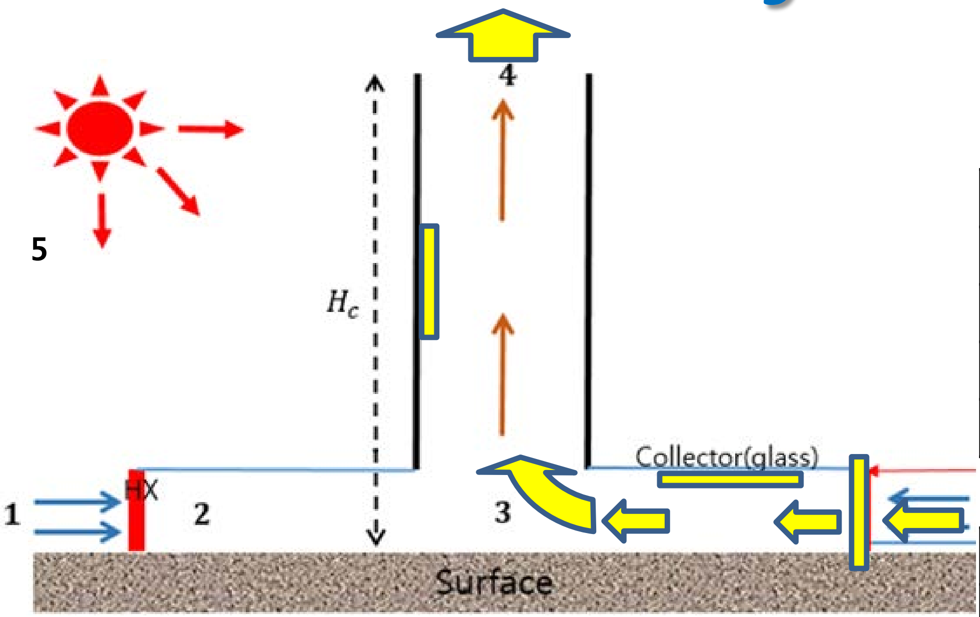
$$\Delta P_{acc} = \frac{m_a^2}{2\rho}(\frac{1}{A_2^2} - \frac{1}{A_1^2})$$

$$\Delta P_{k,3} = K * \frac{\rho}{2} * V_3^2$$

$$\Delta P_{f,chim} = f * \frac{H}{D} * \frac{\rho}{2} * V_{chim}^2$$

$$\Delta P_{k,4} = K_{out} * \frac{\rho_4}{2} * V_4^2$$

# Result of Solar Chimney




At $R_{coll}$ = 500*m*, $H_c$ = 210*m*

- Temperature, Pressure

| | | | |
|---|---|---|---|
| $T_1$ | 35 ℃ | $P_1$ | 100.186 *kPa* |
| $T_2$ | 43.5 ℃ | $P_2$ | 100.09 *kPa* |
| $T_3$ | 57.7 ℃ | $P_3$ | 100.06 *kPa* |
| $T_4$ | 55.6 ℃ | $P_4$ | 97.89 *kPa* |
| $T_5$ | *33.6* ℃ | $P_5$ | *98.64 kPa* |

- Air velocity, Density

| | | | |
|---|---|---|---|
| $v_1$ | 4.7 m/s | $\rho_1$ | 1.13 $kg/m^3$ |
| $v_2$ | 0.7 m/s | $\rho_2$ | 1.09 $kg/m^3$ |
| $v_3$ | 5.1 m/s | $\rho_3$ | 1.05 $kg/m^3$ |
| $v_4$ | 5.9 m/s | $\rho_4$ | 1.03 $kg/m^3$ |

- Pressure difference, pressure drop

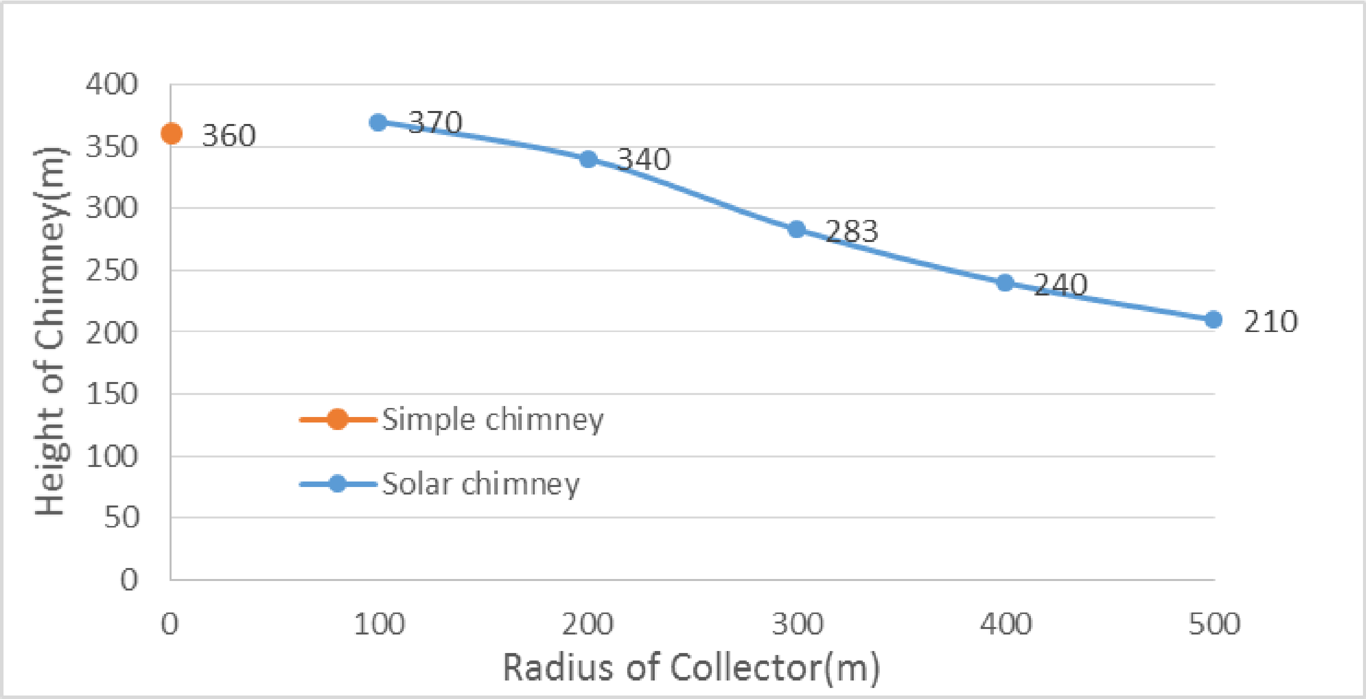
Total driving pressure: 166.9 Pa

Total pressure drop: 148.59 Pa

| | | | |
|---|---|---|---|
| $\Delta P_{k,1}$ | 12.9 *Pa* | $\Delta P_{acc}$ | 13.5 *Pa* |
| $\Delta P_{hx}$ | 78.4 *Pa* | $\Delta P_{k,3}$ | 6.9 *Pa* |
| $\Delta P_{k,2}$ | 12.9 *Pa* | $\Delta P_{f,chim}$ | *0.5 Pa* |
| $\Delta P_{f,coll}$ | 5.1 *Pa* | $\Delta P_{k,4}$ | *18.4 Pa* |

- Mass flow rate = 23760 kg/s

# Comparison of Chimney Height




Height of simple and solar chimney for removing 200$MW_{th}$ heat

# *Conclusion*

- The height of simple chimney is 360*m* for removing 200$MW_{th}$ heat of SMART.

- The height of solar chimney is decreased from 370m to 210m when radius of collector is increased from 100m to 500m.

- Solar energy is not profitable to remove secondary heat, 200MWth.

- The feasibility of solar chimney using solar energy is low.

# Thank you for listening!