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*Gurveer Singh*
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# List of Symbols

| Symbol | Description |
|---|---|
| $A_b$ | Cross sectional area of a partly blocked pore ($m^2$) |
| $A_c$ | Cross sectional area of a clean pore ($m^2$) |
| $A_{c_c}$ | Cross sectional area of 1/6$^{th}$ section of central absorber ($m^2$) |
| $A_{cs}$ | Cross sectional area of an absorber ($m^2$) |
| $A_{tot}$ | The area exposed to concentrated solar irradiance ($m^2$) |
| $A_{cas_c}$ | Cross sectional area of 1/6$^{th}$ section of casing ($m^2$) |
| $A_{p_c}$ | Cross sectional area of peripheral absorber ($m^2$) |
| $A_{ps_cl}$ | Wetted surface area of a clean pore ($m^2$) |
| $A_{ps_bl}$ | Wetted surface area of a partly blocked pore ($m^2$) |
| $A_{rc}$ | Area of influence region around central absorber ($m^2$) |
| $A_{return}$ | Area of return air flow ($m^2$) |
| $A_{rp}$ | Area of influence region around peripheral absorber ($m^2$) |
| $A_{np}$ | Total flow area of absorber ($m^2$) |
| $A_{pore}$ | Cross-section area of absorber pore ($m^2$) |
| $B, B'$ | The coefficients in the quadratic pressure difference |
| $B_c$ | Width of inlet duct of cyclone separator ($m$) |
| $C_d$ | Drag coefficient |
| $c$ | Coefficient |
| $c_{p_ac}$ | Specific heat of primary air in central absorber ($kJ/kgK$) |
| $c_{p_ap}$ | Specific heat of primary air in peripheral absorber ($kJ/kgK$) |
| $c_{p_c}$ | Specific heat of central absorber ($kJ/kgK$) |
| $c_{p_cas}$ | Specific heat of casing ($kJ/kgK$) |
| $c_{pf}$ | Specific heat for fluid/air ($kJ/kgK$) |
| $c_{p_p}$ | Specific heat of peripheral absorber ($kJ/kgK$) |
| $c_{p_rc}$ | Specific heat of return air in central absorber ($kJ/kgK$) |
| $c_{p_rp}$ | Specific heat of return air in peripheral absorber ($kJ/kgK$) |
| $d_{cl}$ | Hydraulic diameter of a clean pore ($m$) |
| $d_{bl}$ | Hydraulic diameter of a partly blocked pore ($m$) |
| $d_{out}$ | Outer diameter of an absorber pore ($m$) |
| $d_{pore}$ | Diameter of an absorber pore ($m$) |
| $dA_{c_s}$ | Surface area of differential element section for central absorber ($m^2$) |
| $dA_{p_s}$ | Surface area of differential element section for peripheral absorber ($m^2$) |
| $dA_{cas_s}$ | Surface area of differential element section for casing ($m^2$) |
| $dA_{nh_c}$ | Surface area of differential element section for pores in central absorber ($m^2$) |
| $dA_{nh_p}$ | Surface area of differential element section for pores in peripheral absorber ($m^2$) |
| $dA_{pl}$ | Surface area of lower half of peripheral absorber ($m^2$) |
| $dA_{pu}$ | Surface area of upper half of peripheral absorber ($m^3$) |
| $d_{pc}$ | Cut point diameter ($m$) |
| $d_{pj}$ | Diameter of particle entering in a cyclone separator ($m$) |
| $dV_{a_c}$ | Volume of differential element section for primary air in central absorber ($m^3$) |
| $dV_{a_p}$ | Volume of differential element section for primary air in peripheral absorber ($m^3$) |
| $dV_{ab_c}$ | Volume of differential element section for central absorber ($m^3$) |
| $dV_{ab_p}$ | Volume of differential element section for peripheral absorber ($m^3$) |
| $dV_{cas}$ | Volume of differential element section for casing ($m^3$) |
| $dV_{rc}$ | Volume of differential element section of region $r_c$ ($m^3$) |
| $dV_{rp}$ | Volume of differential element section of region $r_p$ ($m^3$) |
| $dm_{cas}$ | Mass of differential element of casing ($kg$) |
| $D_c$ | Diameter of a cyclone separator ($m$) |
| $D_e$ | Outlet diameter of cyclone separator ($m$) |
| $F_b$ | Buoyant force ($N$) |

| | |
|---|---|
| $F_c$ | *Centrifugal force (N)* |
| $F_{c_pl}$ | *View factor of central absorber to peripheral absorber* |
| $F_{cas_pu}$ | *View factor of casing to peripheral absorber* |
| $F_d$ | *Drag force (N)* |
| $F_{pl_c}$ | *View factor of peripheral absorber to central absorber* |
| $F_{pu_cas}$ | *View factor of peripheral absorber to casing* |
| $g$ | *Gravitational acceleration (m/s²)* |
| $G$ | *Half of the gap between central and peripheral absorber (G = S/2) (m)* |
| $h_{a_c}$ | *Heat transfer coefficient in pores of central absorber (W/m²K)* |
| $h_{a_p}$ | *Heat transfer coefficient in pores of peripheral absorber (W/m²K)* |
| $h_{cl}$ | *Heat transfer coefficient in a clean pore (W/m²K)* |
| $h_{bl}$ | *Heat transfer coefficient in a partly blocked pore (W/m²K)* |
| $h_{rc_c}$ | *Heat transfer coefficient in region $r_c$ (W/m²K)* |
| $h_{rp_cas}$ | *Heat transfer coefficient in region $r_p$ for casing (W/m²K)* |
| $h_{rp_p}$ | *Heat transfer coefficient in region $r_p$ for peripheral absorber (W/m²K)* |
| $Hc$ | *Height of inlet duct of cyclone separator (m)* |
| $H_f$ | *Total enthalpy of fluid/ air (kJ/kg)* |
| $Hv$ | *Number of inlet velocity heads* |
| $I$ | *Intensity of irradiance at a given location in Bougour's law (W/m²)* |
| $I_o$ | *Intensity of incident irradiance in a pore (W/m²)* |
| $k_c$ | *Thermal conductivity of central absorber (W/mK)* |
| $k_d$ | *Thermal conductivity of dust (W/mK)* |
| $k_{ca}$ | *Thermal conductivity of primary air in central absorber (W/mK)* |
| $k_{cas}$ | *Thermal conductivity of casing (W/mK)* |
| $k_{cr}$ | *Thermal conductivity of return air in region $r_c$(W/mK)* |
| $k_p$ | *Thermal conductivity of peripheral absorber (W/mK)* |
| $k_{pa}$ | *Thermal conductivity of primary air in peripheral absorber (W/mK)* |
| $k_{pr}$ | *Thermal conductivity of return air in region $r_p$ (W/mK)* |
| $k_s$ | *Thermal conductivity of solid (W/mK)* |
| $K$ | *Pressure drop coefficient* |
| $K_p$ | *The coefficient of pressure drop* |
| $K_\infty$ | *Pressure drop coefficient at a reference temperature* |
| $L$ | *Length of absorbers (m)* |
| $L_c$ | *Perimeter of 1/6$^{th}$ section of central absorber (m)* |
| $L_{cs}$ | *Barrel length of cyclone separator (m)* |
| $L_{cs}$ | *Length of region 3 on casing (m)* |
| $L_{pl}$ | *Perimeter of lower half of peripheral absorber (m)* |
| $L_{pu}$ | *Length of region 1on peripheral absorber (m)* |
| $\dot{m}_a$ | *Mass flow rate of air (kg/s)* |
| $\dot{m}_{bl}$ | *Mass flow rate of air in a partly blocked pore (kg/s)* |
| $\dot{m}_{cl}$ | *Mass flow rate of air in a clean pore (kg/s)* |
| $\dot{m}_r$ | *Mass flow rate of return air entering in the primary side of the absorber (kg/s)* |
| $\dot{m}_{rc}$ | *Mass flow rate in region $r_c$ (kg/s)* |
| $\dot{m}_{return}$ | *Mass flow rate of return air (kg/s)* |
| $\dot{m}_{rp}$ | *Mass flow rate in region $r_p$ (kg/s)* |
| $m''$ | *Mass flux of air (kg/m²s)* |
| $n$ | *Number of pores in absorber* |
| $n_b$ | *Number of partly blocked absorber pores* |
| $n_c$ | *Number of clean absorber pores* |
| $N_e$ | *Number of helical turns* |
| $Nu$ | *Nusselt number* |
| $p$ | *Static pressure (Pa)* |
| $p_{inlet}$ | *Absolute static pressure at the absorber inlet (Pa)* |
| $p_{outlet}$ | *Absolute static pressure at the absorber outlet (Pa)* |

| | |
|---|---|
| $Pr$ | *Prandtl Number* |
| $\dot{q}_a$ | *Incident power on the absorber material of the pore (W)* |
| $\dot{q}_{CI}$ | *Incident power in casing (W)* |
| $\dot{q}_{gen_c}$ | *Volumetric heat generation in central absorber (W/m³)* |
| $\dot{q}_{gen_p}$ | *Volumetric heat generation in peripheral absorber (W/m³)* |
| $\dot{q}_s$ | *Incident power on a pore with absorber material (W)* |
| $\dot{q}_t$ | *applied power on the circumference of absorber (W)* |
| $\dot{q}_p$ | *Incident power on the inner surface of the absorber pore through the opening (W)* |
| $\dot{q}_{pr}$ | *Power transferred to the primary air (W)* |
| $\dot{q}_{s_c}$ | *Heat source term in central absorber (W)* |
| $\dot{q}_{s_p}$ | *Heat source term in peripheral absorber (W)* |
| $q''_{in_c}$ | *Incident concentrated heat flux on front wall of central absorber (W/m²)* |
| $q''_{in_cas}$ | *Incident concentrated heat flux on front surface of casing (W/m²)* |
| $q''_{in_p}$ | *Incident concentrated heat flux on front wall of peripheral absorber (W/m²)* |
| $q''_{nu_c}$ | *Non-uniform heat flux entering in pores of central absorber (W/m²)* |
| $q''_{nu_p}$ | *Non-uniform heat flux entering in pores of peripheral absorber (W/m²)* |
| $\dot{q}_r$ | *Power transferred to the return air (W)* |
| $q''_s$ | *The concentrated solar irradiance on the receiver aperture (W/m²)* |
| $\dot{Q}$ | *Volume flow rate of air (m³/s)* |
| $r_{ab}$ | *Radius of absorbers (m)* |
| $r_{cas_i}$ | *Internal radius of casing (m)* |
| $r_{cas_o}$ | *Outer radius of casing (m)* |
| $r_h$ | *Radius of an absorber pore (m)* |
| $r_p$ | *Radius of particle (m)* |
| $r_{pd}$ | *Radius of particle (using drag coefficient) (m)* |
| $r_{ps}$ | *Radius of particle (using Stokes Law) (m)* |
| $R$ | *Gas constant of air (J/kgK)* |
| $R_{th_cl}$ | *Thermal resistance offered by a clean absorber pore (K/W)* |
| $R_{th_bl}$ | *Thermal resistance offered by a partly blocked absorber pore (K/W)* |
| $Re$ | *Reynolds number* |
| $Re_{dh}$ | *Reynolds number at cyclone separator inlet* |
| $Re_p$ | *Reynolds number in an absorber pore* |
| $S$ | *Shortest gap between absorbers (m)* |
| $t$ | *Time (s)* |
| $t_d$ | *Thickness of dust layer in an absorber pore (m)* |
| $T$ | *Temperature (K)* |
| $T_{a_c}$ | *Temperature of primary air in central absorber (K)* |
| $T_{a_p}$ | *Temperature of primary air in peripheral absorber (K)* |
| $T_{atm}$ | *Temperature of surroundings (K)* |
| $T_c$ | *Temperature of central absorber (K)* |
| $T_{cas}$ | *Temperature of casing (K)* |
| $T_o$ | *Temperature of air at inlet of the absorber pore (K)* |
| $T_{out}$ | *Temperature of air at the absorber pore outlet (K)* |
| $T_p$ | *Temperature of peripheral absorber (K)* |
| $T_{rc}$ | *Temperature of return air in central absorber (K)* |
| $T_{rp}$ | *Temperature of return air in peripheral absorber (K)* |
| $v_p$ | *Average speed of air in an absorber pore (m/s)* |
| $V_{in}$ | *Inlet speed of air in cyclone separator (m/s)* |
| $V_r$ | *Radial velocity (m/s)* |
| $V_t$ | *Tangential velocity (m/s)* |
| $Z_c$ | *Cone length of cyclone separator (m)* |
| $\Delta p$ | *Pressure drop (Pa)* |
| $\Delta p_o$ | *Total pressure drop in an open volumetric air receiver (Pa)* |

$\Delta p_\infty$ *Pressure drop at a reference temperature (Pa)*
$\varepsilon$ *Porosity of absorbers*
$\xi$ *Extinction coefficient ($m^{-1}$)*
$\in_{ab}$ *Emissivity of absorber material*
$\in_{cas}$ *Emissivity of casing material*
$\rho$ *Reflectivity of absorber material*
$\rho_f$ *Density of fluid/air ($kg/m^3$)*
$\rho_{f_bl}$ *Density of air in a partly blocked pore ($kg/m^3$)*
$\rho_{f_cl}$ *Density of air in a clean pore ($kg/m^3$)*
$\rho_g$ *Density of gas ($kg/m^3$)*
$\rho_p$ *Density of particle ($kg/m^3$)*
$\rho_{a_c}$ *Density of primary air in central absorber ($kg/m^3$)*
$\rho_{a_p}$ *Density of air in peripheral absorber ($kg/m^3$)*
$\rho_{ab}$ *Density of absorbers ($kg/m^3$)*
$\rho_{rc}$ *Density of return air in region $r_c$ ($kg/m^3$)*
$\rho_{rp}$ *Density of return air region $r_p$ ($kg/m^3$)*
$\rho_\infty$ *Density of air at a reference temperature ($kg/m^3$)*
$\eta_j$ *Collection efficiency of a cyclone separator*
$\eta_{th}$ *Thermal efficiency of an open volumetric air receiver*
$\eta_{ov}$ *Overall efficiency of an open volumetric air receiver*
$\eta_r$ *Efficiency ratio ($\eta_{th}/\ \eta_{ov}$)*
$\zeta_c$ *Pressure drop coefficient in Casal and Martinez model*
$\mu$ *Dynamic viscosity of air (kg/ms)*
$\upsilon$ *Kinematic viscosity ($m/s^2$)*
$\upsilon_f$ *Kinematic viscosity of fluid/air ($m/s^2$)*
$\upsilon_{f_bl}$ *Kinematic viscosity of air in a partly blocked pore ($m/s^2$)*
$\upsilon_{f_cl}$ *Kinematic viscosity of air in a clean pore ($m/s^2$)*
$\upsilon_\infty$ *Kinematic viscosity of fluid/air at a reference temperature ($m/s^2$)*
$\sigma$ *Stephen-Boltzmann constant ($W/m^2K^4$)*
$\Sigma$ *Emissivity of solid*

## List of Abbreviations

| *Abbreviation* | *Full form* |
|---|---|
| ARR | Air Return Ratio |
| ASTM | American Society of Testing and Materials |
| CFD | Computational Fluid Dynamics |
| CSI | Concentrated Solar Irradiance |
| CST | Concentrated Solar Thermal |
| DNI | Direct Normal Irradiance |
| HP | Hagen-Poisseuille equation |
| LFR | Linear Fresnel Reflector |
| MFR | Mass Flow Rate |
| NDL | Non-uniform Dust Layer |
| OVAR | Open Volumetric Air Receiver |
| PoA | Power on Aperture |
| PTC | Parabolic Trough Collector |
| SATS | Solar Air Tower Simulator |
| SIMPLE | Semi-Implicit Method for Pressure Linked Equations |
| UDF | User Defined Function |
| UDL | Uniform Dust Layer |
| WBL | Without Boundary Layer |