Analysis of a new proposed method to prevent energy waste in rotary kilns in the cement industry

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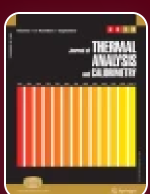

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Abstract

About 40% of the total energy used in cement production is wasted. More than 15% of this energy is wasted through the external surface of the rotary kiln. In this paper, simulation results of new model of heat recovery from the rotary kiln shell using thermoelectric generators are presented. In this new proposed model, their cold surfaces are cooled by being placed on rectangular aluminum tubes and by forced convection of water flow inside the tubes as the working fluid. To simulate the proposed model, the program was written and executed in the EES thermodynamic software environment. The simulation results showed that the maximum temperature difference for the cold surfaces of the TEGs occurs at a distance of 24.9 m from the beginning of the rotary kiln $\left({{\text{as}}: W_{{{\text{tegs}}}} = 314.2 \left({{\text{W}}\,{\text{m}}^{{{ - }{2}}} } \right)} \right)$. From the analysis of the results of changes in the temperature of hot water exiting the aluminum channels in the proposed model, it can be concluded that the proposed model is a system for simultaneous production of heat (e.g., hot water at a temperature of 360 K) and direct electricity by thermoelectric modules. As the simulation results show, the superiority of forced convection over natural convection is quite clear.

Data availability

No datasets were generated or analysed during the current study.

Abbreviations

A_{m}: Thermoelectric module area (m)

A_{k}: Lateral surface area of the rotary kiln (m)

C_{w}: Specific heat capacity of water (kJ) ($\text{kg}-\text{K}$)$^{-1}$)

D_{hyd}: Hydraulic diameter of aluminum channel (m)

$h_{\text{r}-\text{gap}}$: Radiative heat transfer coefficient of the secondary shell (W) (${\text{m}}^{2}-\text{K}$)$^{-1}$)

$h_{\text{c}-\text{gap}}$: Convective heat transfer coefficient of the secondary shell (W) (${\text{m}}^{2}-\text{K}$)$^{-1}$)

$h_{\text{r}-\text{amb}}$: Ambient radiant heat transfer coefficient (W) (${\text{m}}^{2}-\text{K}$)$^{-1}$)

$h_{\text{c}-\text{amb}}$: Ambient convective heat transfer coefficient (W) (${\text{m}}^{2}-\text{K}$)$^{-1}$)

h_{water}: Convective heat transfer coefficient of water (W) (${\text{m}}^{2}-\text{K}$)$^{-1}$)

K_{Al}: Aluminum conductivity (W) ($\text{m}-\text{K}$)$^{-1}$)

K_{air}: Air conductivity $(\text{W}$) ($\text{m}-\text{K}$)$^{-1}$)

K_{Water}:

Water conductivity (W ($\text{m}-\text{K}$)$^{-1}$)

L_{kiln}: Rotary kiln length (m)

$\dot{m}_{\text{w}, \text{tot}}$: Water mass flow rate (kg s^{-1})

N_{tegs}: Number of thermoelectric modules per unit area

$N_{\text{tegs},\text{total}}$: Total number of thermoelectric modules

Nu_{water}: Dimensionless of the water Nuselt number

Pr_{air}: Dimensionless of the air Prandle number

Q_{c}: Heat flux rejected from cold surfaces of thermoelectric modules per unit area (w m^{-2})

Q_{h}: Heat flux through the hot surfaces of thermoelectric modules per unit area (w m^{-2})

$Q_{\text{c},\text{ total}}$: Total of heat flux rejected from cold surfaces of thermoelectric modules (kJ)

$Q_{\text{h}, \text{total}}$: Total of Heat flux through the hot surfaces of thermoelectric modules (kJ)

r_{gap}: Secondary shell radius (m)

r_{kiln}: Rotary kiln radius (m)

R_{gap}:

Total thermal resistance of the space inside the gap $(m^2\text{-}k)\ w^{-1}$

R_{amb}: Total thermal resistance of ambient $(m^2\text{-}k)\ w^{-1}$

R_{w}: Total thermal resistance of water inside aluminum channels $(m^2\text{-}k)\ w^{-1}$

R_{m}: Internal electrical resistance of a single module Ω

Re: Dimensionless Reynolds number inside a single channel

t_{gap}: Thickness of the gap (m)

T_{amb}: Ambient temperature (K)

T_{c}: Cold surface temperature of thermoelectric module (K)

T_{h}: Hot surface temperature of thermoelectric module (K)

T_{kiln}: Rotary kiln temperature (K)

T_{s}: Temperature of sky (K)

$T_{\text{w},\text{in}}$: Water inlet temperature (K)

$T_{\text{w},\text{out}}$: Water outlet temperature (K)

U_{gap}: Overall heat transfer into gap $(w\ (m^2\text{-}k)^{-1})$

U_{amb}:

Overall heat transfer of ambient (w $(m^2\text{–}k)^{-1}$)

${U}_{\text{w}}$: Overall heat transfer of water inside the channels (w $(m^2\text{–}k)^{-1}$)

${V}_{\text{wind}}$: Wind speed (m s^{-1})

${W}_{\text{tegs}}$: Electricity generation by thermoelectric modules per unit area (w m^{-2})

${W}_{\text{tegs}, \text{total}}$: Total electricity generation by thermoelectric modules (kW)

${ZT}_{\text{tegs}}$: Figure of merit for thermoelectric nodules

α: Seebeck coefficient of single module

$\eta_{{{\text{tegs}}}}$: Electrical efficiency of thermoelectric modules Electrical efficiency of thermoelectric modules (%)

$\varepsilon_{{\text{k}}}$: Rotary kiln emissivity

$\varepsilon_{{\text{c}}}$: Emissivity of the cold surface of the thermoelectric module

$\varepsilon_{{\text{h}}}$: Emissivity of the hot surface of the thermoelectric module

σ: Boltzmann radiation constant

ω: Rotary kiln rotational speed (rpm)

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Ethics declarations

Conflict of interest

The authors declare no competing interests.

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