STUDIES ON THERMAL PERFORMANCE EVALUATION OF BOX TYPE SOLAR COOKERS

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STUDIES ON THERMAL PERFORMANCE EVALUATION OF BOX TYPE SOLAR COOKERS

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CERTIFICATE

This is to certify that the thesis entitled **"STUDIES ON THERMAL PERFORMANCE EVALUATION OF BOX TYPE SOLAR COOKERS"** being submitted by Mr. Alok Singh to the Indian Institute of Technology Delhi, for the award of the degree of **Doctor of Philosophy** is a record of bonafide research work carried out by him. He has worked under our supervision and his thesis has attained a standard required for a Ph.D. degree of this Institute. The results presented in this thesis have not been submitted in part or full to any other University or Institute for the award of any degree or diploma.

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(Alok Singh)

ABSTRACT

The present study aims at providing relevant insights into the thermal performance of box type solar cookers primarily focusing on the effect of absorber tray temperature on the value of First Figure of Merit (F_1). The focus of the study is on thermal characterization of the box of the box type solar cooker - The booster mirror has thus been considered as external to the box for augmenting the solar radiation. Experiments were conducted on a control (reference) solar cooker during different periods of the year for the above purpose. A simple correlation (in analytical form) has been developed for the top heat loss coefficient (U_t) of box type solar cooker that is able to capture the variation of F_1 with absorber tray temperature. From the study presented in the thesis it may be inferred that the value of F_1 be determined for moderate temperature (absorber tray temperature in the range of 110-120 ^{o}C) conditions and the same can then be used for determining the value of Second Figure of Merit (F_2). The proposed correlation can be used to scale up/down the values of F_1 for use in calculating the values of second figure of merit (F_2) besides deciding a representative value of F_1 for characterization of the box type solar cooker. For the case of control cooker, the correlation for U_t was verified with the values obtained through experiments.

Experiments were also performed on the control cooker to study the variation in the values of F_2. It was noted that if the values of F_1 obtained at T_p of 110-120 ^{o}C are used for calculation of F_2, the variation in the values of F_2 is reduced. For this purpose, the values of F_1 as obtained in the present study for moderate temperature were used. Despite variation in the time required for heating water up to a certain desired temperature during different periods of the year, the values of F_2 were reasonably stable indicating the suitability of the existing approach for its determination. Studies performed on the control cooker to decide the termination temperature (T_{w2}) indicated that the same should preferably be 10 ^{o}C below the boiling temperature of water: between 85-90 ^{o}C.

In order to study the applicability of the proposed correlation for U_t for commercially available family type box solar cooker, experiments were conducted on five different designs of the same. It was observed that the proposed equation is able to predict the trend of variation in U_t (specially with respect to absorber tray temperature) for these box type solar cookers.

सारांश

वर्तमान अध्ययन का उद्देश्य बक्सनुमा सौर कुकर के उष्मीय कार्य निष्पादन में प्रासंगिक अंतर्दृष्टि प्रदान करना है, जो मुख्यतः अवशोषक ट्रे के तापमान के, प्रथम फिगर ऑफ मेरिट (F_1) के मान पर पड़ने वाले प्रभाव पर केंद्रित है। इस अध्ययन का मुख्य उद्देश्य बक्सनुमा सौर कुकर के बक्स का उष्मीय अभिलक्षणन करना है – इस कारण बक्सनुमा सौर कुकर में लगे दर्पण को उपलब्ध सौर उर्जा के अभिवर्धन में प्रयुक्त मानते हुए बक्स से बाहर समझा गया है। उपरोक्त उद्देश्य के लिए वर्ष की विभिन्न अवधियों के दौरान एक संदर्भ सौर कुकर पर प्रयोग किए गए। बक्सनुमा सौर कुकर की ऊपरी सतह के ऊष्मा ह्रास गुणांक (U_t) के लिए एक साधारण सहसंबंध (correlation) (विश्लेषणात्मक रूप में) विकसित किया गया है जो अवशोषक ट्रे तापमान के F_1 पर प्रभाव को प्रदर्शित करने में सक्षम है। इस शोध ग्रंथ में प्रस्तुत अध्ययन से यह निष्कर्ष निकलता है कि किसी बक्सनुमा सौर कुकर के लिये F_1 का मान निकालने के लिये अवशोषक ट्रे का तापमान 110-120 ^oC के मध्य होना चाहिये और इन्ही परिस्थितियों के लिये बक्स्नुमा सौर कुकर के द्वितीय फिगर ऑफ मेरिट (F_2) का मान भी निकालना चाहिये। बक्सनुमा सौर कुकर के अभिलक्षणन हेतु F_2 के प्रतिनिधि मान को तय करने के अतिरिक्त प्रस्तावित सहसंबंध का उपयोग F_2 का मान निकालने के लिये आवश्यक F_1 के मान का उचित निर्धारण करने के लिये भी किया जा सकता है। संदर्भ सौर कुकर के लिये U_t के प्रस्तावित सहसंबंध का प्रायोगिक सत्यापन भी किया गया है।

F_2 के मान में भिन्नता का अध्ययन करने के लिए संदर्भ कुकर पर भी प्रयोग किए गए। यह देखा गया कि यदि F_1 का मान 110-120 ^oC के अवशोषक ट्रे तापमान पर निकाल कर F_2 का मान निकालने के लिये प्रयोग किया जाय तो F_2 के मानों मे भिन्नता बहुत कम हो जाती है। इस उद्देश्य के साथ वर्तमान अध्ययन में F_1 का मान मध्यम तापमानों पर निकाला गया है। वर्ष की विभिन्न अवधियों के दौरान एक निश्चित वांछित तापमान तक पानी को गर्म करने के लिए आवश्यक समय में भिन्नता के बावजूद, F_2 के मान इसके निर्धारण के लिए मौजूदा दृष्टिकोण की उपयुक्तता को इंगित करते हुए यथोचित रूप से स्थिर थे। टर्मिनेशन तापमान (T_{w2}) तय करने के लिए संदर्भ कुकर पर किए गए अध्ययनों से संकेत मिलता है कि इसे अधिमानतः पानी के उबलते तापमान से 10 ^oC कम होना चाहिए: 85-90 ^oC के बीच।

U_t के लिए प्रस्तावित सहसंबंध की प्रयोज्यता का, व्यावसायिक रूप से उपलब्ध पांच पारिवारिक बक्सनुमा सौर कुकरों के लिये भी अध्ययन किया गया। प्रस्तावित सहसंबंध इन कुकरों के लिये भी U_t की भिन्नता (मुख्यतः अवशोषक ट्रे तापमान के साथ) को समुचित रूप से प्रदर्शित कर सकता है।

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NOMENCLATURE

A = Aperture area (m^2)

C_p = Specific heat ($J\ kg^{-1}\ K^{-1}$)

C_R = Heat capacity ratio $=(MC)_w / (MC)'_w$

F_1 = First Figure of Merit for box type solar cooker (m^2KW^{-1})

F_2 = Second Figure of Merit for box type solar cooker

F' - Heat exchange efficiency factor

h_c = Convective heat transfer coefficient ($W\ m^{-2}\ K^{-1}$)

h_r = Radiative heat transfer coefficient ($W\ m^{-2}\ K^{-1}$)

h_{cp1} = Convective heat transfer coefficient between absorber plate and inner glass cover ($W\ m^{-2}\ K^{-1}$)

h_{c12} = Convective heat transfer coefficient between inner and outer glass cover ($W\ m^{-2}\ K^{-1}$)

h_w = Wind heat transfer coefficient ($W\ m^{-2}\ K^{-1}$)

h_{rp1} = Radiative heat transfer coefficient between absorber plate and inner glass cover ($W\ m^{-2}\ K^{-1}$)

h_{r12} = Radiative heat transfer coefficient between inner and outer glass cover ($W\ m^{-2}\ K^{-1}$)

h_{r2a} = Radiative heat transfer coefficient between outer glass cover and sky ($W\ m^{-2}\ K^{-1}$)

I = Intensity of solar radiation on the aperture of the solar cooker ($W\ m^{-2}$)

I_b = Intensity of direct (beam) solar radiation on the aperture of the solar cooker ($W\ m^{-2}$)

I_d = Intensity of diffuse solar radiation on the aperture of the solar cooker ($W\ m^{-2}$)

I_s = Average intensity of solar radiation at stagnation (Wm^{-2})

k = thermal conductivity of air ($W\ m^{-1}\ K^{-1}$)

K = Extinction coefficient of glass (m^{-1})

l = Length of absorber tray (m)

L_1 = Air gap spacing between absorber plate and inner glass cover (m)

L_2 = Air gap spacing between inner and outer glass cover (m)

$(MC)_w$ = heat capacity of water in pots (JK^{-1})

$(MC)'_w$ = heat capacity of water including the pots and certain portion of the cooker interior (JK^{-1})

Nu= Nusselt Number

Pr= Prandtl Number

$\dot{Q}_b''$= Bottom heat loss flux (Wm^{-2})

$\dot{Q}_t''$ = Top heat loss flux (Wm^{-2})

$\dot{Q}_c''$ = Convective heat loss flux (Wm^{-2})

$\dot{Q}_r''$ = Radiative heat loss flux (Wm^{-2})

R^2 = Coefficient of determination

Ra= Rayleigh Number

T_a = Ambient temperature (K/^oC)

T_{as} = Average ambient temperature at stagnation (K/^oC)

T_p = Average absorber tray temperature (K/ ^oC)

T_{ps} = Average absorber tray temperature at stagnation (K/ ^oC)

T_s = Effective black body sky temperature (K/ ^oC)

T_1 = Temperature of inner glass cover (K/ ^oC) (=(T_{1i} + T_{1o})/2)

T_2 = Temperature of outer glass cover (K/ ^oC) (=(T_{2i} + T_{2o})/2)

T_{1i} = Temperature of inner surface of inner glass cover (K)

T_{1o} = Temperature of outer surface of inner glass cover (K)

T_{2i} = Temperature of inner surface of outer glass cover (K)

T_{2o} = Temperature of outer surface of outer glass cover (K)

T_{mp1} = Mean temperature of absorber tray and inner glass cover (K)

T_{m12} = Mean temperature of inner and outer glass cover (K)

T_w = Water temperature (K/ ^oC)

T_{w1} = Initial water temperature (K/ ^oC)

T_{w2} = Final water temperature (K/ ^oC)

U_L = Overall heat loss coefficient ($Wm^{-2}K^{-1}$)

$(U_L)_{exp}$ = Overall heat loss coefficient from experiments ($Wm^{-2}K^{-1}$)

$(U_L)_{th}$ = Overall heat loss coefficient from theory ($Wm^{-2}K^{-1}$)

U_t = Top heat loss coefficient ($Wm^{-2}K^{-1}$)

$(U_t)_{exp}$ = Top heat loss coefficient from experiments ($Wm^{-2}K^{-1}$)

$(U_t)_{th}$ = Top heat loss coefficient from theory ($Wm^{-2}K^{-1}$)

U_b = Bottom heat loss coefficient ($Wm^{-2}K^{-1}$)

U_s = Side heat loss coefficient ($Wm^{-2}K^{-1}$)

$U_{(b+s)}$ = Combined bottom and side heat loss coefficient ($Wm^{-2}K^{-1}$)

V_w = Wind speed (ms^{-1})

Greek letters

ρ = Mass density ($k\ m^{-3}$)

α_P = Absorptivity of absorber tray

ε_P = Emissivity of absorber tray

σ = Stefan-Boltzmann constant

ΔT_p = Difference of absorber temperature during time interval $d\tau$

θ_1= Angle of incidence (degrees)

θ_2 = Angle of refraction (degrees)

ε_g = Emissivity of glass

ν = Kinematic viscosity of air

δ = Declination angle (degrees)

ϕ = Latitude of place (degrees)

ω = Hour angle (degrees)

η_0 = Optical efficiency

μ = Refractive index

n = day number (with n=1 for January 01)

τ_{12} = Time period to increase water temperature from T_{w1} to T_{w2} (s)

τ_{boil} = Time required to boil water (s)

Subscripts

i = Inner surface of glass -cover

o = Outer surface of glass-cover

p1= Absorber tray to inner (first) glass-cover

12 = Inner glass cover to outer glass-cover

2a = Outer glass cover to ambient

2s = Outer glass cover to sky