EVAPORATION CHARACTERISTICS OF A SOLAR IRRADIATED NATURALLY VENTILATED CLASS A PAN

MD. ASHIKUR RAHMAN

FACULTY OF ENGINEERING
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EVAPORATION CHARACTERISTICS OF A SOLAR IRRADIATED NATURALLY VENTILATED CLASS A PAN

MD. ASHIKUR RAHMAN

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DECLARATION

This Master of Engineering (M.Eng) thesis is an original research work. Wherever, I have taken help from the others researcher in writing the literature review, paper references are made for clarity and acknowledgement. The work was done under the guidance of a committee. The committee has three members. Associate professor **Dr. Chris Chu Chi Ming** is the chairman of this committee, at the chemical engineering program, and the other two members are **Dr. Mizanur Rahman** & **Dr. Noor Ajian Mohd. Lair** at Mechanical Engineering Program, Faculty of Engineering, Universiti Malaysia Sabah (UMS), 88400 Kota Kinabalu, Sabah, Malaysia.

Date: 01 April 2016

____

Md. Ashikur Rahman
MK1321007A

CERTIFICATION

Name : **MD. ASHIKUR RAHMAN**

Matric No : **MK1321007A**

Title : **EVAPORATION CHARACTERISTICS OF A SOLAR IRRADIATED NATURALLY VENTILATED CLASS A PAN**

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Viva Date : **23rD FEBRUARY 2016**

DECLARED BY

1. Supervisor

Assoc. Prof. Dr. Chris Chu Chi Ming Signature

____

2. Co-Supervisor

Dr. Mizanur Rahman

____

3. Co-Supervisor

Dr. Noor Ajian Mohd Lair

____

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ABSTRACT

Evaporative water loss is of significant importance in many fields ranging from hydrology and agriculture, to food science and engineering applications. Water removal from industrial effluent streams, food processing industry and the biodiesel conversion process from microalgae is an important step in wastewater and sludge treatment, harvesting and drying of crops. The purpose of the experiment was to observe the characteristics of evaporation from class A pan and to enhance the rate of evaporation flux by using enhanced natural draft that showed Chu et al. in (2012) by installing wire mesh on the chimney to impede cold inflow. This study monitors the effect of natural draft flow enhancement on evaporation. Experiments were conducted in square shape pan at three different sizes. Dimensions of the experimental pans were side lengths 1.07m, 0.6m and 0.6m; depth 0.254m, 0.254m and 0.2m respectively. The solid wall type solar irradiated chimney was used to enhance natural draft in this research. There were two designs of solar irradiated naturally ventilated pan (SINVAP). The specification for Design-1 category SINVAP was 0.105m^2, 0.28m^2 and 0.77m for inlet opening area, outlet opening area and solid wall chimney height respectively. The dimensions 8.65×10^{-3} m^2, 0.26m^2 and 1.2m were the corresponding values of Design-2 type SINVAP. A 0.64mm×0.64mm size wire mesh was installed at the outlet of the SINVAP to impede cold inflow in the SINVAP. Over about 100 days evaporation readings were taken using the different pan configurations. The experimental result showed the evaporation flux from the SINVAP with wire mesh at outlet opening was around 14% more than the open pan; in the SINVAP without wire mesh at outlet opening was lower than the open pan evaporation rate. The SINVAP evaporation flux was found to be moderately influenced by the net radiation, vapor pressure deficit and natural ventilation draft. The daily average net radiation in the SINVAP water was reduced due to reflection of incoming global radiation at the transparent plastic sheet. Reduction of net radiation in the SINVAP could have caused evaporation to be lower than open pan. The vapor pressure deficit followed the opposite trend of net radiation; as a result, the evaporation flux from the SINVAP with wire mesh has been increased. The elevated vapor deficit in the SINVAP with wire mesh could have caused evaporation to be higher than the open pan. This research found the average local wind run over the open pan was higher than the SINVAP inlet air flow. The nature of the local wind flow profile was unsteady and always fluctuated. However, the inlet air flow profile in the SINVAP was smooth, with little fluctuation. The smooth inlet air flow in the SINVAP was instrumental in transferring higher amount of water vapor molecules from the pan into the air. According to the findings of this study, the use of Chu et al., (2012) enhanced natural draft in the application fields of pond natural evaporation seems promising. The dimensions if chosen properly can thus substantially increase evaporation rates.

ABSTRAK

EVAPORATION CHARACTERISTICS OF A SOLAR IRRADIATED NATURALLY VENTILATED CLASS A PAN

Kehilangan air akibat penyejatan adalah amat penting dalam pelbagai bidang yang terdiri daripada hidrologi dan pertanian, sains makanan dan aplikasi kejuruteraan. Penyingkiran air dari aliran efluen perindustrian, industri pemprosesan makanan dan proses penukaran biodiesel daripada mikroalga adalah satu langkah yang penting dalam rawatan air kumbahan dan enapcemar, penuaian dan pengeringan. Ia telah terbukti boleh dilaksanakan dalam banyak contoh. Tujuan eksperimen ini adalah untuk melihat ciri-ciri penyejatan dari pan kelas A dan peningkatan kadar penyejatan sinaran dengan menggunakan sistem pengudaraan semula jadi berasaskan matahari. Kajian ini adalah untuk memantau kesan draf semulajadi Chu et al., (2012) yang dipertingkatkan pada kadar penyejatan. Draf ini digunakan pada kajian Chu et al, Kesan aliran masuk sejuk pada ketinggian cerobong draf semula jadi menara pendingin. Kajian telah dijalankan dalam kuali berbentuk segi empat sama yang mempunyai tiga saiz yang berbeza. Menurut ujikaji pada kuali, panjang sisi kuali ialah 1.07m, 0.6m dan 0.6m dan kedalaman adalah 0.254m, 0.254m dan 0.2m. Kajian Chu et al. (2012) yang menggunakan draf semula jadi yang dipertingkatkan telah dijalankan pada kajian ini dengan menggunakan cerobong matahari yang berdinding pepejal Terdapat dua jenis reka bentuk kuali radiasi matahari dengan pengaliran udara semula jadi (SINVAP) telah digunakan. Spesifikasi reka-bentuk yang pertama kategori SINVAP adalah seperti berikut :Luas bukaan dalaman, luaran dan tinggi cerobong berdinding pepejal masing-masing adalah $0.105m^2$, $0.28m^2$ dan 0.77m. Spesifikasi reka-bentuk yang kedua kategori SINVAP: adalah menurut dimensi $8.65 \times 10\text{-}3m^2$, $0.26m^2$ dan 1.2m. Saiz jaring dawai adalah 0.64mm × 0.64mm telah digunakan pada alur keluar SINVAP. Kira-kira 100 hari bacaan penyejatan diambil pada konfigurasi kuali yang berbeza. Hasil uji kaji menunjukkan kadar penyejatan dari SINVAP dengan jaring dawai pada ~~pem~~bukaan luaran adalah kira-kira 14% lebih daripada kuali terbuka; ia adalah rendah ~~di~~ pada SINVAP tanpa jaring dawai pada bukaan luaran. Kadar penyejatan SINVAP dipengaruhi oleh pengubahsuaian radiasi bersih, defisit tekanan wap dan draf pengudaraan semula jadi. Purata radiasi bersih harian dalam air SINVAP semakin berkurangan disebabkan oleh pantulan sinaran pada kepingan plastik telus. Penurunan radiasi bersih dalam SINVAP menyebabkan kadar penyejatan menjadi lebih rendah daripada pan terbuka. Keputusan defisit tekanan wap mengikut trend yang bertentangan dengan radiasi bersih. Hasilnya, kadar penyejatan dari SINVAP dengan dawai telah meningkat. Keputusan defisit wap meningkat pada SINVAP yang berdawai dan ini menyebabkan kadar penyejatan adalah lebih tinggi daripada pan terbuka. Keputusan kajian ini menunjukkan purata gerakan angin tempatan pada kuali terbuka adalah lebih tinggi berbanding aliran udara masuk SINVAP. Sifat profil aliran angin tempatan adalah tidak stabil dan sentiasa berubah-ubah. Walau bagaimanapun, profil aliran udara masuk di dalam SINVAP adalah licin dan stabil. Kelancaran aliran udara masuk di dalam SINVAP telah memindahkan sejumlah besar molekul wap air dari air kuali ke dalam udara.

Ramalan yang baik berkenaan dengan penyejatan oleh model penyejatan yang berbeza menunjukkan bahawa kajian Chu et al. (2012) yang menggunakan draf semula jadi yang dipertingkatkan adalah sah pada penyejatan. Menurut hasil kajian ini, penggunaan kajian Chu et al., (2012) yang menggunakan draf semulajadi jadi dalam bidang kolam penyejatan semula jadi adalah cerah. Pemilihan dimensi yang betul boleh meningkatkan kadar penyejatan dengan ketara.

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LIST OF ABBREVIATIONS

SINVAP	-	Solar Irradiated Naturally Ventilated Class A Pan
OP	-	Open Pan
NWS	-	National Weather Service
f(u)	-	Wind function
CNRS	-	Centre National de la Recherché Scitifique
VDP	-	Vapor Pressure Deficit
RMSE	-	Root Mean Square Error
MBE	-	Mean Bias Error
MSE	-	Mean Square Error
DE	-	Deviation of Evaporation
UMS	-	Universiti Malaysia Sabah

LIST OF SYMBOLS

R_n	-	Net radiation (W/m^2)
R_{ns}	-	Net incoming short wave radiation (W/m^2)
R_{nl}	-	Net outgoing long wave radiation (W/m^2)
E	-	Evaporation flux (kg/m^{2}s)
e_s	-	Saturated air vapor pressure (Pa)
e_a	-	Actual air vapor pressure (Pa)
Q_n	-	Net solar energy (W/m^2)
Q_h	-	Net sensible heat loss (W/m^2)
Q_e	-	Energy used for evaporation (W/m^2)
ΔQ	-	Heat storage in water (W/m^2)
ΔP	-	Differential pressure drop (Pa)
ΔP_{st}	-	Buoyancy or stack pressure (Pa)
ΔP_w	-	Wind draft (Pa)
Q	-	Flow rate (m^3/s)
T_a	-	Ambient air temperature (°C)
T_i	-	Indoor air temperature (°C)
A	-	Cross sectional area of opening (m^2)
K	-	Flow resistance coefficient (Dimensionless)
U_2, W	-	Wind speed (m/s)
C_d	-	Pressure coefficient (Dimensionless)
A_{eff}	-	Effective area of opening (m^2)
h	-	Canopy chimney height (M)
G	-	Gravitational acceleration (m/s^2)
E_{pan}	-	Pan evaporation (kg/m^{2}s)
E_a	-	Aerodynamic function of evaporation (kg/m^{2}s)
P_a	-	Atmospheric pressure (Pa)
T	-	Mean daily temperature (°C)
R_s	-	Global solar radiation (W/m^2)
R_a	-	Extraterrestrial radiation (W/m^2)

C_T	-	Temperature constant (Dimensionless)
C_w	-	Wind constant(Dimensionless)
C_H	-	Humidity constant (Dimensionless)
H_m	-	Relative Humidity (%)
C_s	-	Sunshine coefficient (Dimensionless)
S	-	Sunshine percentage (Dimensionless)
C_E	-	Elevation coefficient (Dimensionless)
T_{dp}	-	Dew point temperature (°C)
V	-	Pan cavity volume (m^3)
D	-	Diameter of Pan (mm)
H	-	Depth of Pan (mm)
L	-	Plan length of Pan (mm)
Δ	-	Slope of saturated vapor pressure vs temperature curve (Pa/°C)
γ	-	Psychrometric constant (Pa/°C)
Λ	-	Latent heat of vaporization (J/kg)
ρ_a	-	ambient air density(kgm^{-3})
ρ_i	-	Indoor air density (kgm^{-3})

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CHAPTER 1

INTRODUCTION

This thesis presents a research of open water surface evaporation represented by pan evaporation, and assessment of different evaporation estimation methods that have been used for many years.

This thesis proposes using the principle of natural ventilation to provide enhanced air flow over a square pan by using enhancing chimney made in the vertical duct in East Malaysia. The goal of the thesis is to explore a method to enhance the evaporation rate by utilized solar energy for commercialization of pond natural evaporation system in many fields such as water removal from industrial effluent, brine distillation, salt cultivation, food processing and drying, microalgae drying, evaporative cooling, mining, etc.

There have been many experimental studies completed worldwide, featuring open water surface evaporation. Historically, many cases where the natural evaporation has been used there are required to operate at higher evaporation rate. Natural evaporation can be enhanced by changing the meteorological climates; those are the elements of evaporation function. According to Liu and Xia (2012), the rate of natural evaporation is more responsive to net radiation, followed by relative humidity, air temperature and air flow over the free surface of the water body. Chu et al.; (2012a) showed the draft was enhanced through the natural draft solar chimney by installing wire mesh on the chimney exit to impede cold inflow. The area of this study is to use the enhanced natural draft that is shown Chu et al. in 2012 for increasing evaporation rate.

Literature searches were conducted to survey on open water surface evaporation, standard pan evaporation, measurements of flow into the solar irradiated natural ventilation system were made, and different evaporation estimation models evaluated. Through analysis and experimental studies, the possibility of designing a solar irradiated naturally ventilated class A pan model with higher rates of evaporation was evaluated.

1.1 Research Questions

a. Are existing equations for estimating the natural water evaporation from class A pan applicable to the Malaysian climate?

b. Do existing equations for estimating the natural water evaporation rate from class A pan applies to pan modified by a canopy ventilator acting as a chimney?

c. What are the effects of the pan shape and size on the water evaporate?

d. Is the draft enhancement found in the modified chimney system reported by Chu, Rahman and Kumaresan (2012a) using air as the working fluid applied to the evaporation system?

1.2 Statement of Research Problem

Class A pan have been the general adoption of direct measurement of natural evaporation rate. The alternative to direct measurement has been greatly influenced by the availability of data of evaporation functions elements. The evaporation from a free water surface is determined using the existing equations that originated from ecological and environmental studies would unlikely be suited for designing pan evaporation rates. However, the pan evaporation rate is little higher than the pond natural evaporation rates (Gundalia and Dholakia, 2013). Therefore, those responsible for estimating daily evaporation are still faced with a bewildering array of calculation methods, many of which give small, but significant between the experimental and predicted evaporation by evaporation models in the final calculated value. The key problem of this study with choosing evaporation models of prediction of evaporation at the Solar Irradiated Naturally Ventilated Class A Pan (SINVAP). Because, the available daily natural evaporation rate measurement equations does not account for predicting evaporation from the SINVAP.

Pan evaporation data is useful information for estimating water vapor flux from lakes, reservoirs and other water bodies. It can be affected by global and net solar radiation, vapor pressure, air velocity, relative humidity, rainfall, water temperatures, and air temperatures in obtaining the evaporation rate. The combinations of natural air ventilation with open water surface evaporation, using direct irradiated solar energy with other effects has to investigate because, the canopied ventilation that refers to the natural draft enhancement by installing a wire mesh on a solar chimney have been evaluated the flow rate only.

Chu et al. (2012b) concluded that the higher rate of air velocity over the pan water surface can generate such a wave in the pan and splash water out of the pan in several minutes. The splash loss increases as the air velocity increase, with the loss rate at least one order of magnitude greater than the evaporation rate. The important question, is whether the proposed SINVAP that is based on the enhanced natural draft work shown by Chu et al. (2012a) able to produce a splash effect on the pan water?

1.3 Scope of Research

As indicated previously, there has been very little research or basic data collected on evaporation rates under the natural ventilation system. These techniques generally require highly specialized measurements of air velocity and vapor pressure gradients and are based on assumptions that would not be expected to be met in the solar irradiated natural ventilation. Due to the many possible complicating factors, it was decided that the present study, being a pilot project for solar irradiated natural ventilated pan evaporation, should be limited to investigating the validity of the more commonly used methods. The first requirement was for adequate reliable basic data. To obtain this data, standard procedures were used to collect data from observations. The research works performed was limited as per list below: