MODELLING OF TRANSPORT PHENOMENA NEAR GREENHOUSE SCREENS

A. F. Miguel, A. M. Silva
Department of Physics, Évora University
Colégio Luis António Verney
Rua Romão Ramalho 59, 7000 Évora
Portugal

N. J. van de Braak and G. P. A. Bot
IMAG-DLO
Mansholtlaan 10-12 Postbus 43
6700 AA Wageningen
The Netherlands

Keywords: screens, greenhouse, airflow, free convective heat transfer

Abstract

Experiments were conducted with the aim to examine the airflow characteristics (permeability and porosity) of some currently employed greenhouse screens, and to obtain equation coefficients for estimation of free convection heat transfer between heating pipes and the air, and horizontal screen and the air.

Experiments demonstrated that thermal and shading screens have permeabilities of approximately 10^{-11}m^2 and their porosities are less than 10%. Free convective heat transfer coefficient (α) for the upper and lower screen surface is given, respectively by $\alpha = 3.24\ \Delta T^{0.30}$ and $\alpha = 2.16\ \Delta T^{0.31}$.

1. Introduction

The potential benefits resulting from the use of screens in protected horticulture have been increasingly recognised in recent years. Screens are a simple and successful means for avoiding night-time heat loss and controlling the solar radiation inside a greenhouse.

In order to optimise the use of screens in greenhouses, an extensive knowledge of their characteristics is required. Experiments have been conducted to determine the airflow characteristics and convective heat exchange coefficients of several screen materials.

2. Material and methods

2.1. Experimental arrangement

2.1.1. Airflow characteristics

Airflow characteristics of screen materials are the porosity and the permeability (Bear, 1972).

Since porous screens are always made of thin materials, their porosity can be given by:

$$\varepsilon = A_a/A \qquad (1)$$

where A_a represents the area of space filled with air (m^2) and A the area occupied by the solid matrix and the air (m^2).

Porosity can be determined by simply magnifying the samples with the help of a microscope and measuring the respective areas A_a and A.

Permeability represents the ability of the medium to transmit a fluid through it, and can be obtained from Forchheimer equation (Forchheimer, 1901):

$$\Delta p/H=(\rho Y/K^{1/2})u^2+(\mu/K)u \tag{2}$$

where Δp represents the pressure difference (Pa), u the air velocity (m/s), ρ the density (kg/m^3), Y inertial factor (-), μ the dynamic viscosity of air (Pa s), H the thickness of sample (m) and K the permeability (m^2).

In order to obtain data to fit this equation, experiments were carried out in a wind tunnel. Air was forced through the test samples in order to create a pressure drop (Miguel, *et al.*, 1998). The maximum pressure drop created was 140 Pa. This pressure prevents tearing occur due to tension created by the airflow.

Four different well known commercial screens were tested (parallel strips and woven sheet screens used as thermal and shading screens). The trade names are in Table 1.

2.1.2. Convective heat transfer coefficients

The convective heat transfer coefficient is defined according to (Holman, 1990) :

$$Q=\alpha\,\Delta T \tag{3}$$

with :

$$\alpha= c_\alpha\,\Delta T^{\,n}$$

where Q is the convective heat flux (W/m^2), α the convective heat transfer coefficient (W/(m^{2}K)), ΔT the temperature difference between the surface and the air (K), c_α and n convective coefficients.

In order to obtain the convective heat transfer coefficients α, experiments were conducted in twin-span glasshouse with an air-tight aluminised screen assembled horizontally between the ground and the roof, under constant heat flux conditions. This screen has the same roughness, as the screens used in greenhouses. In order to generate temperature differences between the air and the screen, horizontal electrical pipe shaped heaters (generating a power of up to 820 W/m^2) were placed between the ground and the screen. Experiments were performed during the night to exclude the effects of short wave radiation. In order to study the influence of the location of heating pipes on free convective heat transfer, the heating pipes were placed at 0.20 m and 2.10 m from the soil surface.

The temperatures were measured by copper-constantan thermocouples: ten in the air space above the screen, twelve on the screen, ten in the air space below the screen and eight on the heating pipes.

3. Results

3.1. Airflow characteristics

Screens porosities obtained using Eq. (1) are presented in Table 1.

The data of all the samples tested in the wind tunnel, were fitted with a second order polynomial :

$$\Delta p=au^2+bu \tag{4}$$

This agree with the Forchheimer equation (Forchheimer, 1901), and coefficient b can be defined as :

$$b=\mu H/K \tag{5}$$

The coefficients a, b and K, as well as the squared correlation coefficient r^2, are also presented in Table 1.

Table 1. Coefficients for the best fit equation ($\Delta p = au^2 + bu$), permeability and porosity.

Sample Trade name	ε (m^2/m^2)	a	b	K(m^2)	r^2
EH/P	0.09	303.17	101.43	9.08×10^{-11}	0.99
LS10	0.09	348.53	134.06	6.87×10^{-11}	0.98
SLS10	0.06	1130.2	241.73	3.81×10^{-11}	0.99
Phormilux	0.05	1957.8	371.37	2.48×10^{-11}	0.99

3.1.1. Convective heat transfer coefficients

The data obtained from the experiments were fitted with Eq. (3). Coefficients c_α and n, as well as the squared correlation coefficient r^2, are presented in Table 2.

Table 2. Free convective heat transfer coefficients c_α and n (Eq. 3).

	c_α	n	r^2
Upper surface of screen	3.24	0.30	0.96
Lower surface of screen (pipes at 0.20m from the ground)	2.17	0.31	0.97
Lower surface of screen (pipes at 2.10m from the ground)	2.14	0.31	0.98
Heating pipes (pipes at 0.20m from the ground)	2.99	0.24	0.98
Heating pipes (pipes at 2.10m from the ground)	3.03	0.24	0.99

4. Discussion and concluding remarks

4.1.1. Airflow characteristics

According to Table 1, screens usually used as thermal and shading screens have permeabilities close to $10^{-11}m^2$ and porosities between 5% and 9%.

The airflow through screens can be easily predicted using the Forchheimer equation and airflow characteristics presented in Table 1.

4.1.2. Convective heat transfer coefficients

According to the values presented in Table 2 and Eq. (3), free convective heat transfer between the screen surfaces and air, and the heating pipes and air can be predicted.

From the analysis of Table 2, the following conclusions can be drawn:

- the difference of convective heat transfer coefficient obtained when heating pipes were located at 0.20 m and 2.10 m from the soil surface are less than 1.4%. That is, the position of heating pipes in relation to the soil surface did not influence the convective heat transfer between the heating pipes and the air;
- the difference of convective heat transfer coefficient obtained when heating pipes were located at 0.80 m and 2.70 m from lower surface of screen are less than 1.5%. That is, the position of heating pipes in relation to the lower screen surface did not influence

the convective heat transfer between the heating pipes and the air,

- the difference of convective heat transfer coefficient obtained when lower surface of screen was located at 0.80 m and 2.70 m from the heating pipes are less than 1.5%. That is, the position of heating pipes in relation to the lower screen surface did not influence the convective heat transfer between the lower surface of the screen and the air.

References

Bear J., 1972. Dynamics of fluids in porous media. American Elsevier Environmental Sciences Series, New York, USA.
Forchheimer P., 1901. Wasserbewegung durch boden. Z. Ver. Deutsch., 45, 1782-1788
Holman, J.P., 1990. Heat transfer. MacGraw-Hill, Singapore.
Miguel A.F., van de Braak N.J. and Bot G.P.A., 1998. Analysis of the airflow characteristics of greenhouse screening materials. Journal of Agricultural Engineering Research (*in press*).