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AN INVESTIGATION OF THE AIRFLOW IN MUSHROOM GROWING STRUCTURES FOR MODELLING NEW STRUCTURES

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Abstract: *This paper is an examination of the airflows in mushroom growing rooms. An experimental investigation of the nature of the flows in Irish tunnels showed them to be of low magnitude at the crop but controllable in principle for single and 3 layers growing shelvets. The provision of air flow solutions for the wide range of new growing systems would be difficult using empirical methods alone and therefore a modelling approach was sought to complement and aid the experimental work. In the application to mushroom growing structures, the principles of the application of CELS3D to flows around obstructions in the flow domain were examined and the difficulties identified.*
Keywords: *Agaricus Bisporus, Irish Growing Tunnel, US Growing Room, Fluide Flo, Microclimate Condition*

1. INTRODUCTION

This paper presents a the study of airflows in mushroom growing structures. Although we analyzed the conditions for different types of fungi, we have focused attention on the growing Agaricus bisporus. Mushrooms, as a crop, do not photosynthesise and have no specialised fluid transport system equivalent to the green plants vascular system. Water is transported by capillary action between the cells and fungal strands that make up the organism and osmotically by the cells themselves. In order to have the control over the growth of the organism it is necessary to gain control of the evaporative conditions at the cropping surface, i.e. the crop micro-climate. Control the environment in a mushroom mean manipulation of evaporation power of the air, which is usually defined as the product of gap vapor pressure and air velocity [4]. Thereby, achievement of properly designed air flow in the across the of crops in the developing is essential to the success of the production process.
The mushroom crop, during 70 days production cycle, moves through a number of phases of development. In the first two phases (21-30 days) of vegetative development where strands of fungal mycelium colonise the compost that supplies its nutrients and water, air speed at the crop is not a critical quantity [9]. Air at this time functions largely as a medium for the removal of heat produced by the metabolic reactions in the mycelium. After this period the inoculated compost is placed in special growth rooms for a period of 38-42 days. The microclimat condition at this stage of the process (according to manufacturer's recommendations) is presented in the graph below.

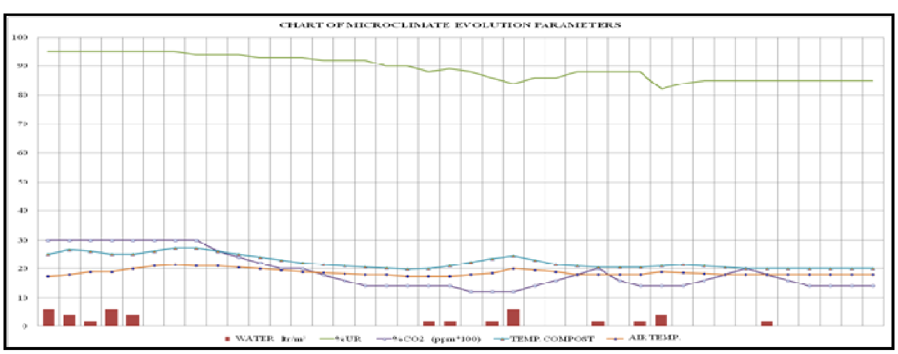

Figure 1: Microclimate parameters in mushrooms groving room (for Agaricus bisporus)

In order to achieve the correct conditions of evaporation, the vapor pressure deficit control is relatively easy for air humidity, can be added to the steam or fine mist injected or removed by passing air over the heat exchanger. Setting the correct airspeed is more difficult and, in particular, to ensure uniformity across the surface conditions of a culture requires airflow to be well understood for different cropping structures.
There are a number of different commercial mushroom-growing systems in Europe and in the United States. All the production is carried out indoors and there are a variety of growing systems and associated structures. Some growing rooms are approximately square or rectangular in section and others are curved, polyethylene-covered tunnels with a variety of cross-section shapes that can deviate markedly from a semi-circle.
The square geometries are used traditionally for multi-tier growing and these pose the greatest difficulties in the provision of uniform air flow at all points on a cropping surface.

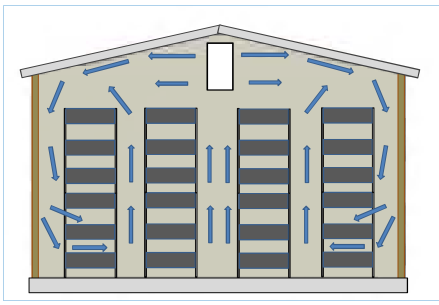

Figure 2: Schematic of an American mushroom growing room

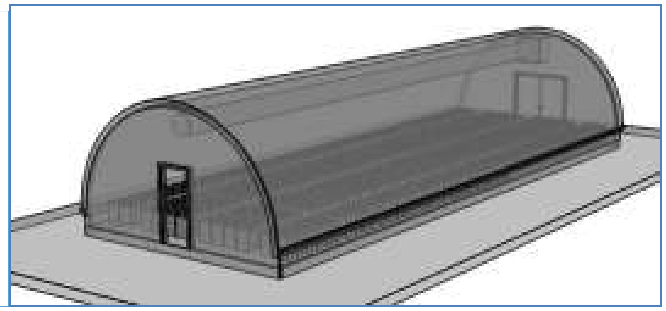

Figure 3: Schematic of an Irish mushroom-growing tunnel

While a full measurement programme that could be used to validate the output from a mathematical flow model was not implemented in time for use in this work, an experimental investigation of the general characteristics and some important features of the air flow in Irish mushroom-growing tunnels was carried out.
A crucial relationship in the air-delivery system is the relationship between the speeds at the apertures on the distribution duct and the corresponding speeds at the cropping surface. The air delivery system in an Irish mushroom growing tunnel, has the advantage that it allows high exit speeds (4 to 7 m/s) at the distribution duct and hence a large volume of air to be supplied while providing the very low air speed that is required for the microclimate at the growing surface. The provision of a speed control for the fan means that the grower has control of the air exchange rates at the crop and a damper system provides a controllable mixture of the fresh and the recirculated air. The damper is used to provide control of the carbon dioxide concentration in the tunnel and, with suitable outside conditions, can be used to. Since the air speed at the crop depends partly on the attenuation of the airflow by the tunnel structure and there are many variations in the number and size of holes in the distribution ducts as well as varying models of axial fans with slightly different pressure/output characteristics, it would be anticipated that there would not be a general relationship between the duct exit and the cropping surface air speeds but that the characteristic should be similar in most cases.
An important practice for high quality production is the quick drying of the surfaces of the mushrooms after watering. If a mushroom surface remains damp then there is a threshold level of bacterial population that can be exceeded and brown patches or surface pitting can occur [9].
To determine and find a solution as close to the ideal condition of ventilation, have developed several theoretical and practical models. The results are characterized by near constant sliding velocity jets of air to the surface of the harvest, the recommended ideal speed 0.4 m/s.
Measurements for different ventilation systems with one, two or three main ventilation tubes led to the development of mathematical models of analised phenomena that occur during operation.

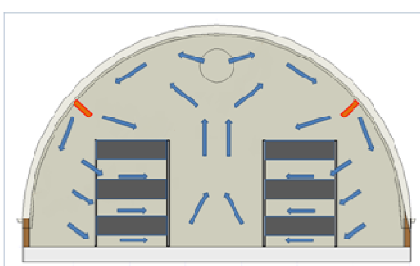

Figure 4: One-duct air distribution system+deflectors

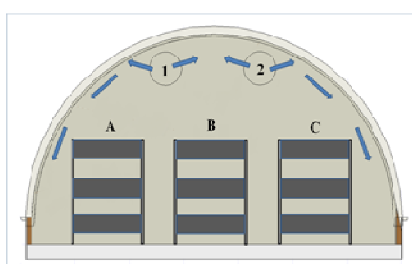

Figure 5: Orizontal two-duct air distribution system

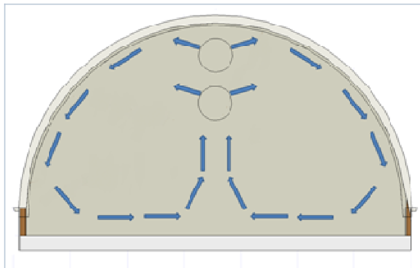

Figure 6: Vertical two-duct air distribution system

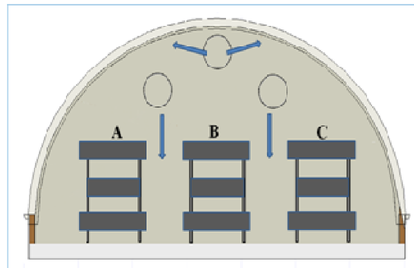

Figure 7: Three-duct air distribution system

Some graphical representations of the data collected during the tests are shown in the accompanying graphs.

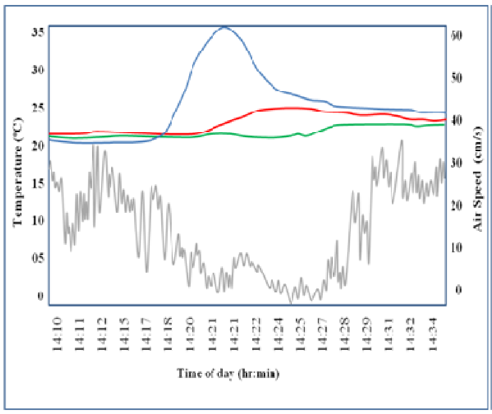

Figure 8: Cropping surface air speed during heating (6 m/s at duct exit)

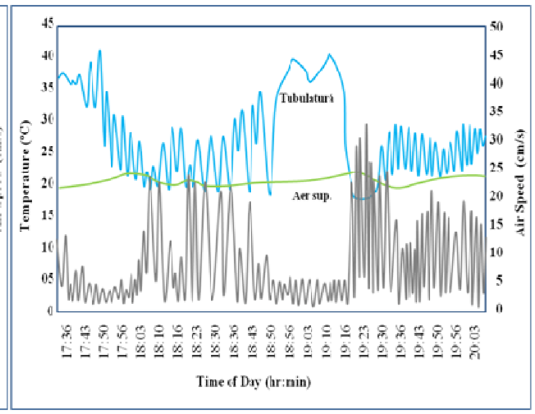

Figure 9: Air speed and temperature for a pulsed heating system.

Results showed the need for installing additional piping to obtain a homogeneous mixture of air and sliding speeds close to the limit of the evaporation.

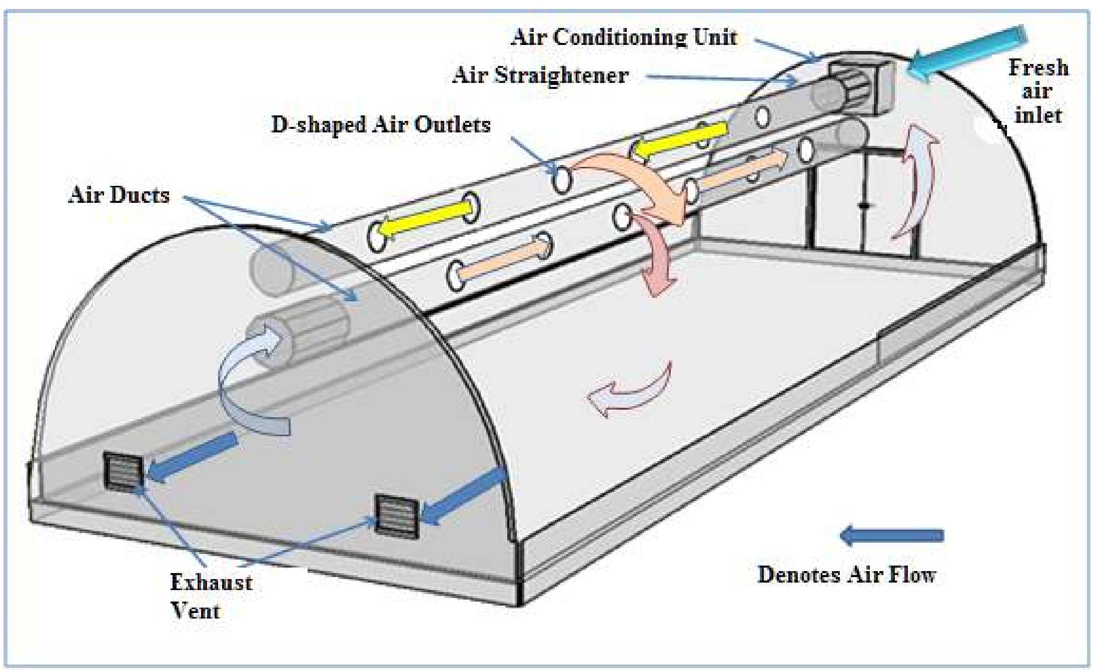

Figure 10: Schematic diagram of a two duct air distribution system.

2. THE EQUATIONS OF FLUID FLOW

The equations that are used to describe fluid flows for the purposes of this thesis share a common form in that they all obey a generalised conservation principle, i.e. there is a balance between the factors that influence a given dependent variable. These are discussed in the book by Patankar (1980) and, if the dependent variable is $\emptyset$, then:

$$\frac{\partial}{\partial t}(\rho\emptyset) + \nabla * (\rho\tilde{u}\emptyset) = \nabla * (\Gamma\nabla\emptyset) + S \quad \text{at} \qquad (1)$$

where Γ is the diffusion coefficient, S is the source term, t is time, ρ is the density and u is the velocity vector.
The dependent variable $\emptyset$ will be the velocity components, temperature and turbulence parameters. The diffusion coefficient Γ and the form of the source term S are different for different dependent variables and an appropriate meaning has to be given in each case.
The other constraint on the flow fields is the continuity or mass conservation equation, given by:

$$\frac{\partial\rho}{\partial t} + \nabla * (\qquad (2)$$

For the isothermal air flows considered in this thesis, density changes are taken as negligible [5] and the continuity equation reduces to:

$$\nabla * \tilde{u} = 0 \qquad (3)$$

3. A MODEL FOR THE DESCRIPTION OF TURBULENCE

Observation has shown that the flow in mushroom growing tunnels is turbulent in nature and that modelling of the airflows involved would require that the effects of turbulence be calculated. There is much general work in the field of turbulent flow calculations and many publications describe work that makes use of techniques similar to those used in the TEACH code. The standard *k-e* turbulence model [6] which is included in the TEACH package is taken as the means of describing turbulence for the purposes of this analise. There are a number of modifications that can be made to the details of this modelling [12] but until it is possible to carry out some model validation in the mushroom growing room application there is little basis for changing from this formulation of the *k-s* equations. For example, Rahnema et al. (1996) implemented a modification in the *e* equation for re-circulating flows whilst Liu et al. (1996) compared three D models for predicting the ventilation air jets, both planefree and plane-wall. They found that the simulations on a number of different grid densities predicted the fluid velocity decay and velocity profile well but over-predicted the jet spread and entrainment ratios by 20 to 40%. A modified turbulence model may ultimately be required for the jets and flow along walls that are part of mushroom tunnel ventilation [4].
Patankar et al. (1977) presented the numerical prediction of the three-dimensional velocity field of a deflected turbulent jet. This study incorporated the hybrid differencing scheme and a line solution technique making use of a sequential/segregated approach to an iterative scheme.
Rodi (1980) described in detail the various turbulence models and their applications and evaluated the models with regard to their predictive capability and computational effort.
Nallasamy (1987) presented a brief account of various turbulence models employed in the calculation of turbulent flows, and evaluated the application of these models to internal flows by examining the predictions of the various turbulence models in selected flow configurations.
Numerical calculations were presented by Hjertager and Magnussen (1981) for two jetinduced three-dimensional flows in rectangular enclosures [5].
Choi et al. (1988 and 1990) applied the *k-e* model in the prediction of the air flow in a slot-ventilated enclosure and for flow around rectangular obstructions [1]. They modified the TEACH code to predict two-dimensional, isothermal air flow patterns and air velocities.
Maghirang and Manbeck (1993) studied the air space of the ventilation slot, which was very similar to the general state of the flow in chambers of growth of the mushrooms. They modelled the airflow and the transport of neutrally-buoyant bubbles using the *k-s* turbulence model [10].
Comparison between the numerical simulation and experimental results showed good correspondence in the velocity fields and bubble trajectories.

4 APPROXIMATION OF THE EXACT EQUATIONS

The equations for turbulent flow have their origin in the conservation laws and these give rise to the exact description of a turbulent flow [3], [4], [7]. The computing resources required for solving the exact equations are large due to the scale of the turbulent elements in a flow relative to the extent of flow domains.

Many of the features of DS can be retained while computing higher Reynolds number flows in the large-eddy simulation (LES) technique. Using a space-filtering procedure, the mean and the large-eddy fields are resolved but the fields smaller than the sub-grid scale have to be mathematically modelled. The instantaneous field can be decomposed as:

$$\phi = \hat{\phi} + \tilde{\phi} \quad (4)$$

where $\hat{\phi}$ is the filtered (resolved) field, while $\tilde{\phi}$ is the residual (unresolved) fluctuation.

Reynolds decomposition is the technique applied and in this the instantaneous values of the dependent variables in the conservation equations (velocity component Ui, pressure P and the scalar quantity ϕ are separated into mean and fluctuating quantities:

$$Ui = \bar{U}_i + u_i \quad P = \bar{P} + p \quad \phi = \bar{\phi} + \varphi \quad (5)$$

$$\sigma_{ij} = -\rho\overline{u_i u_j}. \quad q_j = \rho\overline{u_j \phi_j} \quad (6)$$

As the energy is contained mainly in the large-scale fluctuations this is a velocity scale for the large-scale turbulent motion and, with the eddy viscosity concept, comes the Kolmogorov-Prandtl expression (Rodi, 1980):

$$v_t = c'_\mu \sqrt{k}L \quad (7)$$

The dissipation s is usually modelled as [4]:

$$\varepsilon = C_D \frac{k^{\frac{3}{2}}}{L} \quad (8)$$

The modelled k equation, as used in TEACH, is [4] (using tensor notation):

$$U_i \frac{\partial k}{\partial x_i} = \frac{\partial}{\partial x_i}\left(\frac{V_t}{\sigma_k}\frac{\partial k}{\partial x_i}\right) + V_t \left(\frac{\partial U_i}{\partial x_j} + \frac{\partial U_j}{\partial x_i}\right)\frac{\partial U_i}{\partial x_j} - C_D \rho \varepsilon \quad (9)$$

Diffusion, generation and destruction terms require modelling and the outcome as applied in this work is the following (Rodi, 1980):

$$U_i \frac{\partial \varepsilon}{\partial x_i} = \frac{\partial}{\partial x_i}\left(\frac{v_t}{\sigma_\varepsilon}\frac{\partial \varepsilon}{\partial x_i}\right) + c_{1\varepsilon}\frac{\varepsilon}{k}G - c_{2\varepsilon}\frac{\varepsilon^2}{k} \quad (10)$$

Along with the relation, from equations (3.9) and (3.10):

$$v_1 = c_\mu \frac{k^2}{\varepsilon} \quad (11)$$

The k-s model has become popular and, as a consequence, is one of the most widely tested models. The onstants, for high Reynolds number flows, are determined by examining a number of special cases of the modelled k-s equations and a widely used set is due to Launder and Spalding (1974). These values of the constants are c_μ = 0.09, c_D = 1 , $c_{1\varepsilon}$ = 1.44, $c_{2\varepsilon}$ = 1.92, σ_k = 1 and σ_ε=1.3 and they are the values used in all the work presented in this analise. The derivation of discretisation equations for the finite volume method are wellknown and there is a lucid presentation in Patankar (1980).

$$A_p \phi_p = \sum A_{nb}\phi_{nb} + b \quad (12)$$

The measure of convergence is a given reduction of the residuals for all of the equations to be solved. For equation (4.1), the residual is defined as:

$$R = \sum A_{nb}\phi_{nb} + b - A_p\phi_p \quad (13)$$

Writing the discretised equation as:

$$a_i\phi_i = b_i\phi_{i+1} + c_i\phi_{i-1} + d_i \quad (14)$$

for .=1,2,3,..... ,N which relates the dependent variable to the neighbouring points b_{i+1} and b_{i-1} For the boundary condition equations set c_1 = 0 and b_N =0 so that values outside the calculation domain play no role.

$$\phi_i = P_i\phi_{i+1} + Q_i \quad (15)$$

$$\phi_{i-1} = P_{i-1}\phi_i + Q_{i-1} \quad (16)$$

$$P_i = \frac{b_i}{a_i - c_i P_{i-1}} \tag{17}$$

$$Q_i = \frac{d_i + c_i Q_{i-1}}{a_i - c_i P_{i-1}} \tag{18}$$

5. CONCLUSION

Using mathematical modeling methods TEACH, CELS3D, the reasercer James J. Grant (2002) obtained model generation flow in different types of farming systems mushrooms. Irish case of the tunnel type is shown in the following charts.

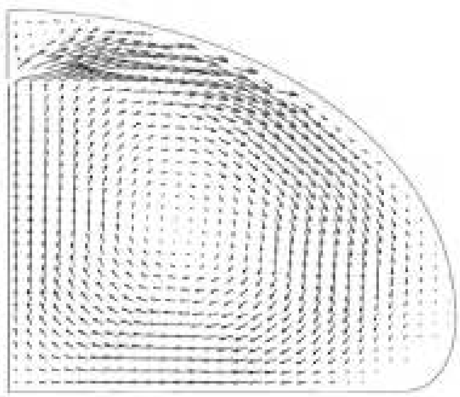

Figure 11: Air flow pattern in a structure with an in-curving wall base.

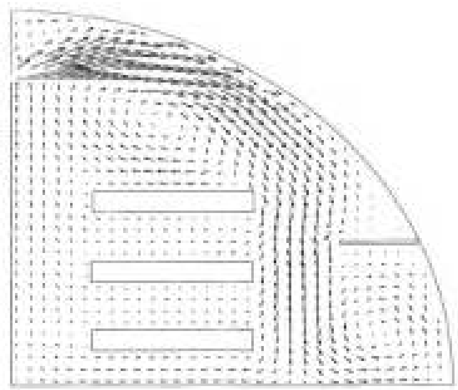

Figure 12: Air flow across shelves with a deflector (Re=3500).

The number of variations in the cropping systems and the variations in air distribution make the empirical approach to optimising airflow in mushroom tunnels very timeconsuming and tedious. The use of flow models and computational fluid dynamics would be a useful part of a problem-solving framework. If a flow model could be validated in a number of situations then the programmes could be used to guide theexperimentation for new situations and could drastically reduce the time required to provide the systems that would deliver a suitable airflow at all times.

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