INVESTIGATION OF AIR FLOW CHARACTERISTICS OF A SIMPLE PLATFORM DRIER FOR COCOA

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RESUMO

A simulação da distribuição de ar dentro de dutos perfurados usando a equação de quantidade de movimento e uma correlação dando as propriedades de resistência ao fluxo de ar é relativamente bem conhecida.

Um modelo matemático baseado nesse tipo de sistema foi solucionado, através da computação e as propriedades do mesmo foram, então, investigadas pela obtenção das mudanças na uniformidade de distribuição do ar após as variações nos parâmetros do referido modelo.

Uma investigação foi também efetuada para mostrar as dificuldades de melhorar a distribuição do ar pelas variações na geometria do duto.

Em vista disto, projetou-se um secador tipo plataforma (em fase de construção) que será utilizado para tentar confirmar experimentalmente os resultados oriundos do modelo.

1. INTRODUCTION

Although not widespread as yet, much interest is being directed towards the development of forced ventilation cocoa driers for use in the Bahia region. One design which is being given particular attention at the CEPLAC Research Centre is a simple platform type drier of ares 10m by 2m.

It is well known that driers of this type can suffer non-uniform drying air flow through the crop, due to variations in static pressure along the plenum duct beneath the cocoa, MARCHANT and NELLIST (1977). With cocoa depths kept to the recognised limit of 20 cm WOOD (1961) and air flow kept low to main economic efficiency SHELTON (1967) the static pressure developed would necessarily be small.

It was thought possible, then, that even small static pressure variatinos along the plenum duct could have a comparatively large effect upon the drying air velocity along the length of the drier leading to exaggerated variations in drying rate. Consequently it was thougth necessary to consider at the designstage the magnitude of this effect and the means by which it could be reduced even if its elimination resulted in a reduced average drying air-flow.

One empirical suggestion at that stage was that an inclined or wedge shaped plenun duct would reduce static pressure variations by maintaining a constant air velocity in the duct. The investigation of this and other simple geometries was another of the objectives of the work.

Since this work can be regarded to a large extent as a sequence of calculations upon which the design of the drier was based, no experimental data is presented. However, when the construction of the unit is completed it is hoped that it will be possible to collect confirmatory data.

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2. DEVELOPMENT OF THE EQUATION

2.1. Aplication of The Momentum Equation

Figura 1 shows an elemento of a rectangular duct of height D_H and width D_W. By the momentum equation we know that:

Net rate of outflow of momentum = Total force acting on the element

= Pressure forces + Shear Stress forces

Assuming isothermal conditions and that the passage of air out through the crop over the element dx is small compared to the change in total mass flow G, we have:

$$- G \, du_m = A_x \, dp + \tau \, dA_p$$

$$- u_m \rho A_x \, du_m = A_x \, dp + \tau A_p \, dx$$

$$\frac{dp}{dx} = - u_m \rho \frac{du}{dx} m - \frac{A}{A} p_x \tau$$

But

$$\frac{A}{A} p_x = \frac{2(D_H + D_W)}{D_H D_W} = \frac{4}{D_m}$$

where D_m is the hydraulic mean diameter of the duct and $\tau = F.(0.5 u_m^2)$ where F is the skin friction coefficient.

Introducing these correlations we obtain:

$$\frac{dp}{dx} = - u_m \rho \frac{du}{dx} m - \frac{2F \rho u_m^2}{D_m} \qquad \text{eq. 1}$$

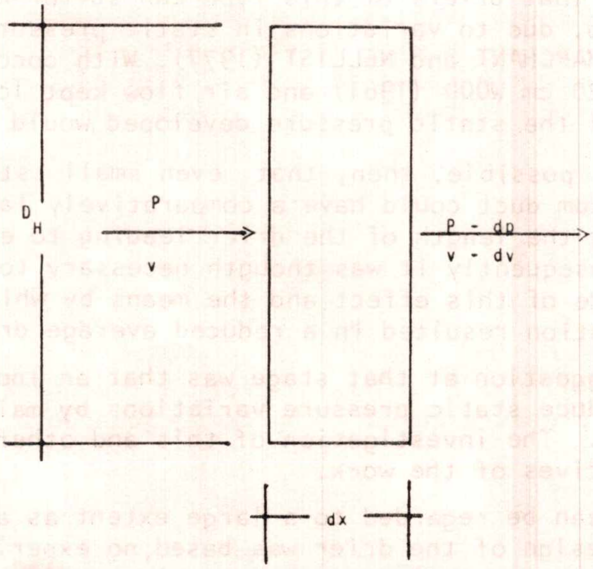

FIGURE 1 - An element of the plenum duct.

Throughout the preceding development a mean plenum duct velocity u_m has bean assumed, yet even in turbulent flow where the velocity profile is relatively flat, the velocity in the neighbourhood of the duct walls will be considerably lower than u_m. The drying air that leaves the duct will tend to be extracted from this low energy layer. The effect of this is that the air in the duct will tend to be decelerated more rapidly than indicated in equation (1). To allow for this, the velocity derivative is often increased by a factor R, the regain coefficient giving:

$$\frac{dp}{dx} = -u_m R\rho \frac{du_m}{dx} - \frac{2F\rho u_m^2}{D_m} \qquad \text{eq. 2}$$

MARCHANT and NELUST, 1977 quote values of R from various sources in the litetature showing a variation of between 0.8 to 1.5 at the fan end on the duct, to 0.2 at the blind end. It seems that little work has been done to relate the regain coefficient to the physics of the system rather than relying upon empirical values. In the absence of correlations for the duct geometry under consideration here, R was taken as unity.

The skin friction coefficient musto be calculated in order to solve equation 2. Although the flow of air in large ducts will almost always be turbulent consideration has to be given to an initial laminar flow region.

for $Re < 2000$ $$F = \frac{16}{Re} \qquad \text{eq. 3a}$$

for $Re > 2000$ $$\frac{1}{\sqrt{F}} = -4\log\left(\frac{K_s}{3.7D_m} + \frac{1.26}{Re\sqrt{F}}\right) \qquad \text{eq. 3b}$$

where:

$Re = U_m \rho D_m/\mu$, the Reynolds number

K_s = absolute roughness of the duct wall, m.

The equation for turbulent flow is that used by MARCHANT and NELLIST, 1977 and involves a trial and error solution for F.

2.2. Flow Through the Cocoa

Although for purposes of analysis G could be assumed constant in the development of equation 2, in fact G will decrease along the length of the duct. Assuming the airflow through the cocoa to have a vertical component of motion only, over the element dx, then we have:

$$dG = u_c \rho D_W dx$$

$$d(u_m \rho A_x) = u_c \rho D_W d_x$$

$$\frac{du_m}{dx} = \frac{u_c}{D_H} \qquad \text{eq. 4}$$

The velocity of drying air through a crop is dependent upon the crop depth, d, and the static pressure beneath the crop. Such data is usually correlated in the form:

$$p = K_1 u_c^{K_2} d \qquad \text{eq. 5}$$

Rearranging and substituting for u_c in equation 4, we have:

$$\frac{du_m}{dx} = \frac{1}{D_H}\left(\frac{p}{K_1 d}\right)^{1/K_2} \qquad \text{eq. 6}$$

2.3. Conditions for Zero Static Pressure Regain

If static pressure regain is prevented we can say:

$$P = P_L$$

and eq. 7

$$\frac{dp}{dx} = 0$$

Then from equation (2) we have:

$$0 = -R\frac{du}{dx}m - \frac{2Fu}{D_m}m \qquad \text{eq. 8}$$

and from equation (4) we have:

$$\frac{du}{dx}m = \frac{u_c}{D_H} \quad \text{where } u_c \neq f(x) \qquad \text{eq. 9}$$

Rearranging equations (8) and (9) we have:

$$F u_m = -\frac{Ru_c D_m}{2D_H} \qquad \text{eq. 10}$$

From equation 3b, F can be seen to be a function of u_m (through Re), and assuming that the absolute roughness K_s cannot be manipulated then the left-hand side of equation 10 bears an inevitable functional relationship to x, the distance along the duct. Since for the conditions of equation 7 we know that u_c is to be constant, then for these conditions to be maintained we know that:

$$\frac{D}{D_H}m = \frac{2D_W}{D_W + D_H} = f(x) \qquad \text{eq. 11}$$

That is, for finite conditions, static pressure regain cannot be prevented unless D_H or D_W varies with **x**. Conversely, for a uniformly rectangular duct static pressure regain must take place. The necessary variation of D_H can be investigated by rewriting equations 10 and 11, such that:

$$D_H = -D_W\left(\frac{Ru}{Fu_m}c + 1\right) \qquad \text{eq. 12}$$

It now becomes obvious that for a boundary condition $u_L = 0$, the necessary duct height for zero static pressure regain would be infinite. Note that this conclusion is independent of variations in any of the other parameters.

The other possible parameter for eliminating static pressure regain, the cocoa depth, d, can ve investigated by substituting equation 5 into equation 12 which on re-arranging gives:

$$d - \frac{p}{K_1}\left\{\frac{RD_W}{Fu_m(D_W+D_H)}\right\}^{K_2} \qquad \text{eq. 13}$$

In this case, too, it can be seen that as u_m tends to zero the required cocoa depht will tend to infinity.

3. SOLUTION OF THE EQUATIONS

3.1. Definition of The Boundary Conditions

Using a notation that defines conditions at the fan end of the duct with subscript 0 and those at the blind end by L, two different sets of boundary conditions can be defined:

$$U_L = 0, \qquad P_0 = \text{value defined by chosen fan capacity.}$$

and:

$$U_L = 0, \qquad P_L = \text{specified value}$$

The first set of conditions will give the drying air profile for known fan delivery while the second will work back to define a fan requirement for specified blind end static pressure. The first results in a boundary value solution and the second the more convenient initial value solution. For this investigation the initial value solution was used throughout.

3.2. Solution Methods

The numerical solution of equations 2 and 6 with initial value boundary conditions could be achieved either by predictor-corretor or Runge-Kutta methods WILLIAMS, 1973. The former is most useful in systems with dependent variables which increase or decrease at greatly differing rates (stiff systems). The Rouge-Kutta method is widely used, however, by the non-specialist solving well ordered stable systems. It has the advantages of being easy to program and requiring no special starting routine. In this work a Runge-Kutta solution was applied with a step length of 0.01m. The results showed no evidence of instability. Solution was carried out on an IBM 360 system with IBM package sobroutine RKGS, 1971, based on a fourth order Runge-Kutta-Gill solution method.

The solution of equation 3b also involved use of a package subroutine, RTW1, based upon Wegsteins Iteration method.

3.3. System Testing

To test the model solution a set of typical data was compiled, the chosen basic values are shown in Table 1. The implied geometry of the drier indicates the intended scale of the system under consideration. As previously stated R was set at unity.

TABLE 1 - Basic Parameter Values for System Testing

D_W	2.0	m
D_H	0.8	m
D_L	10.0	m
R	1.0	
K_S	0.0015	m
K_1	2308.9	
K_2	1.542	
d	0.2	m
T	60	^0C

The absolute roughness value required to calculate the turbulent friction factor was taken as 0.0015m, for all surfaces, a value typical of the concrete plenum chamber base and walls. The effects of the perforated metal plates and their supports were assumed at this stage to be comparable with a concrete surface.

No accurate pressure drop data for cocoa has been found in the literature and in order to obtain a correlation suitable for use here information was extracted from that presented by HAYNES, 1958 in graphical form for cocoa at 50% moisture content wet basis. The coeffcients K_1 and K_2 shown in Table 1 were derived by a linear regression on 5 data points, for static pressures in the range 0 to 270.5 N/m^2.

The air density and viscosity were calculated from the specified air temperature by means of polynomial correlations of data from the literature. The quoted temperature of 60^{0}C is typical for forced ventilation artificial drying of cocoa (2). (WOOD, 1961).

The static pressure boundary condition was chosen as 13.25 N/m^2 which would give an air velocity of 0.1 m/sec through the crop (calculated at 60^{0}C). It is assumed throughout that this is the design value of u_c and any deviations - from this value are to be avoided. The static pressure profile and corresponding drying air flow distribution derived from this input data are shown in Figure 2.

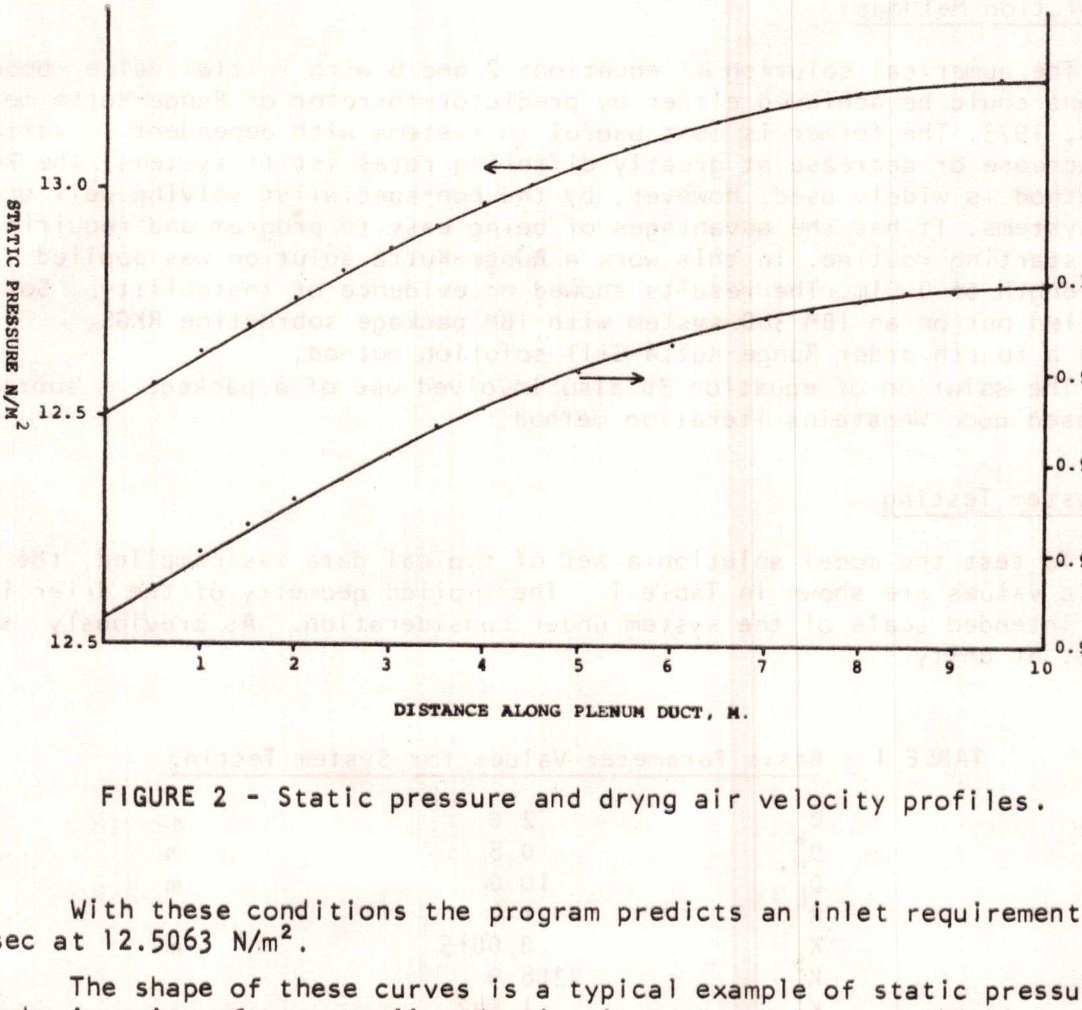

FIGURE 2 - Static pressure and dryng air velocity profiles.

With these conditions the program predicts an inlet requirement of 1.974 m^3/sec at 12.5063 N/m^2.

The shape of these curves is a typical example of static pressure regain whereby in spite of an overall reduction in system energy as the air moves the duct, the static pressure actually increases. This effect can be deduced from equation 2 wherein a negative mean velocity derivative results in a positive static pressure derivative. In empirical terms the deceleration of the air along the plenum can be regarded as a conversion of velocity energy to static pressure energy.

A point that must be made is that for the quoted conditions the static pressure regain is not a significant factor and would be unlikely to have any great effect upon the drying rate along the length of the drier since the velocity of air through the crop varies between 0.1 m/sec and 0.0963 m/sec. only.

4. DISCUSSION OF THE RESULTS

4.1. Definition of an Error Criterion

In order to be able to compare the static pressure profiles derived for the various conditions to ve investigated, and error criterion, E, was defined by which the deviation from the set boundary value, P_L, was measured.

$$E = \frac{1}{N} \left(\sum_{n=1}^{N} (p_n - p_L)^2 \right)^{0.5} \qquad \text{eq. 14}$$

For the base conditions listed in Table 1 a deviation value, E_b, of 0.552 was obtained.

A reduction in **E** due to some manipulation of the parameters would indicated an approach to the ideal situation of zero static pressure variation along the duct. To indicate such tendencies better, a relative deviation error criterion, e, was definide:

$$e = \frac{E}{E_b} \qquad \text{eq. 15}$$

In the work on variable plenum duct heights it was necessary to compare the profile with that for maximum duct height and an alternative relative error criterion e_X was defined as:

$$e_X = \frac{E}{E_X} \qquad \text{eq. 16}$$

where E_X is the value for D_H^{MAX}

4.2. Parameter Sensitivity Analysis

The sensitivity of the model to parameter variations has important implications. It defines those values to which the model reacts greatly and which should be fixed with accuracy. It also indicates which parameters could be varied to improve the system behaviour. System behaviour for these purposes can be split into two areas of interest, the static pressure profile through e and the size of fan which would be required to give an airflow u_{mo} or V_o at a static pressure p_o. Although this latter case is of less interest here due to the very small pressures involved, the shole sequence of results are presented since interesting and, in different circumstances, important, results can be drawn.

A resume of the results obtained is presented in Table 2.

4.2.1. Effects Upon the Static Pressures Profile

Although the magnitude of the effect varies, it can be seen that improved uniformity of **p** can be achieved by increasing D_H, K_S, K_1 **d** and T or by decreasing D_W, D_L, R K_2 or indeed by decreasing the design static pressure P_L. However it can also'be seen that the effects of D_W and K_S are of negligible magnitude.

The independence of static pressure distribution on K_S is significant . On the one hand this supports the rather arbitrary choice of absolute roughness value while on the other indicates that a smooth surface correlation for F might be quite adequate. A run with K_S = 0 was carried out, giving e = 1.0102, p_o = 12.497 and V_o = 1.974, which differ hardly at all from the values quoted in section 3.3. for the base conditions.

Another important point to note is the strong dependance of the static pressure profile on each of the coefficients in the pressure drop correlation equation 5. The values of K_1 and K_2 quoted in Table 1 can only be regarded as approximate due to the uncertain nature of their origin. It is obvious that for application of this method these coefficients should be determined as accurately

Table 2 Parameter Sensitivity Analysis

PARAMETER	Upwards Perturbation					Downwards Perturbation					J
	P_o	e^+	V_o	V_o/V_{ob}	U_{mo}	P_o	e^-	V_o	V_o/V_{ob}	U_{mo}	
Base	12.506	1.000	1.974	1.000	1.234	12.506	1.000	1.974	1.000	1.234	-
D_w	12.505	1.002	2.172	1.102	1.234	12.509	0.997	1.777	0.900	1.234	0.801
D_h	12.629	0.833	1.978	1.002	1.124	12.344	1.222	1.969	0.997	1.367	0.752
D_L	12.361	1.120	2.166	1.097	1.354	12.641	0.865	1.781	0.902	1.113	1.031
R	12.428	1.104	1.972	0.999	1.232	12.585	0.895	1.977	1.002	1.236	0.996
K_s	12.507	0.999	1.974	1.000	1.234	12.506	1.001	1.974	1.000	1.234	0.988
K_1	12.591	0.885	1.859	0.942	1.162	12.400	1.144	2.110	1.069	1.319	0.798
K_2	12.129	1.511	2.422	1.227	1.514	12.801	0.602	1.535	0.778	0.959	1.285
b	12.591	0.885	1.859	0.942	1.162	12.400	1.144	2.110	1.069	1.319	0.798
P_L	13.734	1.132	2.099	1.063	1.152	11.276	0.873	1.845	0.935	1.312	1.037
F	12.512	0.993	1.974	1.000	1.234	12.501	1.007	1.974	1.000	1.234	0.994

as possible. Furthermore variations due to moisture content changes, which have not been taken into account here, could be significant.

Equally important is the need for precise measurement of the depth of cocoa on the drying plataform. It can be seen that variations in **d** have an identically great effect upon **E** as changes in K_1 (due to their appearance in the model only as the product). In reality it would be experimentally difficult to maintain a definite and uniformly constant value of d. Furthermore it is now apparent that the unavoidable undulations in cocoa depth over the drier area will have an exaggerated effect upon the static pressure profile.

Most important to the work in hand are the responses to changes in D_H and D_W. There is a marked dependancy upon D_H, but, strangely, variation in D_W has only a negligible effect.

It has to be concluded that the ratio F/Dm in equation 2 is insensitive to changes in duct cross-sectional area while the D_H term in equation 6 has a large effect.

In general, the system giving the best static pressure distribution would be that with the shortest duct length, highest plenum, deepest cocoa layer and lowest specified static pressure. It must be added, however, that the last two of these if taken to extreme will result in difficulty in mixing of the crop and slow and non-uniform drying due to moisture content profiles in the vertical plane.

4.2.2. Effects Upon the Inlet Air Flow

The interesting observation has been made that a 10% change in D_W has no effect upon the calculated inlet air velocity, and that the corresponding volumetric flow increases by the same 10%. Conversely the same increase in D_H results in a 10% decrease in u_{mo} with hardly any change at all in V_o.

Variations in the other parameters are less complex since no simultaneous effect upon velocity through duct cross-sectional area takes place, that is V_o/V_{ob} would equal u_{mo}/u_{mob}. The effect of D_L is linear while those of **R** and K_S are negligible. The constant K_1 and the cocoa depth, **d**, have an identical effect while that following a change in K_2 again is dramatically high.

4.3. Linearity of Static Pressure Response

The linearity of the response of **e** to parametric changes can be demonstrated by the factor **j**, where:

$$j = \frac{1-e+}{1-e^-} \qquad \text{eq. 17}$$

For a linear response j = 1 whilst for j > 1 the system reacts stronger to parametric increases and vice versa for j < 1. The values of **j** are presented in Table 2. It should be noted that these values were calculated by 6 significant figura values of **e**, from which those e values shown in Table 2 were derived by truncation.

It can be seen then that, with the exception of D_W, the strongest non-linear effects are exhibited by the parameters which appear in equation 6. The non-linear nature of this equation is obvious; what is less obvious is that the non-linearity of each of these parameters is strongest in the direction which results in worsened static pressure distribution.

The D_H factor in equation 5 in fact is linear and the question arises as to where the non-linearity of this and D_W originates. This must arise either through the u_m^2 term or through **F**, both in the friction term of equation 2.

4.4. Comparison of the Relative Effects of the Momentum and Friction Terms of the Momentum Equation

Much information has been deduced regarding the effects of the flow equation 6, in terms of its non-linear effects and the preferential appearance of D_H and not D_W. Equation 2 has a more subtle behaviour. An investigation of the comparative effects of the friction and momentum terms of equation 2 was carried out to throw more light in this area.

Perturbations of **R** and F respectively will uniquely excite the momentum and friction terms respectively. The results are incorporated in Table 2. It can be seen that variations in the friction term have negligible effects, altering neither inlet air velocity or volumetric flow while modifying the static pressure profile only slightly (only marginally more than a similar perturbation in K_S), thus supporting the previous deduction that friction has only a marginal effect upon the system.

As has been seen before, perturbations of the momentum term, effected by varying R, have only the slightest effect upon air flow but dramatically upsets the static pressure profile.

The effects of variations in either term are only very slightly non-linear.

4.5. Attempts to Reduce or Eliminate Pressure Regain

In the event, static pressure regain would not seen to be a problem under the conditions presented in Table 1. From Figure 2 the variation in u_c can be seen to be only 4%. However, continuing the investigatory side of the work, it was decided to look at the means by which even this small regain could be eliminated.

From Table 1 it can also be seen that for a given drier area only two parameters are available for manipulation, plenum duct height, D_H, and cocoa bed depth, **d**.

In section 2.3 it has been shown that neither of these parameters can actually eliminate static pressure regain since both require non-finite values at the blind end of the duct. However, the possibility of improving the static pressure profile by means of variations in D_H or d was thought worthy of investigation.

The use of D_M for this purpose was prefered, since once designed and built into the drier, no further effort would be required.

The drawback with the use of cocoa depth variations to offset static pressure regain is that the quality of the effect will depend upon the correct profile being maintained after each mixing. An additional problem is that the pressure regain is sensitive to changes in **d** and erros in the depth profile will have a magnified effect.

4.5.1. The Effect of Some Selected Plenum Duct Geometries

Since the analytical expression for the necessary D_H variation is insoluble it was decided to investigate arbitrary inclination of the plenum duct floor. Static pressure regain was thought to be simply due to the deceleration of the air and a wedge shaped plenun duct with the floor upwards inclined from the fan end was expected to result in an improved static pressure profile. For completeness both upwards and downwards inclined configurations were tested.

This was achieved by fixing the duct height at the base value of 0.8m at either the fan end or the blind end and varying the height at the other end in the range 0.1m to 1.5m. For variable D_H values less than 0.8 the upwards inclined mode is achieved when the fan and height is fixed at 0.8m and downwards inclination for the blind end fixed at 0.8. Variable D_H = 0.8 gives the horizon tal or base case.

It can be seen from Table 3 that for both upwards and downwards inclinations the approach to the horizontal is accompanied by an improvement in the static pressure profile.

To follow up this trend the variable D_H values were increased to 1.5m such that the height fixed at 0.8m now becomes the mininum. It can be seen that this results in a continuation of the previously observed trend with an improvement being obtained as compared with the horizontal case.

Constructionally the maximum plenum chamber height of a platform drier will define the support wall height independent of any internal modifications, including any inclination of the duct floor. An alternative way then of testing the quality of the static pressure profile would be to compare with the profile for the horizontal case at D_H^{MAX} (see equation 16).

For variable D_H values less than 0.8, $e = e_X$, hence e_X values are quoted in Table 3 for the higher values of variable D_H only and these error values increase with D_H.

It can now be seeen that it is not possible to improve the static pressure profile of a horizontal duct by any means which involves the reduction of duct height at any point from the maximum value.

To demonstrate further characteristics of the upwards and downwards inclinations of the plenum flow, Figure 3 shows the duct velocity profiles for the horizontal and the 4 inclined cases for D_H perturbation of 0.5m about the base value of 0.8m. It can be seen that for a given slope of the plenum flow the inlet velocity is independent of whether the inclination is upwards or downwards (see also Table 3). The velocities at a given point within the duct, however, are always lower for downwards inclinations that the corresponding upwards inclined values.

TABLE 3 - Inclined Plenum Floor Results

D_h at fan end = 0.8				D_h at blind end 0.8				D_h at opposite end
e	e_x	V_o	U_{mo}	e	e_x	V_o	U_{mo}	
6.176	-	4.452	2.783	3.313	-	0.557	2.784	0.1
3.749	-	3.547	2.217	2.461	-	0.887	2.217	0.2
2.665	-	3.045	1.903	1.974	-	1.142	1.903	0.3
2.047	-	2.707	1.692	1.653	-	1.353	1.692	0.4
1.643	-	2.457	1.536	1.423	-	1.536	1.536	0.5
1.363	-	2.263	1.414	1.348	-	1.697	1.414	0.6
1.157	-	2.105	1.316	1.111	-	1.842	1.316	0.7
1.000	1.000	1.974	1.234	1.000	1.974	1.974	1.234	0.8
0.876	1.0984	1.863	1.164	0.909	1.1390	2.096	1.164	0.9
0.776	1.1193	1.767	1.104	0.852	1.2779	2.208	1.104	1.0
0.694	1.2843	1.682	1.051	0.766	1.4164	2.313	1.051	1.1
0.627	1.3719	1.608	1.005	0.710	1.5541	2.412	1.005	1.2
0.569	1.4566	1.541	0.963	0.660	1.6911	2.504	0.963	1.3
0.519	1.5386	1.481	0.926	0.617	1.8277	2.592	0.926	1.4
0.477	1.6179	1.427	0.892	0.579	1.9624	2.675	0.892	1.5

4.6. The Value of Increased Duct Height for Horizontal Ducts

It was shown in section 4.5.1. that the best plenum duct is horizontal

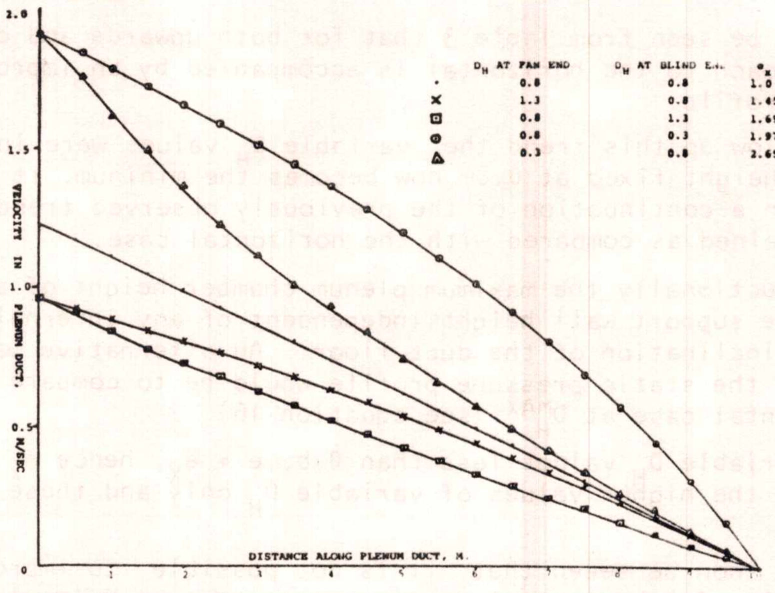

FIGURE 3 - Velocity profiles along inclined ducts.

and of the maximum height. It follows then for a given set of conditions the duct height can be fixed by specifying e maximum tolerable variation of static pressure along the duct. To test this idea, the relative error criterion, E,was calculated for various horizontal ducts of heights ranging from 0.1m to 1.5m; - the results are presented in Table 3 and Figure 4.

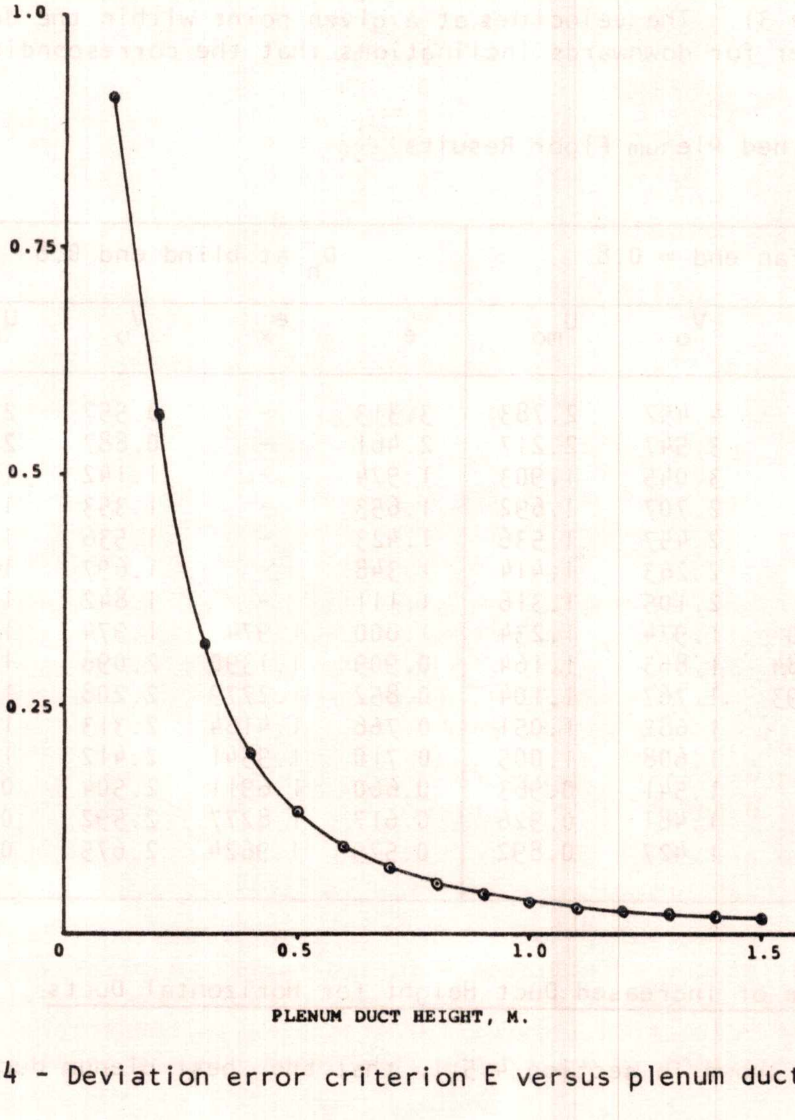

FIGURE 4 - Deviation error criterion E versus plenum duct height.

It can be seen that the approach to the assymptote of E = 0 at D_H ∞ is rapid.

The plenum height chosen for this investigation, 0.8m can be seeen to be a reasonable compròmise value.

The actual values are shown in Table 4 along with the required inlet conditions. Note that although u_{mo} continues to vary quite strongly, V_o rapidly approaches its own asymptote value.

TABLE 4 - Plenum Duct Height Investigation

D_h	P_o	E	U_{mo}	V_o
0.1	16.206	0.9117	7.259	1.452
0.2	16.664	0.5655	4.268	1.707
0.3	19.216	0.3189	3.075	1.845
0.4	10.672	0.1976	2.383	1.907
0.5	11.490	0.1329	1.938	1.938
0.6	11.981	0.0951	1.630	1.956
0.7	12.245	0.0712	1.405	1.967
0.8	12.506	0.0552	1.234	1.974
0.9	12.655	0.0440	1.100	1.979
1.0	12.764	0.0359	0.992	1.983
1.1	12.845	0.0299	0.903	1.986
1.2	12.908	0.0252	0.828	1.988
1.3	12.957	0.0216	0.765	1.990
1.4	12.997	0.0186	0.711	1.991
1.5	13.029	0.0163	0.664	1.992

5. CONCLUSIONS

(1) An investigation of the theory of air flow in a plenum duct beneath a crop has shown that static pressure regain cannot be prevented by finite variations in either duct height or cocoa depth.

(2) Solution of the system model for typical operating data has shown that, in fact, the effect of static pressure regain is not great, u_c varying by only 4%. It has been assumed throughout that the development of the required inlet air flow/static pressure combination occurs outside of the drier as such.

(3) Reduced static pressure regain can be effected by increased D_H, K_S, K_1, **d** and T or by decreased D_W, D_L, **R** and K_2.

(4) The effect of the friction term in equation 2 on static pressure regain and required inlet flow is negligible.

(5) The effect of D_W upon static pressure regain is negligible while D_H variations affect regain considerably. Similarly, variations in D_W have little effect upon the required inlet air velocity but the inlet volumetric flow varies according to the alteration in duct area. Variations in D_H, on the other hand, causes the inlet required velo

city to vary in inverse proportion, while the inlet volumetric flow does not vary at all.

(6) The coefficients of the pressure drop equation have a large effect upon both static pressure and inlet air velocity and should be determined accurately for this method to have validity.

(7) The regain coefficient has little effect upon the required inlet velocity but affects the static pressure development linearly. The values of R for the duct in question should be derived and attempts made to relate in to the physics of the system, notably the cross-sectional velocity profile or boundary layer depth.

(8) Attempts to reduce the effect of static pressure regain by means of wedge shaped plenum chambers, showed that only by increasing the height of the duct can this be achieved. For any inclined duct the static pressure regain will be more pronounced than for a horizontal duct with a height equal to the maximum value from the inclined case. It is recommended that horizontal ducts only be considered with the height fixed by calculation based upon a specified maximum tolerable static pressure regain.

(9) The effect of cocoa depth on static pressure regain is great thougt it has a lesser effect upon the inlet velocity. The effect of variations of d upon regain has yet to be investigated in full.

NOTATION

A_p	Peripheral area of plenum duct	m^2
A_x	Cross sectional area of plenum duct	m^2
d	Depth of cocoa	m
D_H	Plenum duct height	m
D_m	Hydraulic mean diameter	m
D_W	Plenum duct width	m
e	Relative error criterion, equ. 14	
e_X	Relative error criterion, equ. 15	
E	Deviation error criterion, equ. 13	
E_X	Deviation error criterion for D_{DH}^{MAX}	
F	Friction factor	
G	Air mass flow	kg/sec.
j	Linearity coefficient, equ. 15	
K_S	Absolute roughness of plenum wall	m
K_1	Constant in equation 6	N/m^{K_2+3} $sec.^{K_2}$
K_2	Constant in equation 6	
L	Total lenght of the drier	m
N	Number of increments in solution procedure	
P	Static pressure	N/m^2
R	Regain coefficient	
Re	Reynolds number	
T	Temperature	^oC
u_c	Air velocity through the crop	m/sec
u_m	Mean air velocity in plenum duct	m/sec

NOTATION

x	Distance along duct	m
μ	Air viscosity	kg/m/sec.
ρ	Air Density	kg/m^3
τ	Shear stress	N/m^2

SUBCRIPTS

L	Value at $x = L$
b	Value for base conditions (Table 1)
o	Value at $x = 0$

SUPERSCRIPTS

MAX	Maximum value
MIN	Minimum value

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