# COMPARATIVE STUDY OF THE DIFFERENT APPARATA FOR FREEZING IN COLD AIR FLOW
## -review-

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## Abstract

*The comparison of the different freezing apparata is done by takink into consideration the main factors that occur within the process of freeezing in cold air flow.*
*These factors (the shape of the particles, the lenght and height of the article layer, the mixing of the particles in the layer, the freezing time) determine the productivity of the installation involving freezing in fixed or fluidized bed.*
***Keywords**: fixed layer, fluidized layer, length, height, productivity.*

## Introduction

There is little specialty literature available in which there is compared the freezing efficiency of fixed beds with that of fluidized beds, neither are there design equations available to optimize the mixed bed performance where a fluidized bed precedes a fixed one. It should be mentioned that, apart from the eventual differences in the heat transfer coefficient, there are also important differences in the circulation of solids in both types of equipment. Thus, the fluidized bed is characterized by a total mixing in vertical and transverse directions with a certain deviation with respect to the plug flow in longitudinal direction due to the effect of bubbles. However, there is no mixing in the fixed bed, and the particles move with plug flow at the conveyor belt velocity.

The production rate of both alternatives will depend on the relative influence of the explained phenomena and their dependence on the operating and design parameters.

In this paper there is presented the simulation of the freezing of carrots in a fixed bed, and the equipment production is compared to that of a fluidized bed. The effect of the appropriate parameters on both alternatives is also analyzed.

## Experimental

In order to accomplish this paper there were used data from the specialty literature and a software programme for the simulation of these two processes will be used.

## Results and Discussions

In both systems the air temperature changes from that at the entrance through the grid to that at the outlet across the bed surface. In the fluidized bed system it occurs in an exponential way, and in the fixed bed with the function shown in Fig. 1.

The behaviour of the solids in the two types of freezers is essentially different. Solids show total mixing in the vertical direction in the fluidized bed.

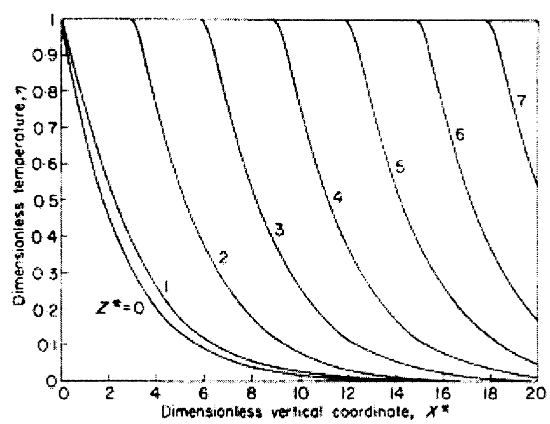


**Fig. 1**: Vertical distribution of air temperature for different longitudinal positions of the fixed bed. Bi=0.4

This allows all the particles to complete their freezing at the same bed length as given by equation the freezing time with the effective heat transfer coefficients, here $f_{eff}$, depending on the bed height. This coefficient corrects the fact that particles are not in continuous contact with the air at $T_{gl}$ and makes the freezing time longer than the corresponding time for a monolayer.

The small degree of longitudinal mixing makes it necessary to adjust, the residence times to longer than the freezing times by means of equation (1):

$$\frac{F}{WL}=\frac{H(1-\varepsilon)\rho_s}{t_c}\left[1-\left(\frac{5{,}41t_cD_z}{L^2}\right)^{\frac{1}{2}}\right] \tag{1}$$

Where:

F is the production rate (mass flow rate of solid feeding);

W the bed width;

L the bed length;

H and $\varepsilon$ are the expanded bed height and voidage, respectively; and $\rho_s$ is the density of the fluidized particles.

This equation ensures that > 95% of the bed particles come out frozen.

However, solids do not mix in the fixed bed and they only circulate at belt velocity $V_b$. The residence time is controlled by the freezing time of the particles placed on the bed top layers which are subjected to higher temperatures. The lack of vertical mixing leads to large residence times.

To *compare* the production *rate in* both systems, assuming that 95% of the particles come out completely frozen, it will be necessary to introduce into equation (2):

$$Z=\frac{Lk_c(T_c-T_{g1})}{V_b\lambda_f\rho_sR_0{}^2Y_0} \tag{2}$$

and

$$x=\frac{0{,}95aH_0k_c}{C_pGR_0} \tag{3}$$

to obtain the required velocity as:

$$V_b\frac{6Lk_c(T_c-T_{g1})}{\lambda_fY_0\rho_sR_0{}^2\left[\left(1+\frac{2}{Bi}\right)+\left(\frac{1{,}9aH_0k_c}{C_pGR_0}\right)\right]} \tag{4}$$

As shown in equation (4) increments in the bed height, $H_0$, require a simultaneous decrease of the belt velocity, $V_b$, to ensure 95% of frozen particles at the outlet.

By taking into account that solids move longitudinally with a plug flow pattern the production rate will be $F = WH_0(1-\varepsilon_0)\rho_s V_b$ and by introducing equation (4) we have:

$$\frac{F}{WL} = \frac{6H_0(1-\varepsilon_0)k_c(T_c - T_{g1})C_pG}{\lambda_f Y_0 R_0\left[C_pGR_0\left(1+\frac{2}{Bi}\right)+1{,}9aH_0k_c\right]} \tag{5}$$

Equation (1) allows the production rate per umt of grid area in the fixed bed to be calculated and compared with the predictions of equation (1) for the fluidized bed.

One problem corresponds to the air velocity. Obviously, the fixed bed requires $V_0 < V_{mf}$ , and the fluidized bed $V_0 > Vmf$; for that reason $V_0 = V_{mf}$ was used in *Fig. 2* to compare on a similar basis.

It is also shown that bed height, $H_0$, is an important operating variable to assure maximum production rates.

Maximum production rates for both beds are shown in *Fig. 3* as a function of length. A value of $H_0$=0.22m was used for the fixed bed and the optimum height for each length (included in *Fig. 3)* was adopted for the fluidized bed freezer.

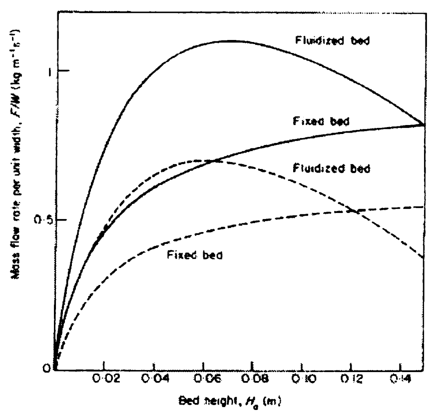


**Fig. 2**: Production rate per unit of bed width for fixed beds

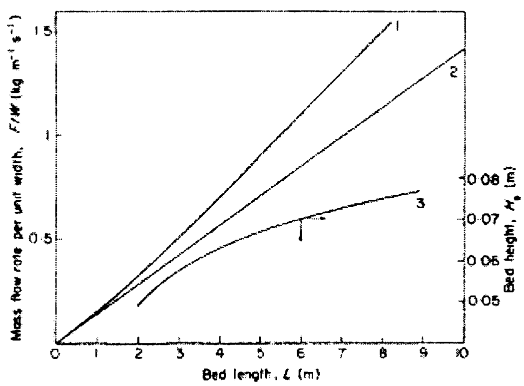


**Fig. 3**: Production rate at optimal height for different bed lengths.
1: Fluidized bed Vo= $1.2V_{mf}$; 2: Fixed bed Vo=$0.8V_{mf}$. $H_0$=0.22 m; 3: $H_0$- fluidized bed

Results show that the fixed bed requires lengths from 20 to 30% longer to attain the same production rate per unit of width.

Comparisons of the power consumption of blowers in both types of beds must also be performed. Thus, the blowing power, P, through a bed is given by:

$$P = \Delta p V_0 W L \tag{6}$$

The pressure drop, Δp, for a fixed bed can be calculated through Ergun's Equation:

$$\Delta p = \frac{150\mu(1-\varepsilon_0)^2 H_0 V_0}{D_0^{\,2}\varepsilon_0^{\,3}} + \frac{1{,}75\rho(1-\varepsilon_0)H_0 V_0^{\,2}}{D_0\varepsilon_0^{\,3}} \tag{7}$$

However, the pressure drop for a fluidized bed can be calculated as:

$$\Delta p = (\rho_s - \rho)g(1-\varepsilon_0)H_0 \tag{8}$$

By introducing Equations (7) and (8) into equation (6) the power consumptions in blowers for both fixed and fluidized beds can be evaluated in terms of their dimensions and operating conditions.

The comparison of the power consumption in blowers for beds of equal dimensions obviously shows a higher consumption for fluidized beds due to the higher superficial velocity, $V_0$, that is used.

However, taking into account that for equal dimensions the production rates are different a comparison of power consumptions for equal production rates will be necessary. Thus, *Fig.4* shows the power consumption in blowers per unit of bed width, *P/W*, as a function of *F/W* for both beds operating with the corresponding optimum height. For the fixed bed with $H_0$=0.22 m the power consumption, P, is linearly dependent on F and non dependent on W and L as can be verified by combining equations (6) and (7) with Equation (5). For the fluidized bed, a value of *F/W* was proposed allowing the calculation of the necessary length and optimum height . From these values the power consumption per unit of bed width*P/W was* calculated through equations (6) and (8).

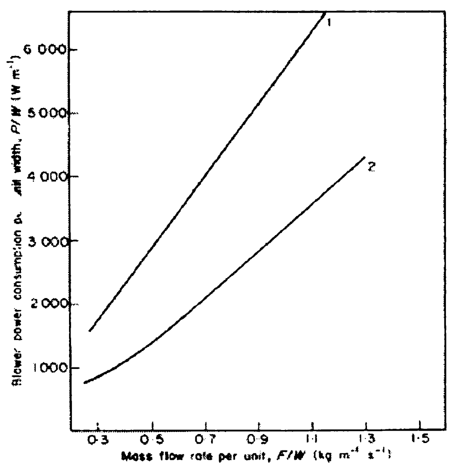

**Fig. 4**: Blower power consumptions for fixed and fluidized bed

Results from Figure 4 show that the power consumption for fixed beds is now much bigger than that for fluidized beds when compared to equal production rate.

## Conclusions

1. A linear analytical relationship between the necessary length for complete freezing of solids and the vertical position in the fixed bed was obtained. From this relationship the production rate, as a function of bed dimensions and operating conditions, can be calculated by accepting that 95% of the particles are completely frozen at the equipment outlet.

2. A comparison under realistic conditions for the two freezers shows a higher production rate for the fluidized bed by 20-30% for equal lengths and optimum bed heights. These production rates can change drastically if the bed depths are not optimal.

3. Similarly to optimum heights, fixed beds need to be 20-30% longer to supply the same production rate as fluidized beds.

4. Comparisons of blower power consumption for equal bed dimensions would lead to an obvious advantage for the fixed bed, but this is reversed when the analysis is performed for equal production rates. Then fixed beds require power consumptions 1.7-2.1 times higher than fluidized beds due to the necessary greater bed height and grid area.

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