CHARACTERIZATION OF THE HYDRODYNAMIC OF A VIBRATING FLUID BED DRYER BY A MODULAR NEURAL NETWORK MODEL

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ABSTRACT

The objective of this work is the modeling of the typical fluidization curves in an experimental vibrating fluidized bed using a modular type neural network under different operating conditions. The input variables are amplitude, frequency and air flow rate through the bed, and its output variable is the pressure drop across the bed. The model was used to predict the fluidization curves for three biomaterials, achieving a good fit with the experimental results. Based on the obtained results, it is concluded that the model is adequate for simulating the fluidization curves for vibrating fluidized beds, and its use is feasible for equipment design and scale up.

Key Words and Phrases: Vibrofluidized bed hydrodynamics; Hybrid Neural Models; Vibrofluidized bed dryer

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INTRODUCTION

Conventional fluidized bed dryers applications in industry are limited by some operational restrictions and other related to the substrate's characteristics. By applying vibration it is possible to mitigate some of these restrictions. When vibrofluidized bed dryers are compared with conventional ones, the former show a number of advantages, such as: better mixing, reduction of air flow requirements, and smaller pressure drops, in addition to the ability to fluidize cohesive and viscous materials, Dong [1].

Research on vibrofluidized bed dryers is extensive, summarized basically as studies on the pressure drop through the bed and the minimum vibrofluidization rate, Alvarez [2].

Many authors have shown that the pressure drop in a vibrating bed is much smaller than that in a conventional one, for a given operating range, and it has also been shown that the minimum fluidization pressure drop in the presence of vibration decreases when the amplitude increases and the frequency decreases. Also, direct effects were found in relation to the height of the bed and the size and shape of the particles, Mujumdar and Gupta, [3]. As was mentioned, vibration helps in the reduction of the minimum fluidization rate and the reduction degree depending of the acceleration vibration. There are correlations for both, the minimum vibrofluidization rate and the pressure drop in the vibrofluidized state. These results, together with phenomenological considerations, constitute the basis for formulating mathematical models meant for designing and simulating the operation. However, the lack of precise knowledge on the mechanisms and parameters involved gives rise to large uncertainty in its usefulness.

As an alternative to these parametric models, the use of artificial neural networks stands out. They have aroused great interest in recent years because of their ability to efficiently correlate nonlinear multidimensional spaces.

Neural networks have a great predictive capacity, as has been shown by several researchers such as Huang and Mujumdar [4]; Heyd et al. [5] ; and Jay and Oliver [6], in their studies on drying. Although the networks provide good results, they require many experimental data for proper fit, and they do not give any additional information on the process. To improve this methodology, researchers have proposed the incorporation of prior knowledge of the process into the neural model, giving rise to so-called Hybrid Models, Cubillos et al.,[7]. For drying processes, this prior knowledge can be included as a semi-parametric design approach in the form of balance equations (Cubillos et al,[7] , and Zbicinski et al,[8], or as modular design approach where the network structure is designed following some process mechanism (or process concept). As an example of this last methodology, Mateo et al, [9], developed a so called Generalized Drying Model (GDM), in which the architecture of the network was designed to weight the contribution of the internal and external resistances in the process, giving good results for the simulation of the drying of fish meal in an indirect dryer, when compared with experimental data.

This work attempts to apply these concepts to the modeling of the pressure drop across a batch-type vibrofluidized bed dryer under various operating conditions, starting from experimental information obtained on the fluidization of three biomaterials.

MODULAR NEURAL STRUCTURE GVM

The structure of the neural model used is that of a feed forward neural network whose hidden layer is partitioned into two sub-layers, one with linear nodes and the other with sigmoid nodes.

In this structure, called a Generalized Vibrofluidization Model (GVM), the input parameters into the network are frequency, amplitude and gas flow-rate, while the output is the pressure drop across the bed. This structure is especially useful when it is desired to represent a phenomenon of the superposition of two resistances, in this particular case the resistance of the distribution plate and of the bed. The proposed scheme is shown in Figure 1 and it is similar to the network used by Cubillos and Reyes [10], for the predictions of drying curves of carrots in a fluidized bed dryer.

Copy Figure 1.

MATERIALS, METHOD AND DATA EXPERIMENTAL

Hydrodynamic test were carried out in a vibrofluidized bed dryer with a 12 cm in diameter and a 50 cm of height. The static bed height was equal to 65 mm for all experiments. The vibration system consists of an eccentric setup and a crankshaft which transmits the motion of the motor to the fluidization container. The system has a 1.5 HP fan to impulse air across of equipment and is illustrated in Figure 2.

Copy Figure 2

The materials used for this study are of an agro-industrial nature, and they are listed, together with their properties, in Table 1. The vibration factors, frequency and amplitude explored for these products are shown in Table 2. The experimental measurements of pressure drop vs superficial air velocity across bed were determined with the conventional methodology . In each run, the superficial air velocity (measure indirectly in a rotameter in term of volumetric rate) was gradually increased from zero to 1.5 m/s, and the corresponding pressure drop across the bed were recorder from a differential pressure manometer.

RESULTS

Bed hydrodynamics

The hydrodynamic characteristic of the tested solids were analyzed in term of the typical variation of the pressure drop with the superficial air velocity. In the Figure 3 is shown a part of the all experimental data (254) obtained for material *nabo, curahuilla and cáñamo*. For details of the experimental work see Lobo [10].

The Figure 3 presents a behavior of curves type c and d, according to the Bratu and Jinescu classification. The curve type b was obtained for the smallest operation amplitudes (1,65-1,95 mm) and almost of the frequencies, mainly to Fv < 3.5. This curve type was also partially observed, for further amplitudes, like in the case of the *nabo* seeds. This behavior is similar to that found in fluidized beds, without the characteristic pressure pick in the curve, which it is softened by the vibration.

The curve type d was obtained in almost all the other operation conditions. Essentially the transition region is located between a static state and fluidized state that extends on a wide of speeds range, the curve clearly it is broken in three different lineal segments. This behavior was observed for intermediate vibration amplitudes (2,5 < TO < 4,5 mm) and generally under moderate operation conditions (1 < FV < 4).

GVM Model

Initially it was necessary to design the structure of the GVM network, which basically consisted in a network having amplitude, frequency and air flow-rate as inputs and the pressure drop through the bed dryer as the output variable. The activation function for the nodes in the hidden sub-layers were linear and sigmoidal (non linear) containing the corresponding bias.

The best architecture of the network was determined by looking for the optimal number of nodes in each hidden sub-layer, which minimizes the error between the predicted and the experimental pressure drop. The design of the network, its programming and training were carried out by means of the neural network toolbox of Matlab. In this way it was found that a network with six nodes in each sub-layer is able to carry out efficiently the prediction work for the three substrates, getting one network for each product.

Prediction of the pressure drop curves

To visualize the quality of the fit of these networks, Figure 4 show the experimental measurements and those predicted by the networks for the all runs listed in Table 2 . The total quadratic error is given in Table 3.

Figure 5 show the corresponding vibrofluidized curves, contrasting the experimental values and those simulated by the network model under different amplitude and frequency conditions.

DISCUSSION AND CONCLUSIONS

From Figure 4 it can be concluded that, for the three products, the GVM is capable of making excellent predictions of the experimental results, without any deviations, either positive or negative, being seen. This implies, beside the network's predicting capacity, that the modular scheme of two resistances is representative of the process that is being studied and can set the basis for the formulation of a phenomenological type of model.

On the other hand, Figure 5 show that the GVM is effective in predicting the typical fluidization curve in a vibrating bed dryer for the wide range of experimental conditions.

It can also be seen that the model is capable of predicting the pressure drop values in the fluidized and vibrofluidized states for different vibration factors. The prediction of these states by a single phenomenological model has not been possible, characterizing both processes by means of separate, usually not consistent, models.

It is concluded that the modular neural network GVM proposed in this paper is capable of modeling and simulating fluidization curves in a vibrofluidized under the different operating conditions. By explicitly considering the operational variables in its structure, it can be used in optimization and design practice.

Copy Figure 4 and 5

NOMENCLATURE

A	Vibration amplitude	mm
d_p	Particle diameter	m
f	Mechanical frequency	Hz
F_v	Vibrational factor	----
Q	Air flow rate	m^3 N/h
ΔP_{EXP}	Experimental pressure drop	Pa
ΔP_N	Predicted pressure drop	Pa
ϕ	Particle sphericity	----
U_g	Superficial air velocity	m/s
ε_m	Bed porosity	----
ρ_p	Particle density	kg/m^3

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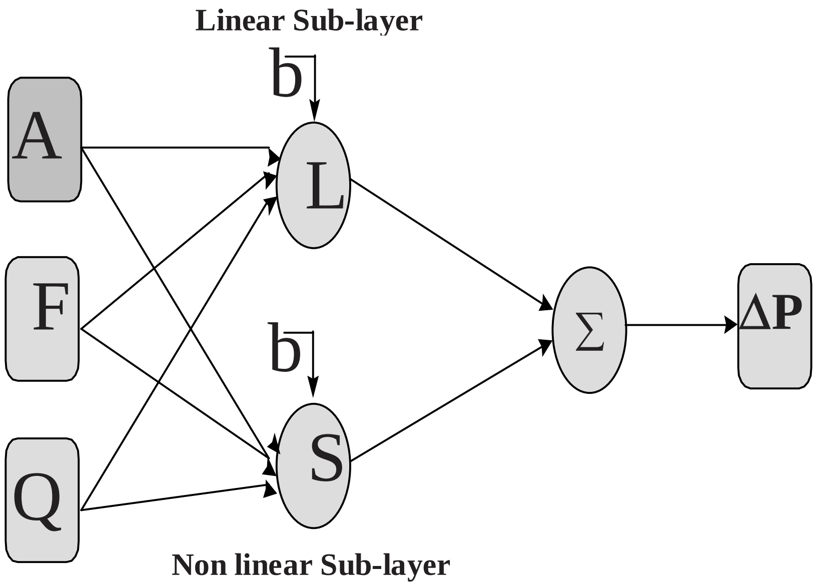


Figure 1: The GVM modular structure

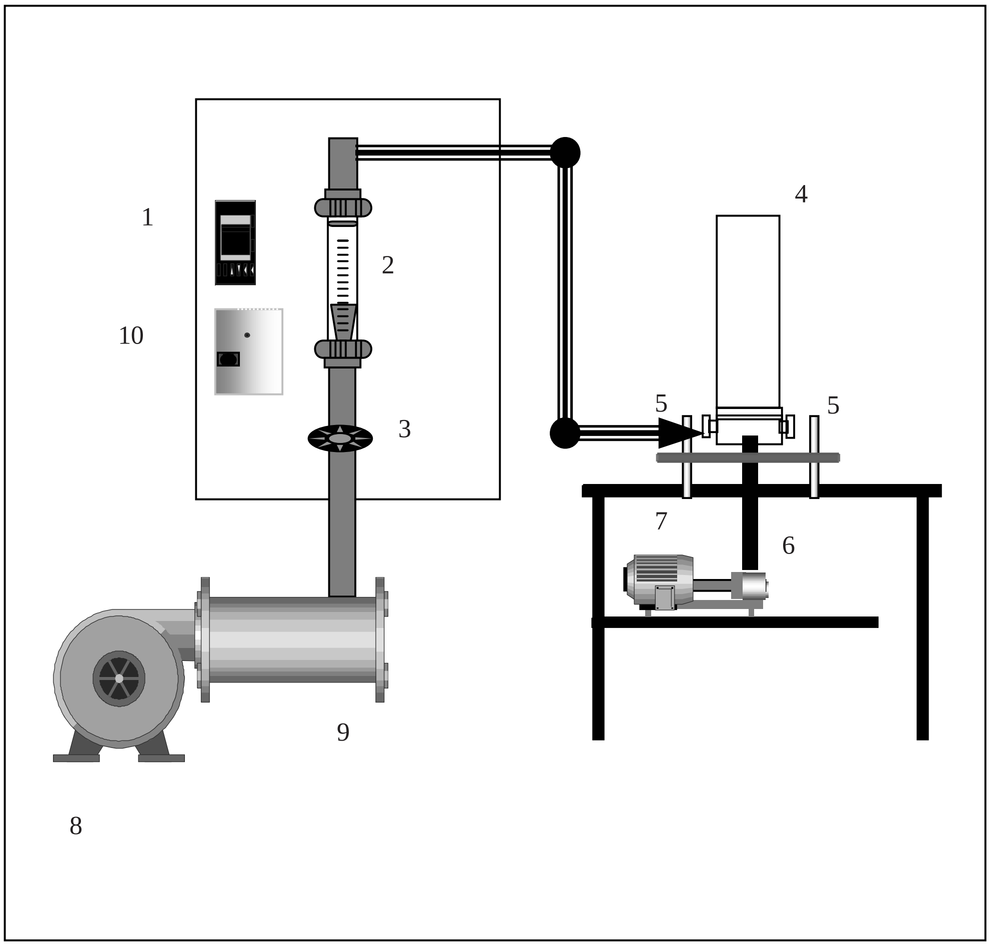


Figure 2. Schematic diagram of the vibrofluidized drying equipment. Main components: 1. Frequency variator; 2. Rotameter; 3. Valve; 4. Fluidization container; 5. Air inlet; 6. Excentric setup; 7. Motor; 8. Fan; 9. Heater; 10. Temperature control panel.

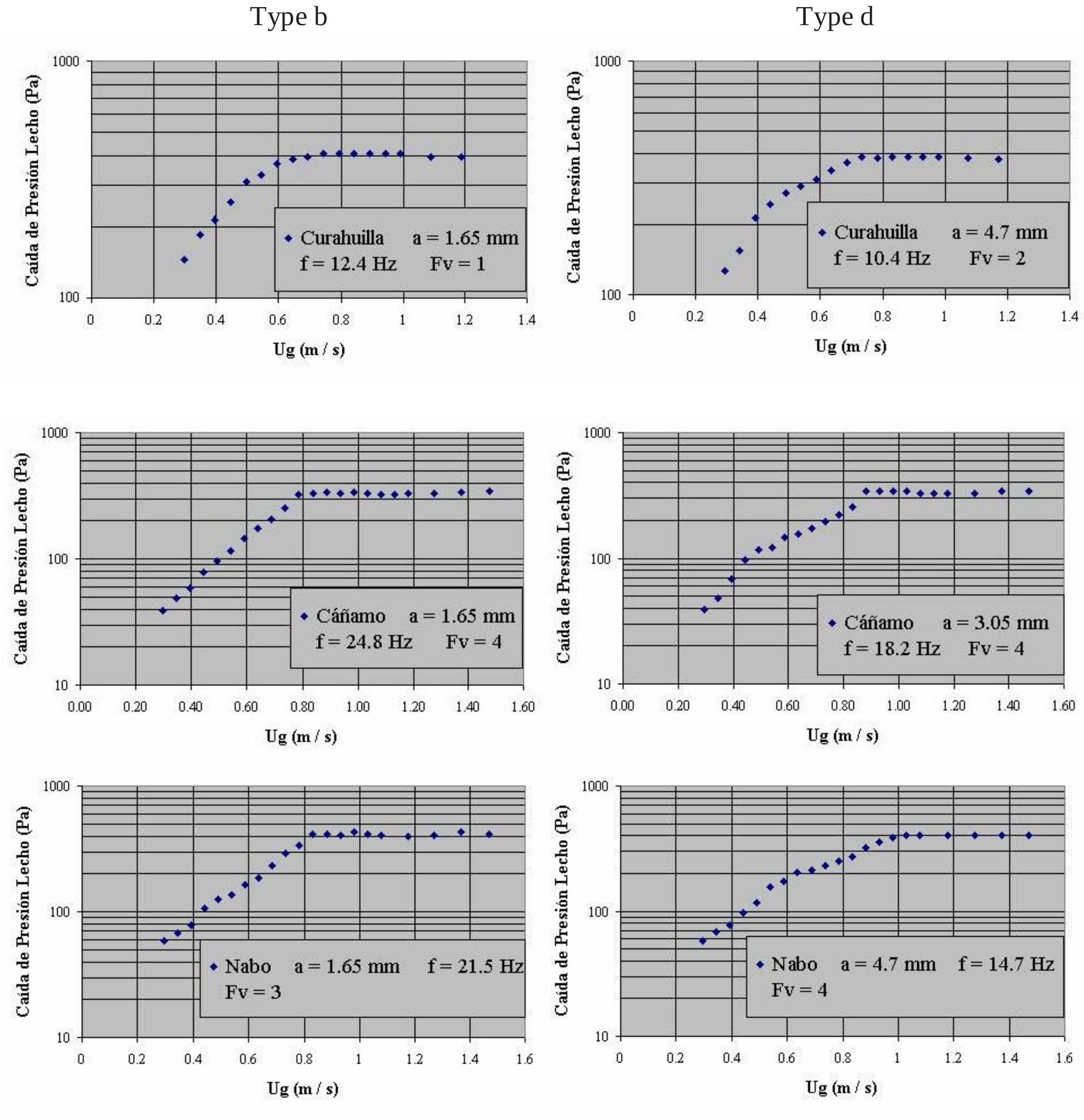
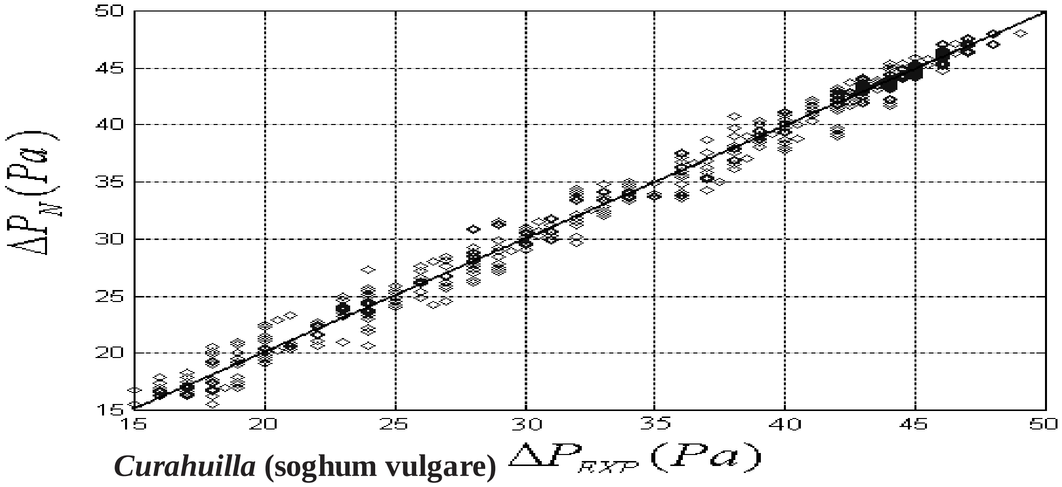
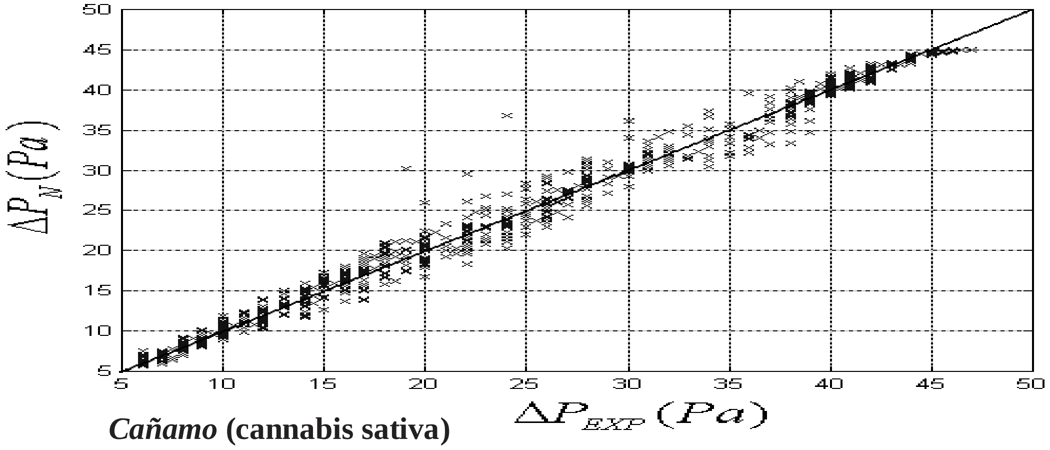


Figure 3. Typical curves of pressure drop across to the bed for tested material.

Nabo **(brassica napus)**



Curahuilla **(soghum vulgare)**



Cañamo **(cannabis sativa)**

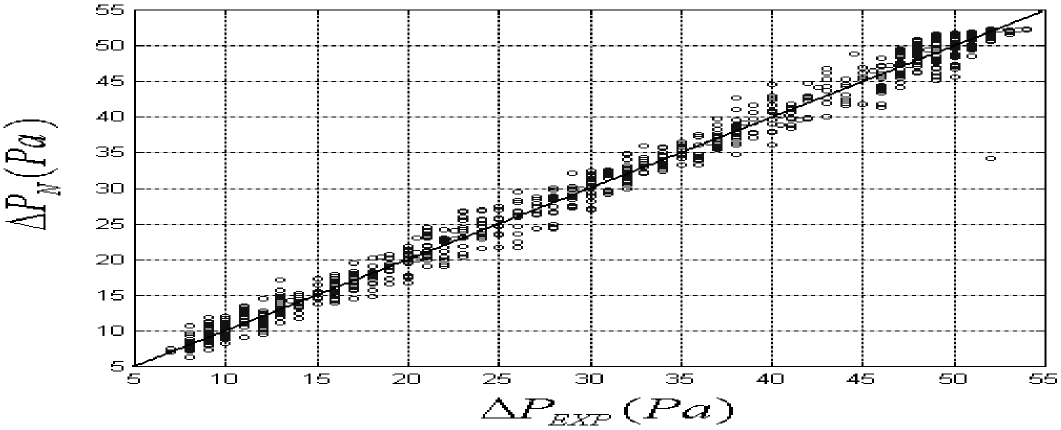
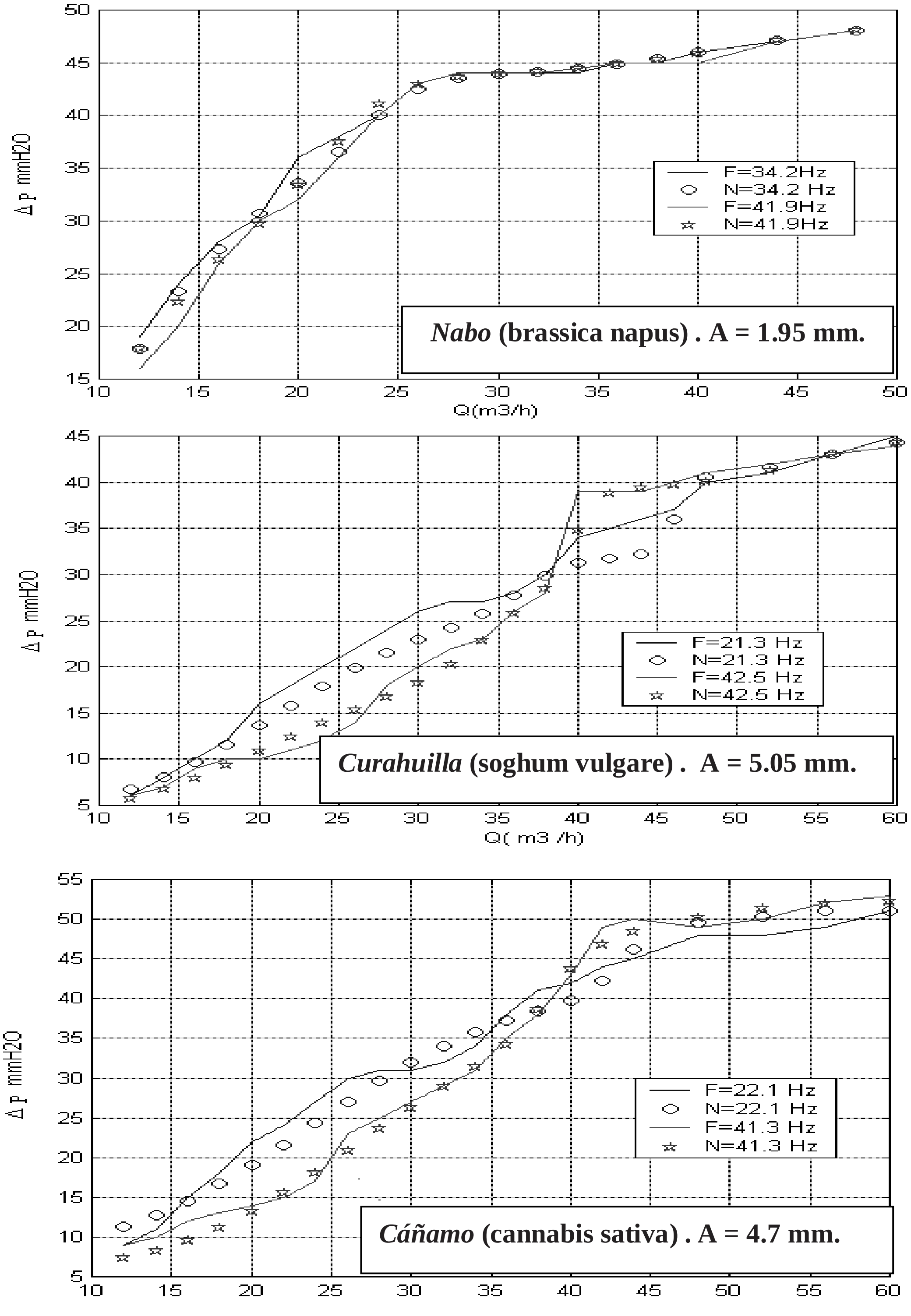


Figure 4. Experimental pressure drop vs predictions for the tested materials



Nabo (brassica napus) . A = 1.95 mm.

Curahuilla (soghum vulgare) . A = 5.05 mm.

Cáñamo (cannabis sativa) . A = 4.7 mm.

Figure 5. Experimental and simulated pressure drop vs. air flow-rate for the tested materials

Table 1. Properties of the products tested.

Material	ρ_P **kg/m^3**	**d$_p$ Mm**	ε_m	ϕ
Nabo (brassica napus)	1050	1.84	0.41	0.95
Curahuilla (soghum vulgare)	1150	2.29	0.42	0.70
Cáñamo (cannabis sativa)	880	2.74	0.45	0.73

Table 2. Operating range for ***nabo***, ***curahuilla*** and ***cáñamo***

A(mm)	**Vibration frecuecies (Hz)**						
1.65	12.4	15.2	17.5	19.6	21.5	23.2	24.8
1.95	11.4	14.0	16.1	18.0	19.7	21.3	22.8
3.05	9.1	11.2	12.9	14.4	15.8	17.0	18.2
3.45	8.6	10.5	12.1	13.5	14.8	16.0	17.1
5.05	7.1	8.7	10.0	11.2	12.3	13.3	14.2
6.25	6.4	7.8	9.0	10.1	11.0	11.9	12.7
F_v	1.0	1.5	2.0	2.5	3.0	3.5	4.0

Table 3. Total quadratic errors

Seed	TCE
Nabo (brassica napus)	0.75
Curahuilla (soghum vulgare)	2.00
Cáñamo (cannabis sativa)	1.59