CHEMICAL ENGINEERING TRANSACTIONS Volume 17, 2009
Editor Sauro Pierucci
 ISBN 978-88-95608-01-3 ISSN 1974-9791
DOI: 10.3303/CET0917119

Flumov Dryer

J. M. Aragón, M. D. Liébanes and M. C. Palancar
Department of Chemical Engineering, Universidad Complutense de Madrid
Department of Chemical Engineering, Faculty of Chemistry, 28040-Madrid (Spain)

A dryer based on a combination of fluidized and moving bed (FLUMOV) is studied. The FLUMOV serves to avoid the solid dragging outside of the fluidized bed, and also serves as a pre-heater of the solid. The experimental study comprises the influence of the inlet air and fluidized bed temperatures and the wet solid flow rate on the drying operation. The main results are: The drying time is about 15 min.; the analysis of the dry solid shows that the Polycyclic Aromatic Hydrocarbon (PAH) concentrations are less than 1μg/kg; the exit air does not have solids in suspension; and the energetic consumption is about 30% lower than in rotary dryers.

1. Introduction

Rotary drums, widely used dryer in the drying of by-products of vegetable origin (Iguana et al., 2003a), requires high temperature of the drying gas (about 600 ºC), solid agglomeration is frequently produced, large installation size and great size cyclones for the cleaning of the exit gases are necessary and the process control is difficult (Aragón et al., 2005). Fluidized bed dryers present some advantages over other types of dryers as the gas-solid contact is very good; and the operation control and monitorization are easy (Davison et al., 2001, Soponnronnart, et al., 2001, Chua and Chou, 2003). The principal problem is that it is necessary to install great size cyclones for the cleaning of the exit gases (Ordoñez, 1998). The moving bed dryers have the advantages that the contact between solid and gas is very good and neither entrainment nor elutriation of solids take place. Nevertheless, the heat transfer is poor and radial and longitudinal temperature gradients can occur within the moving beds. Based on the advantages and disadvantages of fluidized and moving beds commented above, a combination of both types of dryers has been studied recently (Aragón et al. 2003, 2009). The system is a connection in series of a fluidized with a moving bed, which serves to avoid the main fluidized bed disadvantage: the solid dragging outside the fluidized bed. Also, the moving bed could act as a preheater for the solid in a continuos feeding system. The references about fluidized-moving beds are scarce. In some cases, the fluidized-moving state is reached by using physical elements (Nagata et al. 1998 and 1999, Guo and Tokuda, 2002, Abatzoglou et al., 2002). Fan and Wen (1959) referred to the first combination of fluidized and fixed beds without physical separation between them. They studied the properties of a bed that they called semifluidized bed. This bed is generated when the bed expansion is constrained by a physical element, for example a sieve plate, in the upper part of the bed vessel. This sieve plate allows the passing of gas but avoids the

Please cite this article as: Aragon J.M., Liebanes M.D. and Palancar M.C., (2009), Flumov dryer, Chemical Engineering Transactions, 17, 711-716 DOI: 10.3303/CET0917119

pass of the solid. The bed expansion is constrained and finally the bed is separated into two phases clearly differentiated, a packed bed above and a fluidized bed below. Bilbao (1978) developed a new type of contactor based on Fan's contactor but, in this case, the separation in fluidized and packed bed was caused by an expansion of the bed section, forming a fluidized bed in the bottom vessel, of small diameter, and a packed bed in the upper part, of greater diameter.

The main objective of the present work is to develop a small pilot plant scale of fluidized-moving bed. The system is called FLUMOV, from FLUidized and MOVing bed. The dryer is used to dry a by-product from the olive oil mills called alperujo or pomace. The moving bed acts as preheater for the wet solid and as a filter for the exit gas. The FLUMOV presents the following potential advantages: Improvement of the energetic efficiency (the outlet gas from the fluidized bed is used to dry and heat the solid that is circulating through the moving bed); the moving bed acts as a filter of the outlet gas (the fines remain inside the system and the need for cyclones and filters is dramatically reduced); the dryer design and performance are simplified and improved since there are no moving elements between the moving and the fluidized zones (the malfunctioning or faults of the feed device, e.g. deformations, obstructions and breaking, are minimized or eliminated).

2. The FLUMOV dryer

The FLUMOV (Aragón et al., 2003, Aragón et al., 2009) is a multistage fluidized-moving bed, Figure 1. In comparison with precedent systems, no physical elements are present inside the whole vessel. The FLUMOV state is reached by spontaneous and stable equilibrium of forces promoted by the different bed sections. The most characteristic fact is the formation of a vault between the fluidized and the moving beds, Figure 2. The moving bed voidage is similar to a packed bed, Figure 2a. Two forces act in this zone, an upward force due to the airflow and consequent pressure drop and a downward force due to the solid weight. The vault is created by similar effects that occur in hoppers. After the start-up, the air velocity can be moderately decreased with no appreciable changes in the vault characteristics.

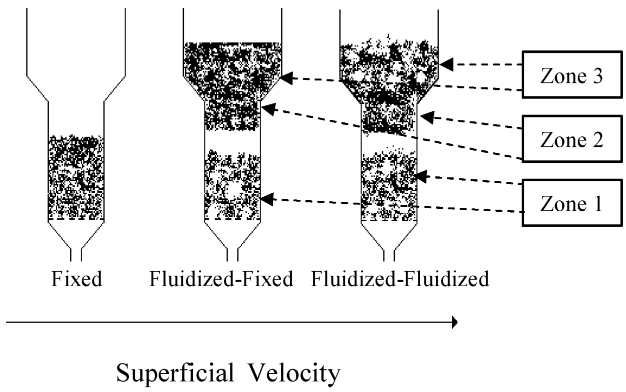

Figure 1. Evolution of the fluid-dynamic regime of a solid in a bed with the air superficial velocity.

The solid flow from the fixed to the fluidized bed can be controlled by injecting air pulses in the conical zone, Figure 2b, so the fixed bed turns to a moving bed and the system is actually a fluidized-moving bed. The gas inlet is at the bottom of the fluidized zone and circulates in countercurrent to the solid.

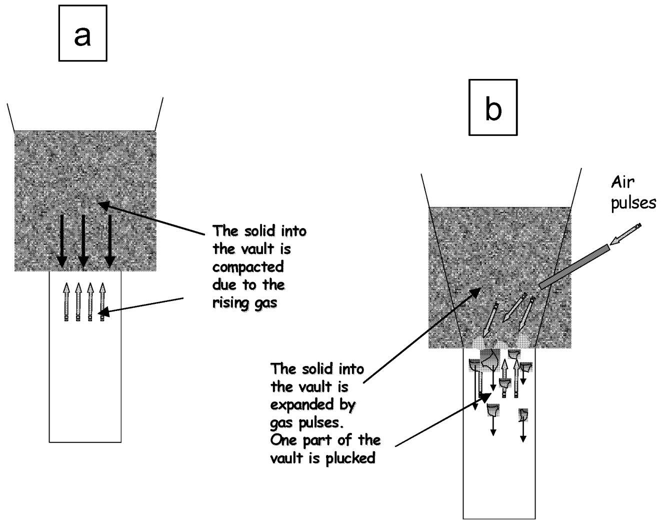

Figure 2. Forces equilibrium in a FLUMOV system.

3. EXPERIMENTAL

3.1 Experimental equipment

The experimental equipment is show in Figure 3. The equipment is a small pilot plant with a feeding capacity of 20 kg/h of wet solid. The dryer has a height of 2.5 m. The diameters of the fluidized and moving beds are 0.15 m and 0.36 m, respectively. The wet solid feeding is made from a hopper, which has a capacity of 90 L. A knife valve with pneumatic actuator is used to discharge the hopper. The pneumatic actuator is activated by an optical level-sensor that detects the solid height into the moving bed zone of the dryer.

Injecting air pulses in the conical zone, Figure 2b, with electrovalves, makes possible the controlled solid feeding from the moving bed to the fluidized bed. The frequency of the air pulses regulates the solid flow rate rather well. The dry solid is discharged at the bottom of the fluidized bed through a butterfly valve. The measured variable used to control the solid feeding is the fluidized bed temperature since there is a high relation between the solid moisture and fluidized bed temperature (Temple et al., 2000, Martínez-Vera et al., 1995). A fan is used to impel the air, which is heated by a heater and finally fed at the bottom of the fluidized bed.

The installation has nine thermocouples and four pressure transducers. This instrumentation is for research purposes; probably the number of measurement points could be reduced in the industrial development of FLUMOV. The monitoring and control of the process variables is made by a SCADA (Supervisory Control And Data Adquisition). An example of the SCADA interface is shown in Figure 4.

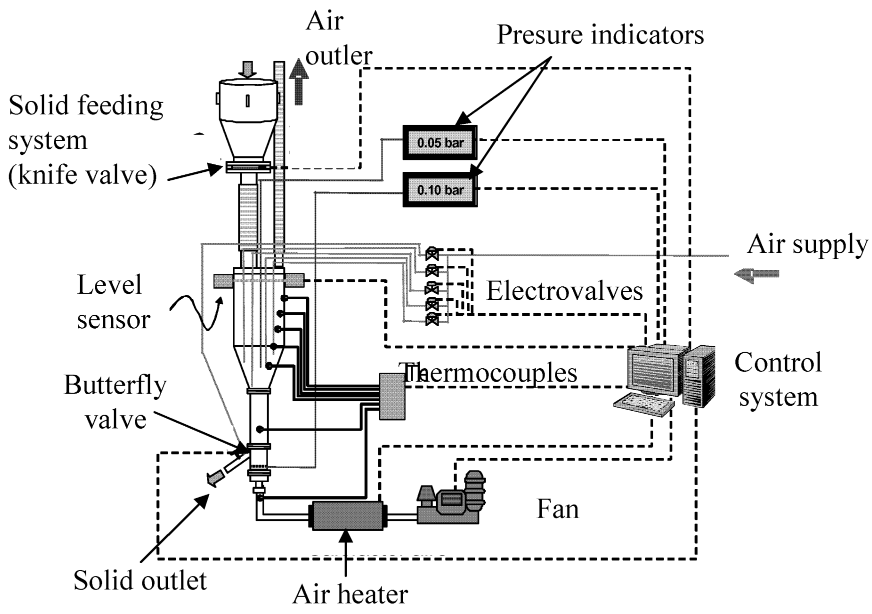

Figure 3. Experimental equipment.

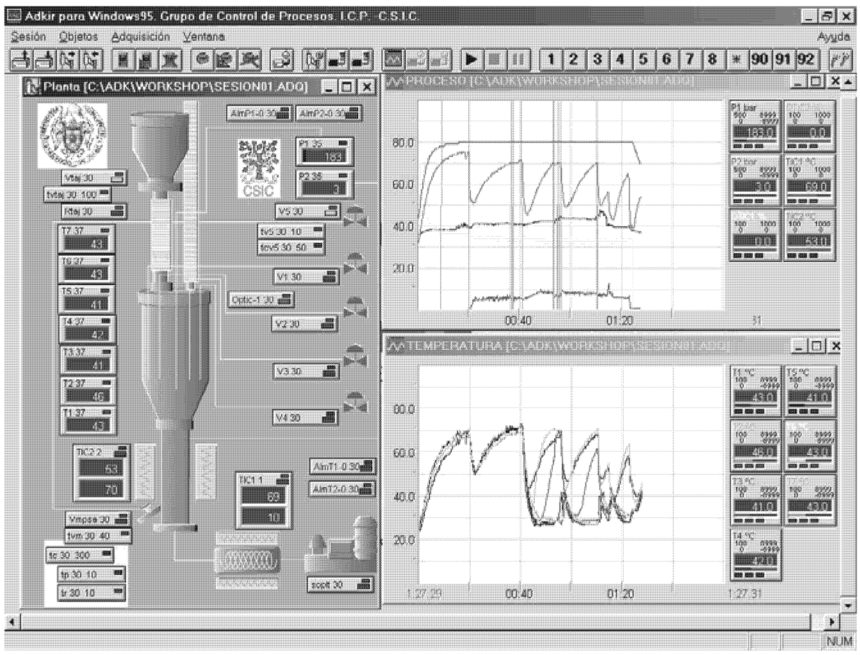

Figure 4. Scada interface.

3.2 Materials

The material to dry is "alperujo" or 2-phase SOB (Solid Olive By-product). The SOB is a wet solid by-product generated in the olive mills that use the modern 2-phase decanters for the extraction of olive oil. The SOB has a high content of water (60%-70%, w.b.) and a remaining fraction of oil (3% to 6%) which can be extracted with hexane from the dried SOB. The current specification of moisture for the dry material is 8% (wet basis). Currently, SOB is dried in rotary cylindrical drums, which operate at high temperature (500-600 ºC). The poor contact between the air and solid gives the drying process a very low efficiency. In rotary drums it is possible to have at the same time very humid zones and others that are overheated, where incomplete combustion phenomena may take place and the production of Polycyclic Aromatic Hydrocarbons (PAH) can contaminate the final product (pomace oil). This major problem can be avoided by the drying in FLUMOV.

3.3 Results

The objective of the experimental work was to obtain the optimal operation conditions of a FLUMOV pilot plant. The optimal conditions should be the ones leading to a dried SOB without solid agglomerations and with uniform moisture of 8% (w.b.). The minimisation of PAH presence in the dried product is also an important aim. The main variables that should be set are: solids flow rate (input of wet and output of dry SOB) inlet air temperature and fluidized bed temperature.

The optimal inlet air temperature is 115 ^{o}C. The fluidized bed temperature is variable along a drying cycle (each batch of solid remains inside the fluidized bed a mean time of 14-16 min). The limit of the fluidized bed temperature was set at 80 ^{o}C. At this temperature the time of drying is adequate (14-16 min) and the formation of PAH is avoided at all. When the solid inside the FLUMOV passes from the moving bed to the fluidized bed the temperature of this bed decreases due to the energy consumption required by the water vaporization. This temperature decreasing occurs until the solid reaches its equilibrium moisture (about 8% w.b.); as the solid becomes more and more dry, the temperature increases up to 80 ^{o}C. The controller operates then and the dry solid is discharged through the bottom of the fluidized bed. After that, a new charge of wet solid is made from the moving bed.

When the FLUMOV works under the optimal operating conditions and cycle described above, the dried solid is very homogeneous whose content in PAH is <1 μg/kg (lower limit of the HPLC with fluorescence detector). The drying cycle is between 14 and 16 min and the mass flow rate of dried solid is 9 kg/h.

The energy consumption of the installation (including electrical heating and air compression power) is at least 30 % lower than the typical energy requirement in conventional rotary drums.

4. CONCLUSIONS

The results obtained in the work allows establishing the following conclusions:

1. The use of FLUMOV systems to dry SOB is technically feasible.

2. The SOB drying in FLUMOV is made at low temperature. This fact implies that the dry solid obtained is a homogeneous material and that the formation of PAH is avoided at all.
3. The energy consumption is about 30 % lower than in conventional rotary dryers.
4. The use of the FLUMOV dryer avoids the presence of cyclones in the installation. So the installation size is dramatically reduced.

Acknowledgements. This study was financially supported by the "BIOLIVE" project (V Framework Program-European Commission), ref. EU-QLRT-2000-00766, and the "FPU" Program of the Ministry of Education and Science, Spain.

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