CHEMICAL ENGINEERING TRANSACTIONS

VOL. 57, 2017

A publication of AIDIC
The Italian Association
of Chemical Engineering
Online at www.aidic.it/cet

Guest Editors: Sauro Pierucci, Jiří Jaromír Klemeš, Laura Piazza, Serafim Bakalis

ISBN 978-88-95608- 48-8; **ISSN** 2283-9216

DOI: 10.3303/CET1757137

Hydrodynamics of the Nonporous Draft Tube Conical Spouted Bed Provided with a Device for Retaining Solids

Mikel Tellabide, Alvaro Casado, Idoia Estiati, Haritz Altzibar, Martin Olazar

Deparment of Chemical Engineering , University of the Basque Country, P.O. Box 644, 48080 Bilbao, Spain
mikel.tellabide@ehu.eus

One of the main limitations of the conical spouted bed lies in its scaling up and a key parameter to solve this problem is the ratio between the inlet diameter and particle diameter. Therefore, operation with fine particles (smaller than 1 mm particle diameter) requires the use of draft tubes, but the fountain height obtained is very high, which causes severe solid entrainment. A new solid retaining device has been developed to avoid bed loosing which allows operating with higher air velocities. Thus, runs have been carried out in conical spouted beds of different geometry to ascertain the effect of the device on the minimum spouting velocity. Different contactor angles, static bed heights, device diameters and distances from the bed surface to the lower end of the device have been used. It can be concluded that the hydrodynamics of conical spouted beds with nonporous draft tube and solid retaining device is influenced by the static bed height and contactor angle, but not greatly by the device geometry.

1. Introduction

There are many applications that require a high contact between two phases and frequently they involve a fluid and a solid. The most common technique used for this purpose is a fluidized bed, but although there is a wide range of fluidized bed regimes, they perform poorly whenever particles are coarse, sticky or have a wide size distribution. Thus, the spouted bed regime is an alternative contact method to fixed and fluidized beds.

Different modifications of the original spouted bed have been proposed in the literature with the aim of improving its performance (Epstein and Grace, 2011), with conical spouted beds being suitable for operating with solids that are difficult to handle due to their irregular texture or because they are sticky. Nowadays, many researchers work with this technology because of their great advantages, i. e., lower pressure drop and a better contact between the two phases than fluidized beds, but the main difference lies in its cyclic movement of the solid. Furthermore, this technique has been applied in many processes, such as granulation (Borini et al., 2009), coating (da Rosa et al., 2010), drying (Correa et al., 2012), combustion (Wang et al., 2013) and pyrolysis (Park et al., 2016).

Spouted beds are gas-particle contactors in which the gas is introduced through a single nozzle at the centre of a conical or flat base. The air penetrates the bed of particles creating a central spout zone, a fountain above the spout and an annulus surrounding the spout. The gas passes upward through the spout, fountain and annulus, while the particles are conveyed up the fountain core and down the fountain periphery and annulus. The recirculation of particles between the spout and annulus is one of the more important characteristics of spouted beds.

However, there are situations in which the gas-solid contact is not fully satisfactory due to the instability of the bed, especially at large scale. The main limitation of this technology lies in its scaling up and a key parameter to solve this problem is the ratio between the inlet diameter and particle diameter. Olazar et al. (1992) observed that the inlet diameter should be smaller than 20-30 times the particle diameter in order to avoid a slugging regime and achieve spouting status. Therefore, operation with fine particles (smaller than 1 mm particle diameter) requires the use of draft tubes.

Nonetheless, draft tubes modify the hydrodynamics and solid circulation flowrate of the system, changing minimum spouting velocity, operating pressure drop, solid circulation patterns, gas distribution and particle cycle times (time required for a solid to complete a full cycle, crossing all the zones in the spouted bed). The

Please cite this article as: Tellabide M., Casado A., Estiati I., Altzibar H., Olazar M., 2017, Hydrodynamics of the nonporous draft tube conical spouted bed provided with a device for retaining solids, Chemical Engineering Transactions, 57, 817-822 DOI: 10.3303/CET1757137

performance of the lower conical section of the contactor is different when the draft tube is used, and largely depends on the bed geometry, draft tube diameter, length of the entrainment zone, and operating conditions (Nagashima et al., 2009).

Different draft tube configurations are reported in the literature: conventional nonporous draft tubes, porous draft tubes, and open-sided draft tubes. The latter have been developed by our research group (Olazar et al., 2012) and they are especially suitable for vigorous contact. Moreover, Nagashima et al. (2009) have developed porous and nonporous draft tubes with a conical-cylindrical geometry.

The most used draft tubes are nonporous draft tubes due to the great advantages they present (Ishikura et al., 2003): decrease the minimum spouting velocity and the peak and operational pressure drops, better control of solid circulation, narrower residence time distribution, the maximum spoutable bed height is avoided, and higher bed stability is attained. Moreover, this type of draft tube enables the operation with solids of any size or nature, such as biomass (Saldarriaga et al., 2015). Nevertheless, the use of nonporous draft tubes limits the access of the air to the bed (poor contact between gas and solids) decreasing heat and mass transfer rates, narrows the distribution of solids cycle times, decreases the degree of mixing, increases risk of tube blockage and makes the design more complex.

Accordingly, the use of nonporous draft tube is the unique way to get a stable spouting status with fine particles, but this leads to very high fountains and a huge amount of solids is entrained from the bed. This situation limits the use to a small range of gas flowrate and a poor solid circulation is obtained. In order to avoid this problem, a new internal device has been proposed. This device is placed above the bed and traps the particles in the fountain, avoiding their entraining. It is a cylindrical tube (made of polymethyl methacrylate) with the upper outlet closed. Therefore, it is possible to operate at high values of gas flowrate without bed loosing and improving solid circulation rate.

Thus, the main aim of this work is to analyze the effect of a solid retaining device on the minimum spouting velocity using nonporous draft tubes with fine particles (0.25 mm of Sauter mean particle diameter). This work is a starting point in the hydrodynamic study of draft tube conical spouted beds equipped with a solid retaining device developed by our research group.

2. Experimental

Different runs have been carried out in a pilot plant shown in Figure 1.

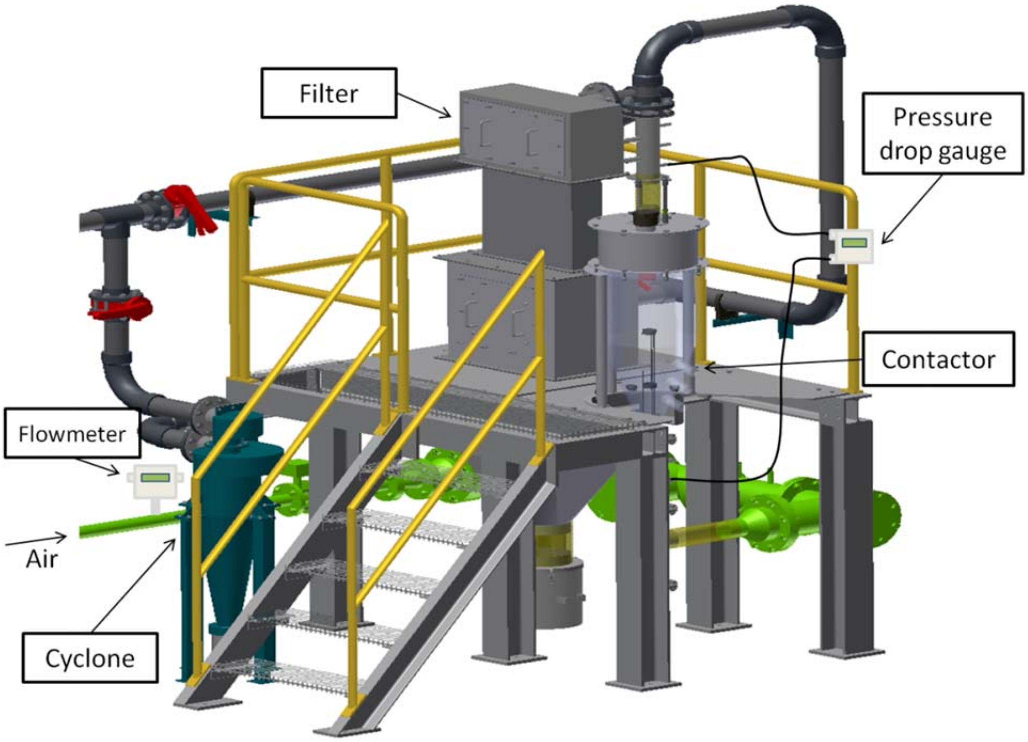

Figure 1. Diagrammatic representation of the pilot plant.

This plant is composed by a blower, flowmeter, pressure drop gauge, contactor, filter and cyclone. The blower has a power of 5.5 kW and supplies air to the contactor. The gas flow is measured by means of a flowmeter, which is used in the range of 0-600 Nm^3/h. The blower supplies a constant flowrate, and the flow that enters in the contactor is controlled by acting on a motor valve that reroutes the remaining air to the outside or changing the frequency of the motor of the blower if strict control is necessary. The pressure measurements are carried out by means of two pressure taps, which are connected to the input and output of the contactor. In order to separate the solids dragged by the air, a filter and a cyclone are connected parallel. The filter traps fine particles meanwhile the cyclone separates coarser particles from the air.

Moreover, the unit alows operating with contactors of different geometry. These contactors are made of polymethyl methacrylate and have a conical geometry. Figure 2a shows the geometric factors of these contactors. The column diameter (D_c, 0.36 m) and the base diameter (D_i, 0.068 m) are the same for the different angles used (γ) of 28, 36 and 45º. The gas inlet diameter used is 0.04 m.

Furthermore, a nonporous draft tube has been used and Figure 2b presents a scheme of this device. The dimensions of the nonporous draft tube are: length of the tube L_T= 0.20 and 0.27 m; height of the entrainment zone (distance between the gas inlet nozzle and bottom of the draft tube) L_H= 0.07 m; diameter of the tube D_T= 0.04 m.

Furthermore, a new device has been used to avoid solid entrinment from the bed and is shown in Figure 2c. This solids retaining device is a cylindrical tube made of polymethyl methacrylate with the upper outlet closed. The dimensions of this device are as follows: length of the device L_{RS}= 0.5 m; diameter of the device D_{RS}= 0.2 and 0.15 m. A stainless steel cone is coupled at the top of the device to avoid the deposition of the solid on the device, i.e., the solids deposited on the cone slip and fall down onto the bed. The device is placed above the bed (Figure 2d) and traps the particles in the fountain. Thus, it is possible to modify the distance from the bed surface to the lower end of the device. Different values of this distance have been tested to ascertain the effect it has on the minimum spouting velocity; H_{RS}= 0.02, 0.04, 0.06, 0.08 and 0.10 m.

The material used for operation is fine sand, which belongs to group B of Geldart classification. The density of the sand is 2390 kg/m^3 and its Sauter mean diameter 0.25 mm. The static bed heights used are 0.20 and 0.27 m.

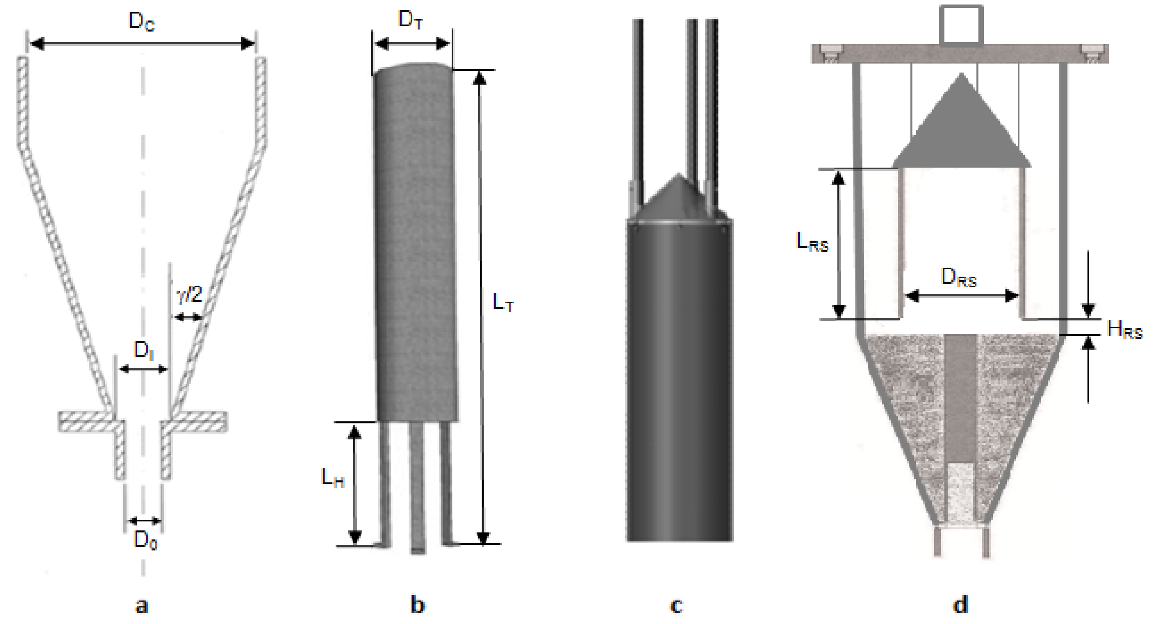

Figure 2. a) Geometric factors of conical spouted bed contactors, b) nonporous draft tube configuration, c) device for retainig solids and d) its location in a conical spouted bed.

3. Results

3.1 Design of experiments

In order to study the effect of the insertion of a device for retaining solids, the device configuration and the different factors of the contactor on the minimum spouting velocity, runs have been carried out by combining all these factors corresponding to the contactors (γ), solids retaining device (D_{RS}, H_{RS}) and operating conditions (H_0) according to a experimental design. To avoid instability problems, all runs (with nonporous draft tube) have been performed with the gas inlet diameter equal to that of the draft tube (0.04 m). Approximately 60 experimental runs have been carried combining all mentioned factors.

From each system analyzed, the minimum spouting velocity is determined. The first step for determination of this property is to loosen the bed. Thus, as air velocity is increased, pressure drop increases to a maximum value, and a subsequently increase in air velocity leads to fountain formation and a sharp decrease in pressure drop. The value of the peak pressure drop is similar for all the runs, so it has not been taken into consideration.

Nevertheless, the fountain created is very high due to the high air velocity required to break the bed and obtain the fountain. Moreover, the fountain created is very dilute because the solids can only enter the spout from the annulus through the lower end of the draft tube. Therefore, only a small fraction of solids access to the spout.

Once the fountain is obtained, the air velocity is decreased until the minimum spouting velocity is precisey obtained. This velocity is the minimum one when the fountain remains constant and stable at the lowest possible velocity. Our polymethyl methacrylate contactor allows a clear visualization of the contactor inside and ensure determining the minimum air velocity for a stable fountain.

3.2 Experimental results

Figure 3 shows as an example typical trends of the evolution of the minimum spouting velocity in the experimental runs carried out by changing differing operating parameters.

As observed, the effect of the static bed height (Figure 3a) is the most significant one because it causes the biggest differences in the minimum spouting velocity. Thus, the values of minimum spouting velocity are much higher as the static bed height is increased for beds made up of fine particles. This trend is similar to that reported in the literature for conical spouted bed with coarse particles and 0.64 mm Sauter mean diameter fine particles (Altzibar et al., 2013). Moreover, despite the fact that only one system has been studied, similar trends of minimum spouting velocity with static bed height have been obtained using open-said draft tubes and without tubes (Olazar et al., 1992; Kmiec, 1983; Altzibar et al., 2013; San José et al., 2007). A higher static bed height means a higher amount of solids in the bed, and therefore a higher air velocity is required to maintain the fountain stable.

Figure 3b shows the evolution of minimum spouting velocity as contactor angle is changed. The values show a minimum for 45º, and narrower angles (28º and 36º) lead to higher values of this velocity. Although the wider angle contains the greater amount of solids in the bed, it leads to the lowest minimum spouting velocity due to the high support of the bed on the walls. Furthermore, the narrower angle means a more vertical contactor walls, and therefore a higher air velocity is required to maintain a spouting status (Altzibar et al, 2013).

Figure 3c shows that as the device diameter is greater, the minimum spouting velocity is slightly lower. In this case, a stable fountain is created with a rather low air velocity due the presence of the draft tube. In fact, stability is provided by the draft tube and not by the fountain device. The latter is essential to hold all the solids in the bed and avoid their entrainment.

Finally, Figure 3d shows the influence of the distance from the bed surface to the lower end of the device on the minimum spouting velocity. In this case, five levels have been used for the distance, but there is no general trend on the influence of this parameter. As observed, the lowest distances lead to the highest minimum spouting velocities and, as the distance from the upper surface of the bed is longer, this velocity decreases. Nevertheless, when this distance is too long, it affects air trajectory and a big crater is formed on the bed surface.

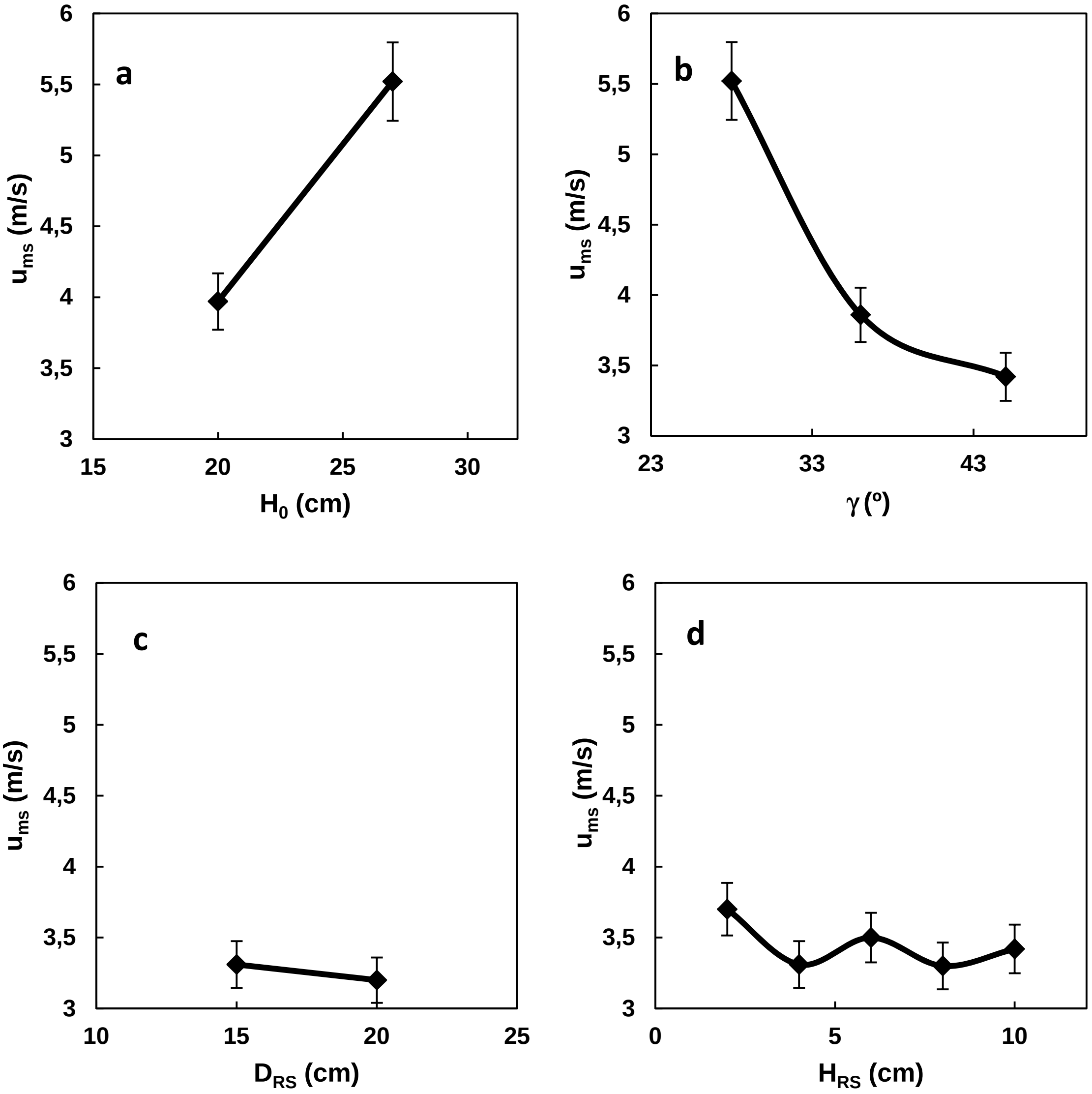

Figure 3. Influence of the static bed height a), contactor angle b), solids retaining device diameter c) and distance from the bed surface to the lower end of the device d) on the minimum spouting velocity. Experimental conditions: a) γ, 36º; D_{RS}, 0.15 m; H_{RS}, 0.04 m; b) H_0, 0.27 m; D_{RS}, 0.15 m; H_{RS}, 0.04 m; c) γ, 45º; H_0, 0.20 m; H_{RS}, 0.1 m; d) γ, 45º; H_0, 0.27 m; D_{RS}, 0.2 m.

4. Conclusions

A hydrodynamic study of conical spouted bed equipped with nonporous draft tube and a device for retaining solids has been carried out for 0.25 mm Sauter mean diameter fine particles. Minimum spouting velocities have been measured in draft tube conical spouted beds for different geometric factors of the contactor (γ), solid retaining device (D_{RS}, H_{RS}) and different static bed heights (H_0).

The results obtained based on an experimental design show that the minimum spouting velocity is influenced by the static bed height and contactor angle, but the solid retaining device geometry hardly affects.

The minimum spouting velocity increases as the static bed height is increased due to the higher amount of solids in the bed. In addition, the minimum spouting velocity has the lowest values for an angle of 36°, and a wider one (45°) and a narrower one (28°) lead to higher values of this velocity.

Furthermore, different factors of solid retaining device (D_{RS}, H_{RS}) hardly affect the minimum spouting velocity, and the main role of the device lies in avoiding solid entrainment and stabilizing the bed.

Acknowledgments

This work has been carried out with the financial support of the Ministry of Economy and Competitiveness of the Spanish Government (Project CTQ2013-45105-R). M. Tellabide is grateful for the Ph.D. grant from the Ministry of Education, Culture and Sport (FPU14/05814). I. Estiati is grateful for the Ph.D. grant from the Department of Education, University and Research of the Basque Country (BFI-2012-234).

Reference

Altzibar H., Lopez G., Bilbao J., Olazar M., 2013. Minimum spouting velocity of conical spouted beds equipped with draft tubes of different configuration. Industrial and Engineering Chemistry Research, 52, 2995-3006.

Park H.C., Lee B. –K., Yoo H.S., Choi H.S., 2016. [TC2015] fast pyrolysis characteristics of biomass in a conical spouted bed reactor. Environmental Progress and Sustainable Energy,

Borini G.B., Andrade T.C., Freitas L.A.P., 2009. Hot melt granulation of coarse pharmaceutical powders in a spouted bed. Powder Technol, 189, 520-527.

Correa N.A., Freire F.B., Correa R.G., 2012. Control of the drying process in spouted bed. Transport Phenomena in Particulate Systems, 124-147.

Da Rosa G.S., Rocha S.C.D., 2010. Effect of process conditions on particle growth for spouted bed coating urea. Chemical Engineering and Processing: Process Intensification, 47, 1252-1257.

Epstein N., Grace J.R., 2011. Spouted and spout-fluid beds. Fundamental and Applications; Cambridge University Press: Cambridge, U.K..

Ishikura T., Nagashima H., Ide M., 2003. Hydrodynamics of a spouted bed with a porous draft tube containing a small amount of finer particle. Powder Technology, 131, 56-65.

Nagahsima H., Ishikura T., Ide M., 2009. Effect of the tube shape on gas and particle flow in spouted beds with a porous draft tube. Canadian Journal of Chemical Engineering, 87, 228-236.

Kmiec A., 1983. The minimum spouting velocity. The Canadian Journal of Chemical Engineering, 61, 274-280.

Olazar M., San José M.J., Aguayo A.T., Arandes J.M., Bilbao J., 1992. Stable operation for gas-solid contact regimes in conical spouted beds, Industrial and Engineering Chemistry Research, 31, 1784-1792.

Olazar M., Lopez G., Altzibar H., Amutio M., Bilbao J., 2012. Drying of biomass in a conical spouted bed with different types of internal devices. Drying Technology, 30, 207-216.

Saldarriaga J.F., Atxutegi A., Aguado R., Altzibar H., Bilbao J., Olazar M., 2015. Influence of contactor geometry and draft tube configuration on the cycle time distribution in sawdust conical spouted beds. Chemical Engineering Research and Design, IO2, 80-89.

San José M.J., Alvarez S., de Salazar A.O., Olazar M., Bilbao J., 2007. Operating conditions of conical spouted beds with a draft tube. Effect of the diameter of the draft tube and of the height of entrainment zone. Industrial and Engineering Chemistry Research, 46, 2877-2884.

Wang Q., Kong X., Liu H., Xiao G., 2013. Combustion experimental study on spouted bed for daqing oil shale semi-coke. Energy Sources, 614-615, 95-98.