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Article · July 2017

DOI: 10.3303/CET1758096

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CHEMICAL ENGINEERING TRANSACTIONS
VOL. 58, 2017
A publication of AIDIC
The Italian Association of Chemical Engineering
Online at www.aidic.it/cet
Guest Editors: Remigio Berruto, Pietro Catania, Mariangela Vallone

ISBN 978-88-95608-52-5; **ISSN** 2283-9216
DOI: 10.3303/CET1758096

Numerical Evaluation of a Seed Distributor Head for Air Seeders

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In previous work, the authors analyse the behaviour of the airflow-seed mixture in distributor heads of air drill seeders. Numerical simulations and laboratory tests performed on a commercial distributor head show similar results, and indicate that most seeds escape through the front outlets ducts. In this paper, the behaviour of a distributor head model, in different working conditions, is studied. The distributor head analysed is designed by the authors (Bourges et al, 2015). Constant air flow and two different sizes of seeds is simulated. In both cases, the seeds are modelled as spherical particles of homogeneous size. Soybean (Glycine max) and amaranth.(Amaranthus cruentus) are used in numerical test.
Keywords: Pneumatic conveying, dilute phase, air drill, numerical simulation, distribution.

1. Introduction

The seed distribution system called air drill, or air seeders, has an American origin. In this system , the storage of the grain and fertilizer is made by means of tanks of great capacity that allow great autonomy in the process of sowing. The standard ASABE S506 OCT2010 (R2014) defines as air drill seeders the type of machinery that uses a centralized hopper and a volumetric metering mechanism to contain and dose the seeds, respectively. The great capacity of work is a very interesting condition for the production proposals in large extensions. Specific works related with air drill seeders can be named, among others, the study on the distribution head by Allam & Wiens (1982) describe experiments on nine different air drill drills. In their work, they evaluated the behavior of different components, commonly used in these equipments. Kumar (et al, 1999) developed an air drill seeding machine for small grains as wheat, oats, barley and sorghum. The work of Kumar & Durairaj (2001) is focused on the influence of the distributor head and the feeding tube in the trajectory of seeds in air drill seeders. McCartney et al. (2005) studied, designed and evaluated modifications to the metering and agitation systems for pasture seeding using three different types of air planters. In field trials, a seed type (Bromus riparius Rehmann) was used which, because of its shape, presents great propensity to get stuck. Trials were also performed with mixtures of fertilizer and seeds. Field-level tests indicated that grasses can be successfully planted using an air seeder. Yatskul & Lemière (2014) carry out an experimental theoretical study of pneumatic transport in an air seeder. The work proposes a method to measure flow concentration and air velocity, with which values to optimize an existing seeder, or to design a new one. In Bourges (et al, 2006), the air flow distribution was analyzed in three seed distributor heads proposed by Kumar & Durairaj (2000), using a two-dimensional analysis and solved by finite elements method. In Bourges & Medina (2007) numerical simulations were performed in full three-dimensional distributor head models of air drill seeder. Bourges (et al, 2009) evaluate the incidence of dents in the inlet tube, in the distribution of air flow in a distributor head is analyzed. It follows that a configuration without dents has better performance in flow distribution air than others with dents distribution. Authors have also performed simulations of trajectories of soybeans using different initial air velocity in horizontal duct (Bourges & Medina, 2012), showing the influence of the coefficients of restitution in the acting forces on the grain. The Magnus lift forces are negligible compared with Saffman, aerodynamic drag, and gravity forces. Bourges & Medina (2013) tested a commercial distributor head in a test bench. The results show an inhomogeneous distribution

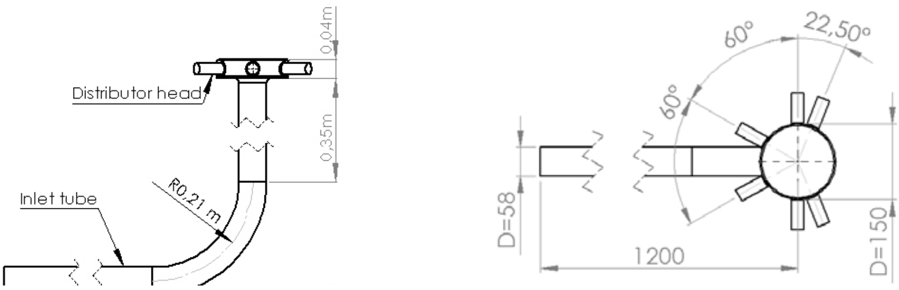
Please cite this article as: Bourges G., Eliach J.J., Medina M.A., 2017, Numerical evaluation of a seed distributor head for air seeders, Chemical Engineering Transactions, 58, 571-576 DOI: 10.3303/CET1758096

between outlets ducts, yielding increased flow of soybean in the front outlets. Then, in the works Bourges & Medina (2014) and Bourges et al. (2014), the authors compare these results with numerical simulations performed under equivalent experimental conditions. The results of that work are consistent with those obtained in controlled trials. In both cases the higher flow of seeds are produced in the front outlets, in contrast with the rear ports which have lower flow.
In this paper, the behaviour of a distributor head model, in different working conditions, is studied. The distributor head analysed is designed by the authors (Bourges et al, 2015). It is evaluated for a constant air flow and two different sizes of seeds is simulated. In both cases, the seeds are modelled as spherical particles of homogeneous size. Used seeds are soybean (Glycine max) and amaranth (Amaranthus cruentus).

2. Materials and methods

2.1 Tested models description

Tested distributor head model is a modification of a commercial distributor. Geometrical characteristics are described in Figure 1. Flow of air-seeds mixture gets into the horizontal tube of inner diameter Di = 0.058 m. Then, mixing flow rise by an elbow and then by a vertical tube subsequently. Thereafter, air flow enters the field expansion, where is splitted between the outlets tubes. This configuration is based on an actual distributor head, obtained from a local manufacturer of agricultural machinery. The original model has equally spaced outlets angularly (Figure 1 a), while modified model (Figure 1 b) have a different configuration. In this model (called Mv2), the angular distance between rear outlets is increased, keeping the other outlets to its original position.



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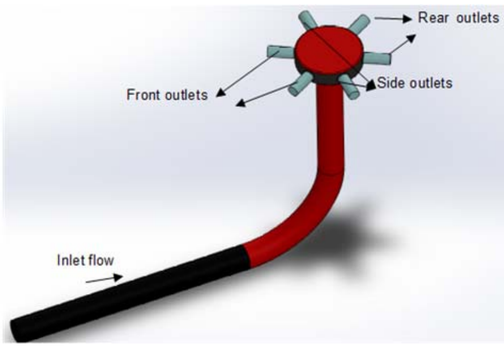

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Figure 1: (a) Lateral view, and (b) Top view of model Mv2. (c) Flow configuration. All dimensions in millimeters.

2.2 Numerical model

Regarding the numerical model, a lagrangian transport model of particles is used in an inhomogeneous turbulent flow. The air-particle mixture is considered as dilute phase flow, and a double coupling between both phases is used. The simulations are performed with the commercial software ANSYS Fluent® v18.0. For the simulation of air flow the Navier-Stokes equations, solved with the realizable k-ε turbulence model (Tsan-Hsing Shih et al, 1995). Particles are regarded as rigid spheres of uniform size. Regarding domain discretization, an unstructured mesh of 1446407 tetrahedral elements and 3246225 nodes is used. Minimum orthogonal mesh quality is 0.153, and mesh maximum aspect ratio is 20.298. Boundary conditions are described in Table 1.

Table 1. Fluid flow model and particle trajectories boundary conditions.

	Inlet surface	Internal walls	Outlet surface
Fluid flow	Normal inflow velocity v_i = 10 m/s	Logarithmic wall velocity grad.	Null pressure
Particle trajectories	Normal velocity v_{ip}= 1m/s	Specular reflection	Freeze

The forces considered are gravity and aerodynamic drag force. The balance of forces per unit mass of the particle is as follows:

$$\frac{d}{\mathrm{dt}}(u_p)=\mathrm{F}_{\mathrm{Drag}}+\frac{g(\rho_p-\rho)}{\rho_p} \tag{1}$$

Where F_{drag} is the aerodynamic drag force per unit mass of the particle given by:

$$F_{\mathrm{Drag}}=\frac{18\mu \mathrm{D}_D R_{\mathrm{ep}}}{24\rho_p {D_p}^2}(u-u_p) \tag{2}$$

Where u is the continuous phase (fluid) velocity, u_p particle velocity, ρ and μ are density and dynamic viscosity of the fluid, ρ_p and D_p are particle density and particle diameter. Reynolds particle number R_{ep} is:

$$R_{\mathrm{ep}}=\frac{\rho \mathrm{D}_p|u-u_p|}{\mu} \tag{3}$$

Term $g(\rho_p - \rho)$ is gravity force per mass of the particle. Drag coefficient is:

$$C_D=\mathrm{a}_1+\frac{a_2}{R_{\mathrm{ep}}}+\frac{a_3}{R_{\mathrm{ep}}^2} \tag{4}$$

Where a_1, a_2 y a_3 are constants dependent R_{ep} values, according with Morsi & Alexander (1972).
Particle rebounds against the system boundaries are considered as elastic collisions, with specular reflection. Regarding rebound model, momentum change if considered through a restitution coefficient like:

$$e_n=\frac{V_{\mathrm{s,n}}}{V_{\mathrm{i,n}}} \tag{5}$$

Where e_n is the normal coefficient of restitution, $V_{s,\,n}$ and $V_{i,\,n}$ are, respectively, relative velocity after collision and relative velocity before collision (Figure 5). Normal coefficient define the absorbed momentum each bounce. Similarly coefficient of tangential restitution e_t relates the tangential velocities post and pre impact. In this work, normal and tangential coefficients of restitution for both seeds (soyben and amaranth) is taken as 0.7 (Zhang & Vu-Quoc, 1999).

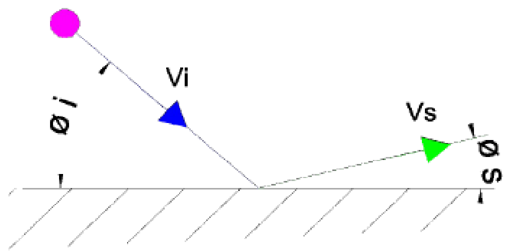


Figure 2. Scheme of particles rebounding against wall.

Stokes number is the relationship between the stopping time of a particle and the characteristic flow time (Israel & Rosner, 2007). Then, Stokes number of the air-seeds flow mixture is:

$$\mathrm{St}=\frac{\tau_p}{t_f} \tag{6}$$

Where τ_p is the characteristic time of the particle, and has the form:

$$\tau_p=\frac{\rho_p D_p^2}{18\,\mu} \tag{7}$$

t_f is the characteristic time of the fluid,

$$t_f = \frac{L_f}{V_f} \tag{8}$$

Let L_f be the length of the input pipe of the flow, V_f the mean velocity of the fluid inlet (Rao et al., 2012). If St << 1, the response time of the flow particles is much lower than the characteristic time associated with the flow field. That is, the particles have time to respond to changes in velocity in the flow field. On the other hand, if St >> 1 the response time of the particles is higher than the flow field, and cannot respond to the velocity changes that occur in the latter (Crowe, 2006). Table 2 describes characteristics of soybeans and amaranth seeds. Amaranth data is obtained from the work of Abalone et al (2004).

Table 2. Seed Parameters for Stokes Number Calculation.

Species	Density ρ_p (kg/m^3)	Size D_p [m]	τ_p (s)
Soybean	700	0.004	31.4
Amaranth	1330	0.0012	5.3

Table 3. Air parameters for Stokes Number Calculation.

Fluid	Density ρ_p (kg/m^3)	Dynamic visc. μ (kg/m.s)	v_f (m/s)	L_f (m)	t_f (s)
Air	1.17	1.983x10^{-5}	20	1.86	0.093

According with Tables 2 and 3, and Eq. (6), (7) and (8), Stokes number of both mixing flows can be obtained. Stokes number for soybean and amaranth is, respectively, St ≈**337** and St ≈**58**. In both cases, St is greater than 1, but the amaranth has a Stokes number 5.9 times smaller than soybean, which implies that the response time could be closer to that of the flow field.

3. Results and Discussion

In Bourges et al. (2014), the difficulty of seeds to escape through the outlet ducts is observed due to the high number of rebounds in the distributor head expansion area. In this sense, present work shows a great amount of seeds rebounds in the expansion zone. Figure 4 shows the distribution of particles in the entire system, colored by their residence time. Colored bar at the left shows a range of residence time (between 0.07 and 2 s). Note that particles remains longer time in the distributor head than in other parts of the system. This is mainly due to the rebounds of seeds against system walls.

Figure 5 shows the seed flow distributions and air flow rates between outlet ducts. The air flow on each outlet, in both cases, are gratified as cyan bars, while the flows of soybean seeds are in red bars, and green bars for amaranth seeds.

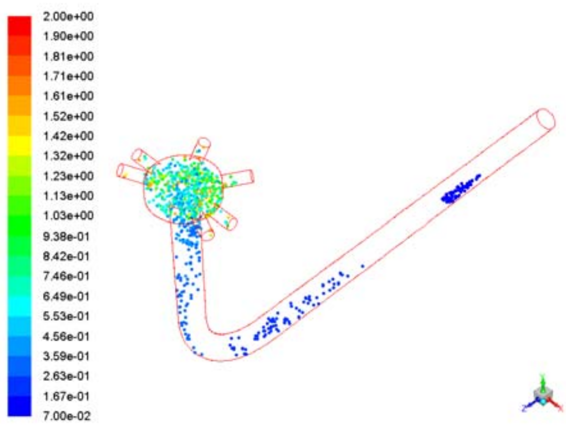
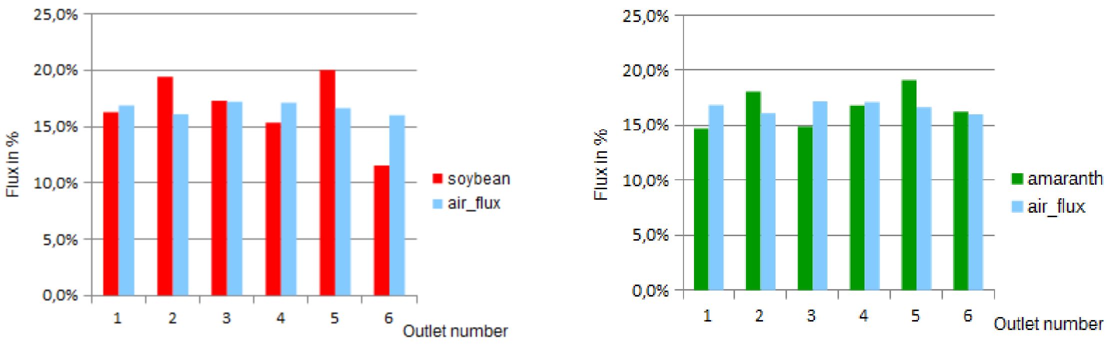


Figure 4. Distribution of particles in the entire system. Coloured bar at the left shows range of residence time in seconds.



a b

Figure 5. Bar charts percentage of particles and air flux (abscissa) vs. output number (ordinate) for: (a) Soybean, (b) Amaranth.

In both cases, seeds distribution between outlet ducts do not coincide with the distribution of air flow. In soybean tests (Figure 5 (a)), the dispersion of seed flows between outlets is greater than for amaranth. Although, outlets 2 and 5 also have the maximum flow rates, it is lower than that observed at output 6 (11.6%). Note that in this case, the distribution of air flows is identical to the tests performed with the amaranth. A lower dispersion of seed flows is observed on simulations of amaranth seeds (Figure 5 (b)). Exits 2 and 5 present the highest seed flow rates (18.1% for exit 2 and 19.1% for exit 5). The difference between the outlet with the highest flow and the lowest one is 4.4%. In both situations, this lack of equivalence between seed distributions and air flows between outlets tubes asserts the idea that, in these types of particles, and due to their high inertia, they behave independently of the continuous phase. The latter states the concept of the Stokes number, defined in Eq. (6). If the Stokes number is small, that is much less than 1, it means that the particle motion is tightly coupled to the fluid motion- that is the particle dispersal is the same as the fluid dispersal. If the Stokes number is large, the particles are not influences by the fluid. Their response time is longer than the time the fluid has to act on it (the fluid time scale may be the rotation time of a characteristic eddy) and so the particle will pass through the flow without much deflection in its initial trajectory. Both seeds have a St> 1, that is to say, they possess important inertia with respect to the flow field. A greater dispersion of soybean seed flow compared with amaranth seed coincides with a larger St of the first with respect to the second.

4. Conclusions

The behavior of a distributor head model is numerically evaluated for a constant air flow and two different sizes of seed, soybean (Glycine max) and amaranth (Amaranthus cruentus). According to numerical results, it could be conclude that in the case of amaranth seeds there is a better distribution in the outlets than soybean seeds due to a less Stokes number, which means a lower influence of inertial flow in that case.
The work team of INTI and FCEIA (UNR), through a cooperation agreement, is working to build a prototype of the designed model, and test it in the facilities of the FCEIA..

Reference

Abalone R , Cassinera A ; Gastón A ; Lara M A, 2004, Some Physical Properties of Amaranth Seeds [J] Biosystems Engineering, Vol 89 (1), No 109–117, DOI:10.1016/j.biosystemseng.2004.06.012.

Allam R K & Wiens H, 1982, An investigation of air seeder component characteristics, Alberta: Winter meeting-American society of agricultural engineers, ASAE [J] , No 82-1505.

ASABE, Terminology and Definitions for Planters, Drills and Seeder , 2010 s, ASABE S506 OCT2010 (R2014). American Society of Agricultural and Biological Engineers. Standards. EEUU.

Bourges G, Eliach J, Balbastro E, Medina M, 2006, Evaluación numérica del distribuidor de semillas por medio de flujo de aire en sembradoras "air drill", XXVII CILAMCE [A], Brazil. No: 04 525.

Bourges G, Medina M, 2007, Evaluación de la performance neumática del sistema de transporte de semillas en sembradoras "air drill". Mecánica Computacional, Vol XXVI [A], ISSN: 1666-6070, No1131-1142.

Bourges G, Mattara M, Ponso R, Medina M., 2009, Determinación de la Pérdida Energética en Distribuidores de Semillas de Sembradoras, Revista AVERMA [A], ISSN 0326-5184, Vol. 13. No 8.27- 8.33.

Bourges G, Medina M, 2012, Trayectoria de semillas en conductos horizontales en sembradoras air-drill, Revista iberoamericana de ingeniería mecánica [A], ISSN 1137-2729, No 75-86.

Bourges G, Medina M, 2013, Verificación experimental en banco de ensayos de cabezales distribuidores de sembradoras “air drill”. XI CIBIM [A]. ISBN 978-950-34-1025-7 (2), No 1174-1181.

Bourges G, Medina M, 2014, Modelling and simulation in a component of an air planter, 2014, Ingeniería y Ciencias Aplicadas: Modelos Matemáticos y Computacionales, Sociedad Venezolana de Métodos Numéricos en Ingeniería. Venezuela [A], No 19-25.

Bourges G; Eliach J; Medina, 2014, Comparación entre resultados experimentales y numéricos en un cabezal distribuidor de sembradora air drill, Mecánica Computacional Vol XXXIII [A],. ISSN 1666-6070. Argentina. No 2555-2563.

Bourges G, Eliach J, Medina M, 2015, Numerical testing of a distributor head modification of an air drill seeder. Performance comparison with actual model. Book of Full Papers of International Scientific XXXVI CIOSTA CIGR V Conference [A], Saint Petersburg State Agrarian University, ISBN 978-5-85983-257-6, No 105-115.

Crowe CT, 2006, Multiphase flow handbook, Taylor & Francis. ISBN 0-8493-1280-9.

Israel R, Rosner D E, 2007, Use of a Generalized Stokes Number to Determine the Aerodynamic Capture Efficiency of Non- Stokesian Particles from a Compressible Gas Flow. Aerosol Science and Technology Volume 2, Issue 1, ISSN: 0278-6826/1521-7388, No 45-51.

Kumar V J F, Durairaj C D, Balasubramanian, M, 1999, Air assisted drill for small seeds. Journal of Agricultural and Engineering Research, [J], Vol. 8, Issue 4, No. 259-265.

Kumar V J F, Durairaj C D, 2000, Influence of Head Geometry on the Distributive Performance of Air-assisted Seed Drills. Journal of Agricultural and Engineering Research [J], Vol. 75, pp. 81-95.

Kumar V J F, Durairaj C D, 2001, Influence of distributor head on the seed trajectory within the feeder plenum of an air drill. International Agricultural Engineering Journal [J], Vol. 10, Issue 3-4, No. 255-267. 2001.

McCartney D, Boyden, A, Stevenson C, 2005. Development of Agitators for Seeding Forages Using Air Delivery Systems, Journal of Rangeland Ecology & Managment [J], Vol. 58(2), No.199-203.

Morsi S A, Alexander A J, 1972, An Investigation of Particle Trajectories in Two-Phase Flow Systems, J. Fluid Mech. [J], Vol. 55(2), No.193–208.

Rao A, Curtis J S, Hancock B C, Wassgren C, 2012, Numerical simulation of dilute turbulent gas-particle flow with turbulence modulation. AIChE J. [J], Vol. 58(3), No. 1381–1396. DOI:10.1002/aic.12673.

Shih T H, Liou W W, Shabbir A, Yang Z, Zhu J, 1995, A New k-ε Eddy-Viscosity Model for High Reynolds Number Turbulent Flows, Model Development and Validation, Computers Fluids [J], ISSN: 0045-7930, Vol. 24, issue 3, No. 227–238.

Yatskul A, Lemière J, 2014, Experimental determination of flow concentration for pneumatic conveying systems of air-seeders, INMATEH-Agricultural Engineering [J], Vol. 44(3), No.19-26.

Zhang X, Vu-Quoc L, 2000, Simulation of chute flow of soybeans using an improved tangential force displacement model, Mechanics of Materials [J]. 32. No. 115-12.