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Improving the Performance of a Spouted Bed via Uniformity Index Using Stochastic Optimization

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Abstract
This work focuses on maximizing the solid's uniformity structure (UI) that could enhance the performance of the spouted bed. Furthermore, UI is affected by operating conditions, which are considered as decision variables of the optimization process. The selected decision variables are; gas velocity, solid's density and solid's diameter. Steady-state measurements were carried out in the 60° conical shape spout-air bed. Concentration of particles (glass and steel beads) at various elevations of the bed under different flow patterns were measured using sophisticated optical probes. Optimization technique is a powerful tool for selecting the best operating conditions could overcome the instability of the system and improves the uniformity of the particles across the bed. The stochastic global genetic algorithm has found the suitable search for the non-linear hybrid spouted bed. The optimal results indicate that maximum UI is 0.534 could be obtained with; gas velocity of 0.741 m/s, solid's diameter of 1.09 mm and solid's density of 6648.0 Kg/m^3. Velocity of gas and diameter of solid particles were observed the sensitive variables with the uniformity index changing.
Keywords: Genetic algorithm, Optimization, Spouted bed, Uniformity index.

1. Introduction

Gas-solid spouted beds are either cylindrical bed with cone base or the whole bed is in a cone shape where the gas enters as a jet. The gas forms a spout region that carries the solids upward in a diluted phase that forms a fountain at the top of the bed where the solids fall down and move downward in the annular region.

A spouted bed is a special case of fluidization. It is an effective means of contacting gas with coarse solid particles. There is increasing a application of spouted such as; coating, desulfurization, CO_2 capture, combustion and gasification of coal and biomass [1].The spouted bed is a kind of high performance reactor for fluid-solid particles reaction, also it is a hybrid fluid-solid contacting system [2].

It is better to develop the design of the spouted bed to overcome the large pressure drop and instability of the operation and enhances the uniformity of the products resulting from the chemical or physical treatment due to the elimination of the back mixing [3]. Uniformity of solid particles enhances the mass and heat transfer in addition improves the conversion of the reactants in the spouted bed.

2. Scope of the work

The present work focuses on study the effect of the selected decision variables (gas velocity, solid's density and solid's diameter) on the uniformity index (UI) of the solid particles in the spouted bed .Steady-state measurements are carried out at different operating conditions using sophisticated optical probes. The objective is to maximize UI.Stochastic genetic algorithm is a global search technique will implement to solve the nonlinear optimization problem .Optimal results guides the decision makers to select the best operating conditions.

3. Material and Methods

3.1. Experimental set-up

The experimental set-up was designed and constructed in the best way to collect the data as explained in Figure 1.The cylindrical spouted bed is made of Plexiglas. The bed is (3 inches in diameter and 36 inches in height) on which 20 holes (0.5 inch in diameter) are perforated vertically. At the bottom of the bed, there is a 60° cone-shaped base (3 inches in height); the Plexiglas spouting nozzle (0.25 inch in diameter) locates in the center of the conical base.

The spouted gas is air supplied from the air compressor and the gas flow rate is controlled by the pressure regulator and measured by the flow meter (Figure 1). The solid particles used are steel and glass beads with different diameters and properties (Table 1).

Holes are drilled at vertical intervals of (1.86 inch) along the column wall in which the optical probes are placed at different radial positions: 1.5, 1.25, 1.0, 0.75, 0.5, and 0.25 inch. The spouted bed divided into three positions: position 1 with head of 7.5 inch while positions 2 and 3 have heads of 5.5 and 3.5 inches respectively above the conical base.

The newly optical probes are used to measure both solids concentration and solids velocity and their fluctuation. The concentrations of solid particles are measured in the radial and axis directions by the particle analyzer (PV6) which manufactured by the 'Institute of Chemical Metallurgy, Chinese, Academy of Science' .It consists of; photoelectric converter and amplifying circuits, signal pre-processing circuits, high-speed A/D interface card and its software PV6, is adapted to the optical probes.

Three decision variables were selected which affect the uniformity index (UI) of the solid particles. These decision variables are; air velocity, particle's density and particle's diameter.

3.2. *Formulating of optimization equation*

In the present work, the uniformity index equation (Equation 1) was derived depended on correlations of [6&7]. The experimental data have been used to correlate the objective (UI) with the decision variables (Equation 2) to facilitate the optimization scheme. The advanced nonlinear regression optimization algorithm used is Hook-Jeevs pattern moves with the aid of the computer program (Statistica version10).

$$UI = C_{avg}-C_{Min}/C_{Max}-C_{min} \qquad (1)$$

$$UI=0.184Vg^{-0.214}\rho s^{0.12}dp^{-0.267} \qquad (2)$$

Subject to inequality constraints:

$$\left.\begin{array}{l} 0.74 \leq Vg \leq 1.0 \\ 2400.0 \leq \rho s \leq 7400 \\ 1.09 \leq dp \leq 2.18 \end{array}\right\} \qquad (3)$$

From Equation (2), one can observe that the density of the solid particles has positive effect on the UI, while the air velocity and diameter of particles have negative effect.

4. Results and Discussion

4.1. *Stability and uniformity*

Figures (2a & b) illustrate the solid concentration distributions in the spouted bed for different positions and flow regimes [4]. Vg selected between 0.74 to 1.0 m/s for glass and steel beads. The solid concentration of steel beads (Figure 2b) is high than that of glass beads (Figure 2a) due to the high density of steel beads. Position 1 indicates to the fountain region at which the solid concentration curve has pulse shape. The instability of fountain region is due to high vortex of flow and interaction of solid particles for different flow regimes compared to the stable conditions appeared at the annuals region (positions 2 &3) as shown in Figures(2a and b). The solid concentration curves have uniform exponential form at annulus region for the same flow regimes. The spouted-air bed behaves as a hybrid fluid-solid contacting system. The efficiency of the spouted bed is dropped at unstable conditions. A stable spouted bed is observed when the particles in the bed fluidized homogenously and they are not discharged from the apparatus.

The solid concentration is much less in the lean bed region at the center than in the dense bed region near the wall as shown in Figures (2a & b). This reduces the heat & mass transfer and the reactants conversion. Therefore, that in the case of spouted bed reactor, the unconverted concentration of material at the center is higher than that at the spouted wall [1]. Figure 3a illustrates the effect of the air velocities on the uniformity index (UI) with the steel and glass beads. The UI decreased with increasing the air

velocity (Vg) because of increasing the desperation of the solid particles due the kinetic energy of the solid particles is increased. In addition, two regions are appeared in these curves, which represent the transition region from the packed bed flow regime at Vg of 0.74 m/s to the stable spouting flow regime at Vg of 0.95 and 1.0 m/s. In addition, The UI of the steel beads is higher than that of glass beads (Figure 2a) due to high scattering occurred with the particles of low density. Low concentrations of solid particles were obtained for all positions with the glass beads system, which affected on the values of UI. The density of the solid particles has the positive effect on the UI of the spouted bed (Figure 3b).Since the increasing of the particles' density could provide the bed more strength and resistance against the vortex of the fountain. Therefore, it gives the solid particles more stability and uniformity. The denser material is continued to spout in the central region while the less dense particle formed vortex around the central spout. The solid beads diameter has negative effect on the UI of the solid particles as shown in Figure 3b. The particles of small size are helpful to raise the mixing speed [5].This provides the smaller particles more uniformity in the radial distribution. However, the uniformity of particles will improve the mass, heat transfer and the conversion of reactants into the spouted bed. In addition, the uniformity enhances the solid hold up and solid void distributions that provide the performance of the spouted bed.

4.2. *Genetic algorithm search*

Since the spouted-gas bed is nonlinear system, genetic algorithm (GA) is the best global stochastic search that based on mechanics of natural selection [8]. The operators of genetic algorithm search were adapted to obtain the best solution.

Table 2 explains the best parameters of the genetic algorithms. Figure 4 illustrates the solutions/operators of GA search. GA implemented with the pattern search by using the hybrid function as shown in Table 2 to refine the decision variables [9]. The best fitness, best function and score histogram as shown in the Figures 4 illustrate that the optimal UI is (0.534).The results of the optimization search (Table 3) have reasonable agreement since the values of the decision variables (Vg , ρs and dp) are within the limits of the operating conditions (Equation 3). In addition, the maximum UI can obtain by the low gas velocity, high-density steel beads of low particle diameter as shown in Table 3, Figure 3 and Figure 4. Therefore, by staying close to this minimum flow condition, it is possible to perform a stable operation and to obtain energy savings. [10].The histogram of the variables in the Figure 4 indicates that the density of solids (variable 2) is the effective variable on UI. Due to the nonlinearity of the spouted process (Equation 2), the optimization equation of UI was solved by (51) generations as shown in Figure 4. The optimal sets of the three decision variables are illustrated in the Figures (5a, b and c) corresponding to the objective UI.The scattering and stochastic of results are appeared in these Figures as a results of natural selection by GA .It is found that the optimal values of the solid density (ρs)are almost constant at its lower bound as explained in the Figure 5b. Gas velocity (Vg) and solid diameter(dp) are changed within its lower bounds(Figures 5a and c) . These behaviors are because of ρs has positive effect while Vg and dp have negative effect on UI as shown in the Figure 3. Most optimal values of the three decision variables are stayed within optimum value of UI which equal to 0.534 as shown in the Figure 5.It is observed that Vg and dp are the most sensitive variables for UI changing as shown in the Figures (5a and c).

5. Conclusions

1. Efficiency of the spouted bed is dropped at unstable conditions. A stable spouted bed is observed when the particles in the bed fluidized homogenously.

2. Uniformity of solid particles enhances the performance of the spouted bed. Maximum uniformity has been obtained with the high-density steel beads of low particle's diameter at low air velocity.

3. Density of solid particles is the effective variable on the uniformity structure of the particles across the bed.

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4. Optimal velocity of spouted gas and diameter of solid particles are the sensitive decision variables with uniformity index changing.

5. Success of optimization search depends on the formulation of objective function, selection of decision variables and selection of suitable searching technique.

6. Genetic algorithm has found the suitable global search for the hybrid nonlinear spouted bed. The reliability of the search could be improved by the adaptation of the genetics' operators.

Nomencluers

C	Relative concentration of solid particles,[-]
C_{avg}	Average concentration of solid particles,[-]
C_{min}	Minimum local concentration of solid particles,[-]
C_{max}	Maximum local concentration of solid particles,[-]
dp	Diameter of solid particle, [mm]
UI	Uniformity index of solid particles,[-]
Vg	Superficial velocity of gas, [m/s]

Greek Symbols

ρs	Density of solid particles,[Kg/m^3]
€	Porosity of bed, [-]
Ø	Sphersity of the solid particle,[-]

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References

[1] Limtrakul, S., Boonsrirat, A.and Vatanathm, T. (2004),"DEM Modeling and Simulation of a Catalytic Gas-Solid Fluidized Bed Reactor: a Spouted Bed as aCase Study", Dept.of Chem.Engng.kasetsar University, Bangkok, Thailand, Elsevier Ltd.
[2] Wang, Z., Chen, P., Li, H., Wu, C.andChen, Y. (2001),"Study on the Hydrodynamics of a Spouting-Moving Bed", *Ind.Engng.Chem.Res*, 40, 4983-4989.
[3] Prachayawrakorn, S., Reuengnarong, S.and Soponronnarit, S. (2005),"Characteristics of Heat Transfer in Two-Dimensional Spouted Bed", School of Energy and Materials, University of Technology, Bangkok, Thailand.
[4] Xu,J.,Bao,X.Wei,W.,Bi,H.T.,Grace,J.R.,and Lim,C.J.(2009),"Chaotic Characteristics of Pressure Fluctuation in a Gas Spouted Bed", *Canadian Journal of Chemical Engineering*, .87, April.
[5] Hao, H., Guoxin, H.and Fengchao, W.(2008),"Experimental Study on Particles Mixing in an Annular Spouted Bed", *Energy and Conversion Management*, 49,257-266, Elsevier.
[6] Nedeltchev,S.,Ookawara,S.,and Ogawa,K..(2000),"Time-dependent Mixing Behaviors in Lower and Upper Zones of Bubble Column", *J.chem.Engng.of Japan*, 33, 5, 761-767.
[7] Zhang, Y., Zhong, W.and Jin, B.(2011),"New Method for the Investigation of Particle Mixing Dynamic in a Spout-Fluid Bed", *Powder Technology*, 24, January.
[8] Gupta, A.K. and Srivastava, R.K.(2006),"Integral Water Treatment Plant Design Optimization: a Genetic Algorithm Based Approach",*IE Journal*,87,September.
[9] Palonen, M., Hasan, A. and Siren, K.(2009),"A Genetic Algorithm for Optimization of Build-ing Envelope and HVAC system Parameters", Eleventh International IBPSA Conference, July 27-30, Glasgow, Scotland.
[10] Correa, N.A., Freire, J.T and Correa, R.J. (1999),"Improving Operability of Spouted Beds Using a Simple Optimization Control Structure", *Brazilian.J.Chem.Engng*.16, 4, Dec.Saopaulo.

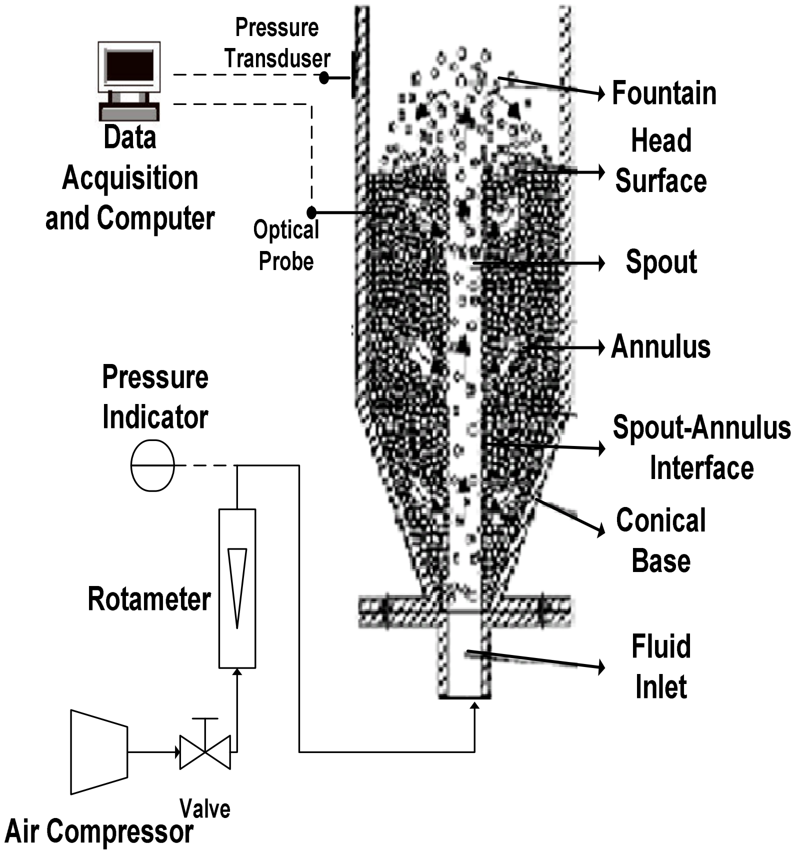

Figure 1. Experimental set-up.

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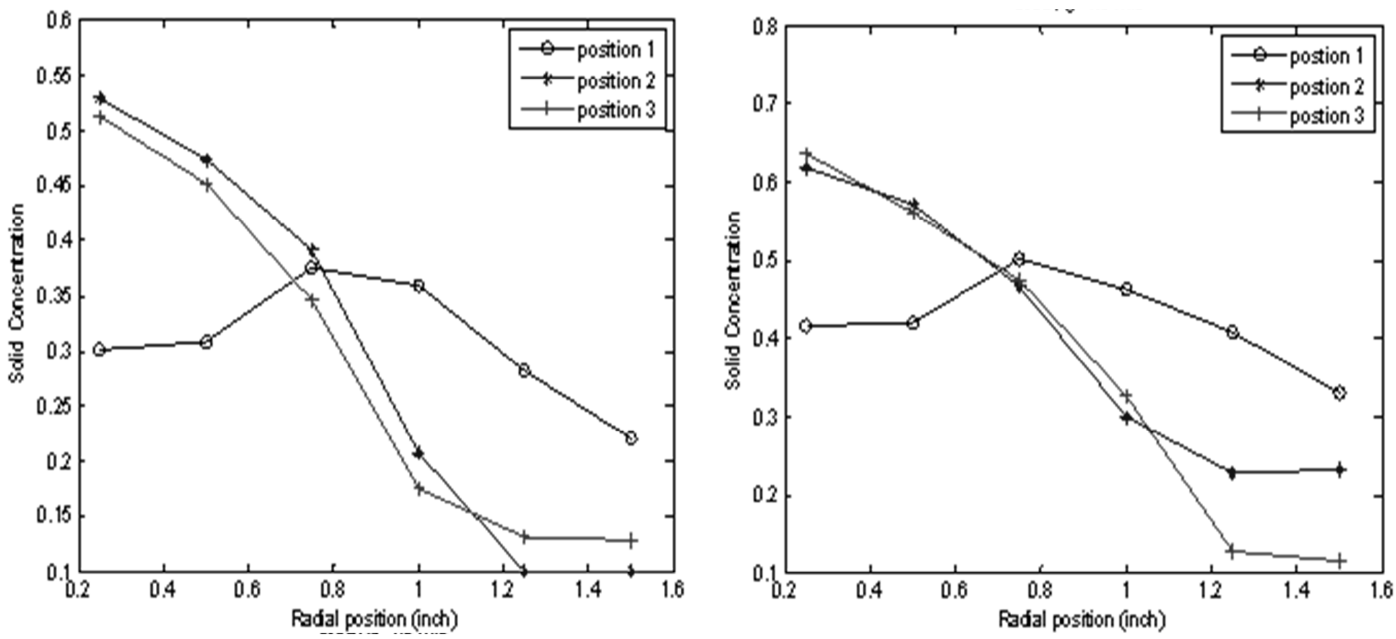
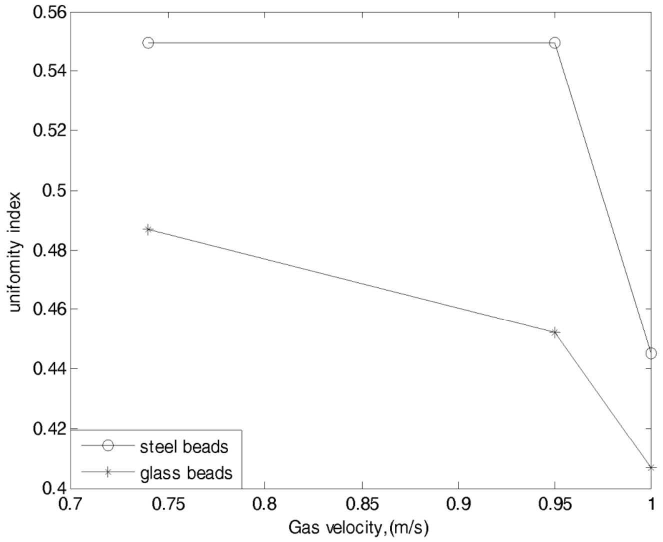
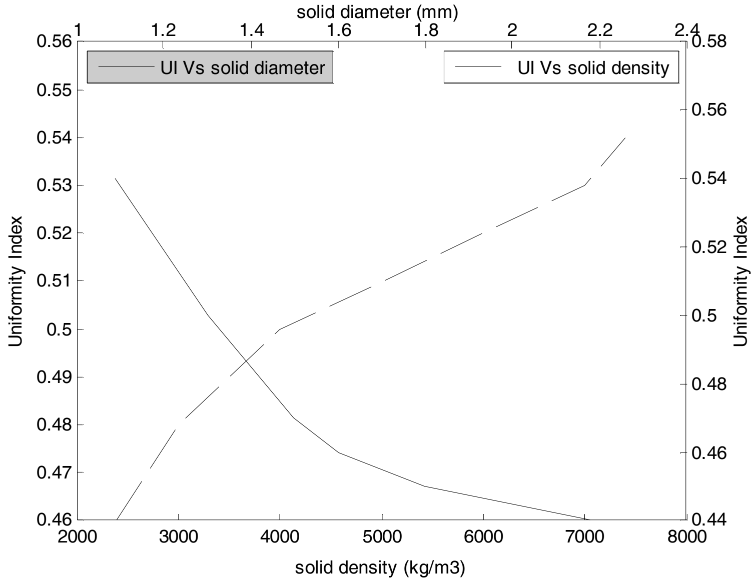


(a) (b)

Figure 2.Solid concentration distribution for (a) glass beads (b) Steel beads.



(a)



(b)

Figure 3. Uniformity index against ;(a) gas velocity,(b) solid density and solid diameter.

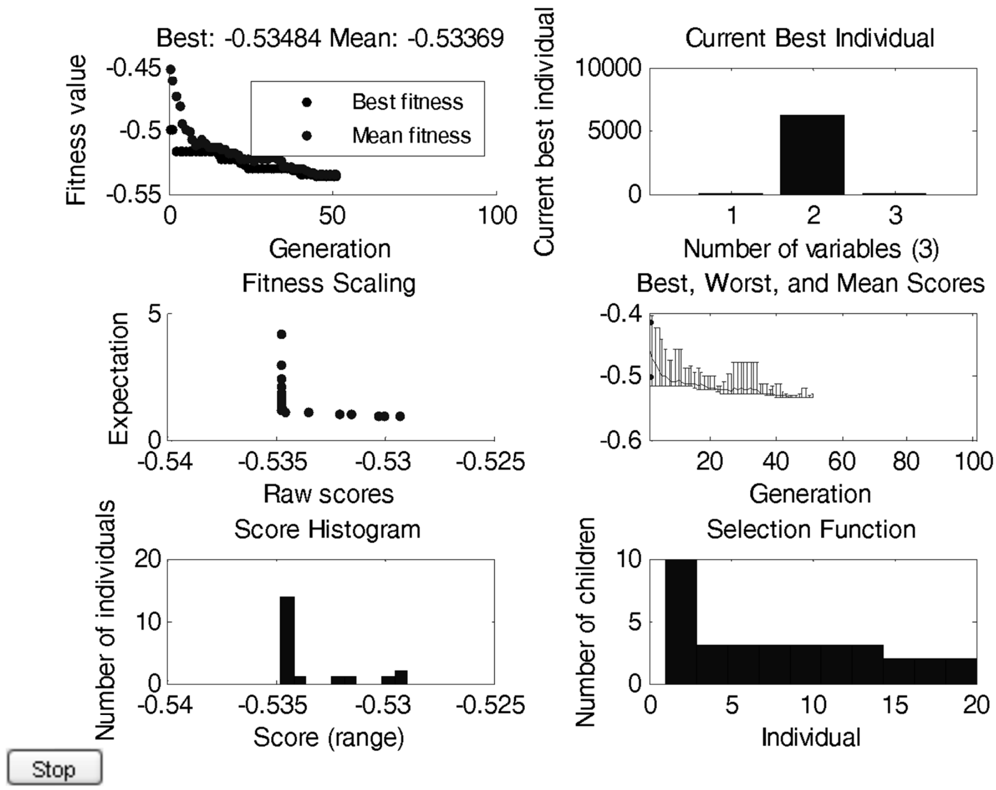
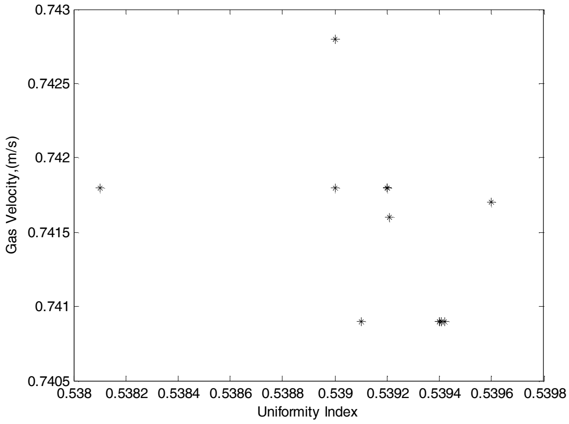
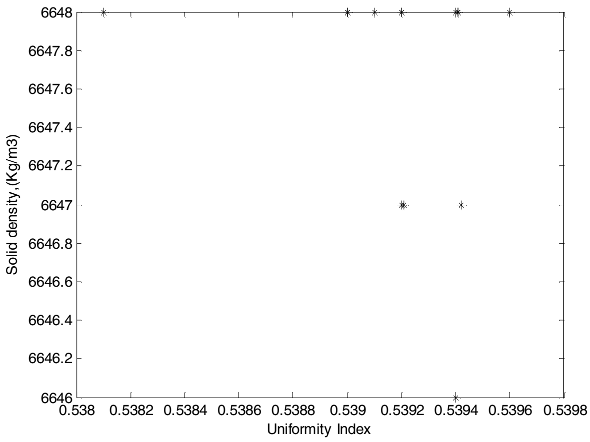


Figure 4. Results/solution of genetic algorithm.



(a)



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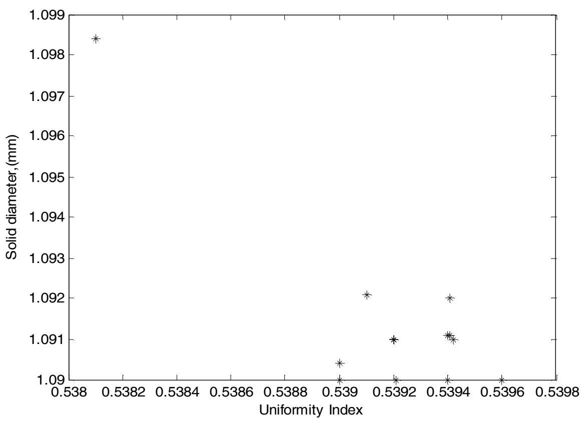

(c)

Figure 5.Optimal values of decision variables corresponding to objective UI.

Table 1. Properties of the particulate materials.

Material	dp(mm)	$\rho s(Kg/m^3)$	€	Ø
Steel beads	1.09	7400.0	0.42	1.0
Glass beads	1.09	2450.0	0.42	1.0
Glass beads	2.18	2400.0	0.41	1.0

Table 2. Adapted parameters of GA.

Parameter	Type/value
Population type	Double vector
Population size	80
Creation function	Feasible population
Scaling function	Rank
Selection function	Roulette
Crossover function	Scattered
Crossover fraction	0.8
Mutation function	Adaptive feasible
Migration direction	Forward
Migration fraction	0.1
Hybrid function	Pattern search
Number of generation	51
Function tolerance	1.0E-6

Table 3. Optimal values of the decision variables.

Decision variables	Optimum value
Gas velocity(m/s)	0.741
Density of solid (Kg/m^3)	6648
Diameter particle(mm)	1.09