Review on Heat Transfer in Sound Assisted Fluidized Bed

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Abstract - Nanoparticles have a rare quality of very small size and a large surface area per unit mass. These are most advantageously used in many applications with their fluidization process. In such particles, for better fluidization process together with the conventional gas fluidization technique some additional forces were studied by many authors. One of them is application of sound waves. The presence of sound waves causes the decrease in the characteristic minimum fluidization velocity with increase in the heat transfer rate from heating element to very small sized particles of fluidized bed. The brief information about sound assisted fluidization process are given in the present article. Similarly, the heat transfer phenomenon in fluidized bed, the effect of sound field on fluidization of powder in presence of sound field are presented.

Keywords - Nano powders, sound field, fluidization, heat transfer.

I. INTRODUCTION

Fluidized bed of nanoparticles is one of the important part of nano technology. The bed gives advantageous outcomes as increased heat and mass transfer rates, ability to deal with a different types of particles and controlled uniform temperature values [1] and are mainly used in the various large scale industries [1,2]. In case of application of this part, essential thing is to disperse the particles and the dispersion is carried out by gas fluidization process. It becomes tough to scatter the nano particles with the technique of gas fluidization only as these particles are having large intermolecular forces [1,2]. Thus, the fluidized bed of nano powder shows difficulty in the simultaneous process with gas fluidization only [3,5]. Researchers studied for some external forces given to this system for effective fluidization quality of powders. Sound field shows capability to disturb all clusters [10,11,14] and decrease in the velocity of minimum fluidization [3,5,10,13,22], bubble free fluid-like behaviour is obtained [11]. The sound energy results for continues vibrations, replaces particle without channeling nature of the bed. Small agglomerates move upward in the column where the movement of these agglomerates occur on the basis of density difference till bed gets reached to the dynamic equilibrium stage [15,22]. Like this, sound assisted fluidized bed of nano powders improves the quality of fluidization process [6] and results more turbulence in the bed and sufficient degree of homogeneity [12]. In case of more heat transfer coefficient in this fluidized bed, quick movement of the particles is necessary and hence for this purpose, gas velocity is made to increase with required contact time of them [4,21].

NOMENCLATURE

r/R	radial ratio
SPL	sound pressure level, dB
H	bed height, m
Gs	solids circulation rate, kg/ m^2s
dp	particle size, μm
f	frequency of sound, Hz
h	heat transfer coefficient, W/m^2K
T	temperature, °C
Ug	velocity of fluidizing gas, m/s
Umf	minimum fluidization velocity

II. LITERATURE SURVEY

SOUND ASSISTED FLUIDIZATION

As discussed previously, Geldart C particle are much complicated to fluidize with conventional gas fluidization process only. Sound shows capability of penetrating the bed of fine powders and in presence of an external force as sound field plays an important role for decreasing the velocity of minimum fluidization, removal of channeling in the bed and causes the relative motion of larger and smaller aggregates inside the column of bed [22]. When adequate frequency of sound and SPL is given, the breaking of large agglomerates occurs and bed collapses suddenly [10,16].

Herrera et al. (2001) [3] experimented for bubbling characteristics of fluidized bed of glass bead (42μm) and alumina (15μm, 42μm) in the presence of sound field, SPL = 170 dB and frequency = 90 Hz. They showed experimentally that, the sound field is capable to disturb the cohesive property of nano powders and fluidization bed gets expanded homogeneously with increase in SPL till bubbling condition was observed. Above SPL = 140 dB, at lower velocity of gas, the bed compaction characteristic of fluidized bed was observed. It was concluded that minimum bubbling velocity is directly proportional to the bed material particle size.

Escudero et al. (2012) [5] investigated the effect of acoustic wave frequencies on velocity of minimum fluidization of fluidized bed. The analysis was done on glass bead material of various sizes (212-600μm) with different bed to height ratio. They resulted that though the Umf decreases with increase in the sound frequency, after a particular frequency increase in that velocity is obtained. The bed pressure drop was obtained upto 150Hz and Umf as a function of bed height, in other words, when H/D ratio was allowed to increase, the Umf also gets changed at constant frequency.

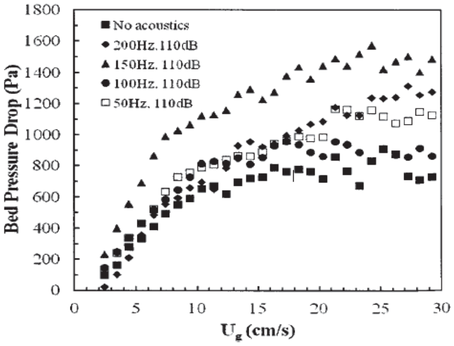

Figure 1: Bed pressure drop vs velocity of superficial gas for 500-600μm glass beads at H/D = 0.5 [5].

Ammendola et al. (2010) [6] made analysis for mixing aeration behaviour of two nano-sized powders as Al_2O_3 (40nm) and CuO (33nm) with nitrogen as a fluidizing gas in assistance of sound field, SPL upto 140dB. They showed that the fluidization quality of bed with only gas fluidization is much poor than that obtained in assistance of sound field. The result were obtained on the basis of bed height and pressure drop. In presence of sound wave, as superficial velocity of gas is increased, the relative increase is shown in the bed expansion ratio (H/H_0). Also, it was observed that, after frequency of 100 Hz and at 140dB the pressure drop gets decreased.

Table 1 [9]: Various fluidization conditions due to presence of sound frequency.

f (Hz)	Fluidization conditions
60-80	Small and medium bubbles throughout bed
100	No visible bubbles
120-140	Channeling and surface spouts
160	Surface spouts
180	Small bubbles throughout bed
200-220	Surface spouts
240-340	Surface spouts
340-550	Deep and surface spouts

Levy et al. (1997) [10] analyzed the effects of sound field characteristics on bubbling process in a gas fluidized bed of fly ash of size 40μm with humidified air as a fluidizing gas. They have reported, the sound wave actuates the bed of material and made disturbances in order to vanish large clusters of particles formed due to intermolecular forces. In this paper, effect of sound intensity on Umf, minimum bubbling velocity and the bed pressure drop were explained. They shows the bed pressure drop reduced upto frequency 150Hz after which the drop remains constant. Various fluidization conditions due to presence of sound frequency for range of 60 to 550 Hz were reported in paper.

Guo et al. (2011) [11] made the prediction of the flow characteristics of bubbling fluidized bed of the quartz sand (74μm) and SiO_2 (0.5μm) particles at high temperature in the presence of sound field. The experimental results were found that, Umf is decreased with frequency rise from 50 to 150Hz and then increased from 150 to 400Hz. For bubble free process, the sound field plays an important role of breaking the large agglomerates without formation of bubble at high temperature upto 800℃. The optimal frequency values were observed as 150Hz for both SiO_2 and quartz particles. They also concluded for the pressure fluctuations inside bed. These pressure fluctuation deviations was homogeneously reduced from 50 to 200Hz and then increased from 200 to 400Hz.

Ajbar et al. (2011) [12] also predicted the effects of sound waves for silica material with size 12 nm, air as a fluidizing gas, SPL of 125dB and the frequency range from 100 to 400 Hz. They concluded that, as velocity of gas increases more than Umf, pressure drop decreases and the bed expands, the void fraction increases leading to decrease in the value of pressure drop. They have been reported, in case of sound assisted performance, the mean of the pressure drop is decreased as compared to no sound performance. Together with this, the addition of sand, i.e., group A powder creates more turbulence in the bed resulting a degree of bed homogeneity.

Raganati et al. [13] reviewed characteristics of fluidizing bed like bed expansion, drop in bed pressure and the velocity of minimum fluidization for four various nano powders ; Al_2O_3, Fe_2O_3,CuO and ZrO_2 with sizes less than 50nm and air as a fluidizing gas. They have found consistent condition of optimum fluidization for Al_2O_3, CuO and ZrO_2 at particular fixed SPL value and the frequency range 100-125Hz and 90-120Hz. With addition of some amount of Fe_2O_3 powder to the mixture, better fluidization behaviour was observed in the bed.

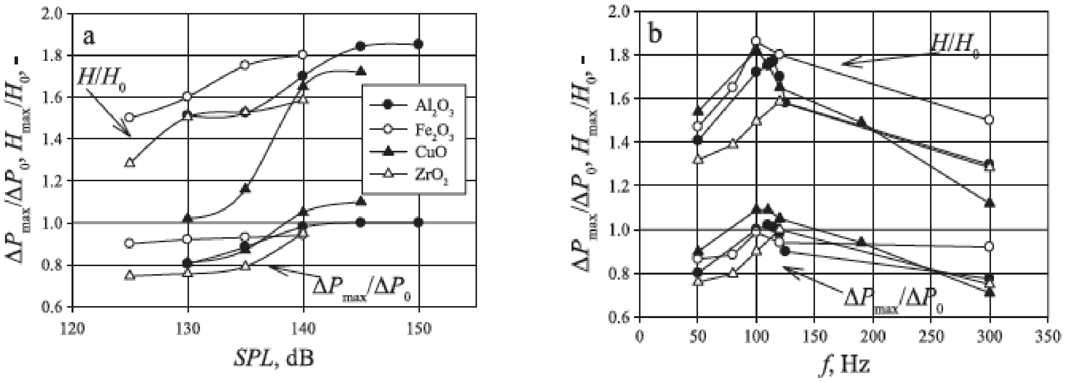

Figure 2: (a) Effect of SPL (f = 120Hz) and (b) effect of sound frequency (SPL =140 dB) on ΔPmax/P0, Hmf/ H0 for all the powders [13].

Russo et al. (1995) [14] studied the sound assisted fluidization of 0.5 to 45 μm zeolite catalysts particles with various weights of powders having range from 1kg to 3kg. For these different weights, different amount of SPL and frequencies were required for the effective breaking of clusters. When insufficient amount of sound intensity is given, it is found that only top portion of powder bed undergo fluidization whereas in lower portion, there was formation of channeling, propagating towards top portion.

Kaliyaperumal et al. (2006) [15] performed experiment for fluidization of sub-micron powders in the presence of sound field. It was found that, the submicron particles causes bed compaction but in case of nanoparticles, it was not found. For submicron particles, the bed expansion ration was increased with increase in the superficial velocity of gas. In the presence of sound than that was obtained in the absence. In another words, the increase in the superficial gas velocity resulted in the increase of fluidization index. It was observed upto 120 Hz and 120dB. For low gas velocity, less than 0.002m/S, the bed compaction was observed. With subsequent increase in the frequencies, Umf was decreased upto 120Hz. After this, the velocity was increased and Umf was obtained for 120dB. Similarly, for nano powders, they have been reported that, maximum bed expansion and maximum fluidization index were at 120Hz and 120dB and Umf for fluidization was found at 110dB.

Guo et al. (2011) [16] investigated for the result of the sound wave on the fluidization process of ultrafine particles as cornstarch, SiO_2 and TiO_2. It was found that, for SPL 100 dB, Umf decreases upto certain frequency. After which there is increase due to the appearance of plugging, channeling and fluidization. It is believed as sound propagates through fluidized bed, sound absorption coefficient varies directly with the square of the sound frequency. Also, maximum amount of sound energy was absorbed by the top portion of the bed and the energy was unable to reach at the bottom which caused the large clusters. It was resulted that, fluidization quality was improved by sine and triangle wave. In another words, sound waveform resulted for effective influence on the fluidization behaviours of ultra-particles.

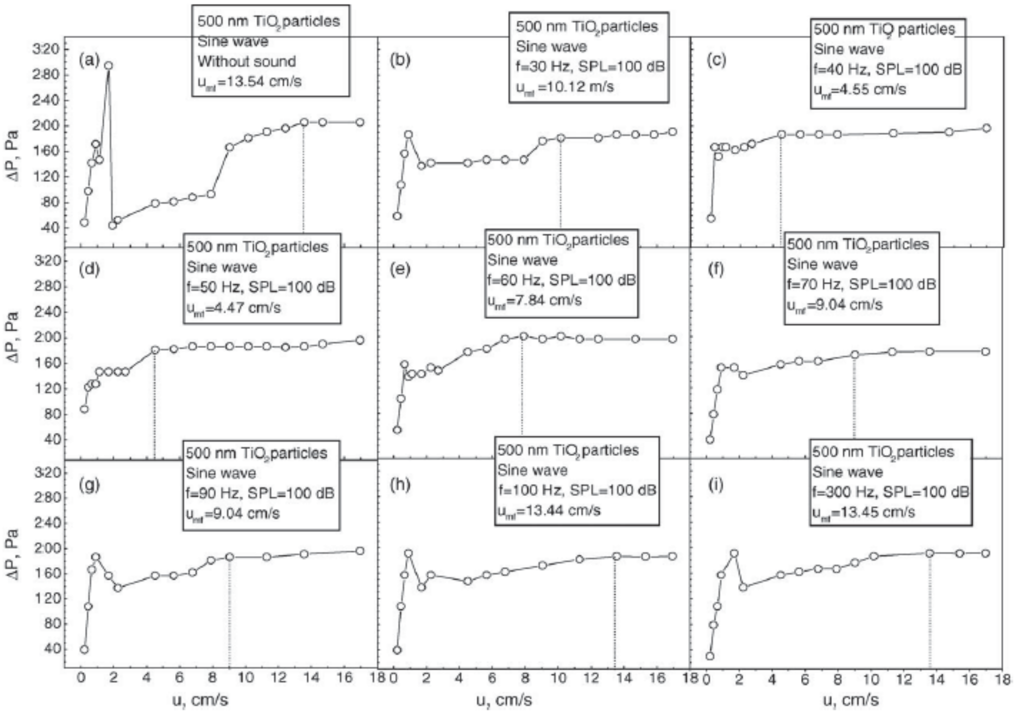

Figure 3: Effect of sound on minimum fluidization velocity with 500nm TiO2 particles [16].

Si et al. (2006) [17] used catalytic cracking particle (FCC) of size 81.5μm for bubbling fluidized bed together with application of acoustic field. The resulted that, Umf has minimum value at frequency of 150Hz and after 150Hz to 500Hz, there was gradual increase in the Umf. Sound coefficient was increased simultaneously with increase in the frequency from 150 to 400 Hz at 120 dB. They did the wavelet analysis for study of pressure fluctuations and proved as an effective tool.

Xu et al. (2007) [18] studied the fluidization behaviour of fine particles consisting Al_2O_3, TiO_2, glass beads and FCC catalysts (avg. sizes of 4.8 – 65 μm). It was found the assistance of sound field enhances the bed fluidization quality with more pressure drop and lower Umf. They predicted, with increase in the velocity of gas beyond a transition value, larger bed voidage was observed. It was resulted that, Umf initially decreased to certain value and then increased rapidly after particular value of frequency. The particle bed for each powder is consolidated in sound field at lower gas velocity. The effect of sound field on fluidization was mainly dependent on the SPL (intensity) value, the frequency of sound applied and the properties of particles. In addition, they also reported the group identification of C/A particles in the presence of sound field. For fluidization, the group C particles showed the decrease in SPL values with unvarying pitch when the gas velocity was allowed to increase. While in case of group A particles, they showed varying pitch with increase in the gas velocity.

Zhu et al. (2005) [22] experimented the sound assisted fluidization of silica nano powder of size 12nm with N_2 as a fluidizing gas. They obtained the results as, with aid of sound field, there was increase in the bed expansion with rise in superficial gas velocity and the value of SPL. They reported that, in assistance of sound field, channeling or slugging of bed quickly vanishes and the bed starts expanded consistently.

HEAT TRANSFER IN FLUIDIZED BED

Hashizume et al. (2006) [8] proposed a relationship for heat transfer coefficient in fluidized bed. The fluidized bed material used were glass (1.9-7mm), ceramics (1.3 – 8.3mm) and chromium (2.4mm). It was observed that, heat transfer coefficient is inverse in proportion of the diameter of particle. Also the value of heat transfer coefficient are dependent on the column diameter and the diameter of the embedded tube. The correlation between these three parameters was given in the investigation as, $h \alpha Dc^{1/4}$ and $h \alpha Dt^{1/4}$; where, Dc is a diameter of column, D_t is a diameter of embedded tube.

Lou et al. (1998) [9] studied the fluidization behaviour of bed and surface to bed heat transfer process. The fluidized bed material was hydrogen absorbing alloy powder (5-15μm), two types of nickel, Ni_1 (5-15μm) and Ni_2 (5-12μm) and hydrogen, helium and nitrogen as a fluidizing gas to avoid humidification inside the bed. It was obtained that, the coefficient of heat transfer gets increased suddenly till Umf is obtained. After Umf, reduction occurs in increase in the heat transfer coefficient and the highest heat transfer coefficient was obtained for fine powder fluidized bed.

Wang et al. (2000) [19] explored the effects of the resistance time of particle on surface of high temperature in the fluidized bed and the heat transfer coefficient from the heating surface. The material for the fluidized bed used was magnesite (0.85-0.35mm) and hollow corundum sphere (1.10-0.87mm). They have been discussed all the tree types of heat transfer phenomenon in the bed during fluidization processes as conduction, convection and the radiation. They found that, the particle resistance time on the surface does not affect the convective heat transfer coefficient however the total heat transfer coefficient gets decreased. Similarly, in case of surface temperature of the heating element, conductive and radiative heat transfer component gets decreased and conductive heat transfer component remains nearly unvarying. Further they reported an increase in (U/Umf) causes a small variation in the convective heat transfer component where conductive and radiative components also gets increased. Total heat transfer coefficient gets reduced with increase in the diameter of heating element. The conduction component gets increased and other both, convective and the radiative heat transfer coefficient gets reduced.

Kim et al. (2004) [24] done experimentation for heat transfer in silica sand (240μm) particle bed at different angular positions of the heating element. It was reported that, with rise in surficial velocity of gas, local heat transfer coefficient rises because of increase in replacement of particle pockets at the tube surface. Changes in the coefficient of heat transfer on the type of tube was small and hence it was obtained that, the solid particles were less affected by the bubbles. The coefficient of heat transfer is contrariwise related to the resistance time of particle on tube surface with more bubbling frequency.

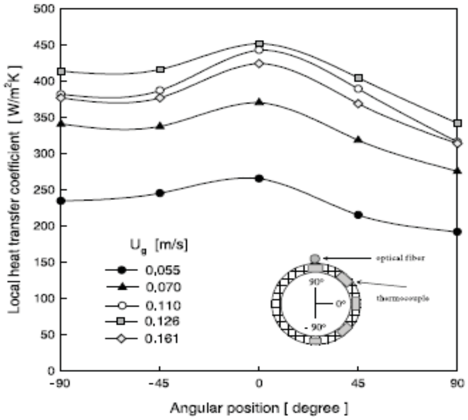

Figure 4: The local-time averaged coefficient of heat transfer for angular positions at different gas velocity [24].

Ma et al. [20] predicted the heat transfer phenomenon for circulating fluidized bed of FCC particles (67µm) and the immersed surface. The different heat transfer coefficient distribution at different axial position are experimented. It was found from the graph that, at center portion, the concentration of the solid particles are much less and unvarying. Due to this, large velocity gas carries these particles to upward. At the opposite hand, this gas velocity is less and hence large size clusters were observed at the wall side portion. So, the distribution of the heat transfer coefficient were resulted as low and much uniform in the central portion than at the wall. Similarly, in case of increase in the bed height, heat transfer coefficient does not get affected more at central portion but at annular portion, heat transfer coefficient starts reducing.

HEAT TRANSFER IN FLUIDIZED BED WITH APPLICATION OF SOUND FIELD

Wankhede et al. (2011) [4] experimented the heat transfer process for different gas velocities, sound field conditions and the various angular positions of the heating surface. Glass beads (462µm) and clay (112µm) were used for fluidizing bed material with air as a fluidizing gas. The information about the selection of acoustic frequency for maximum acoustic energy competence was explored. With increase in the frequencies, there was a particular frequency at which the SPL obtained as maximum and this maximum SPL effectively work for fluidization process. They found for both materials that, the lowering of surface temperature at angular position of 90° due to the rapid replacement of fresh particles at the surface. With increase in the gas velocity, the particle replacement was obtained faster and hence, heat transfer coefficient increases rapidly with excess gas. It was observed that, with subsequent increase in the value of SPL beyond 140dB, the heat transfer coefficient starts reducing as less contact time of the particle to the heating surface occurred and the particle were unable to conduct the heat from heating surface inside the bed.

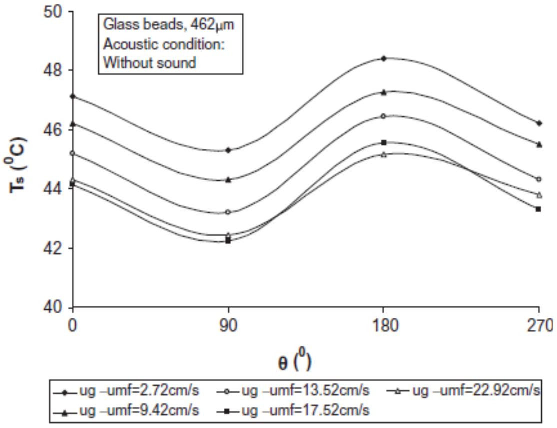

Figure 5: Surface temperature vs angular position around circumference of the tube for glass beads, 462 µm, without sound [4].

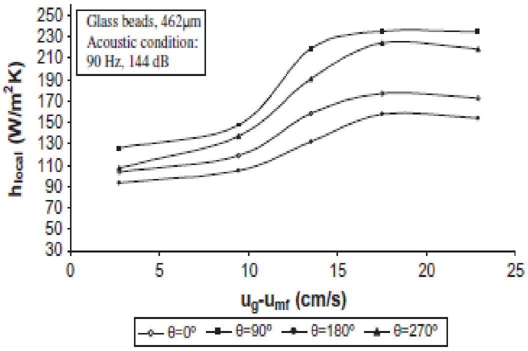

Figure 6: Coefficients of local heat transfer vs velocity of excess air (ug - umf) at various values of h for glass beads, 462µm, 144 dB [4].

Huang et al. (2004) [21] investigated the bubble behaviour and heat transfer coefficient in fluidized bed of Geldart A, B, C materials as glass beads, fly ash HC, fly ash SH, fly ash BW and talc with horizontal heating tube in the presence of sound field. They predicted the increase in the average heat transfer coefficient as excess gas velocity rises together with rise in the values of SPL. More heat transfer rate was obtained at angular positions with more the movement of

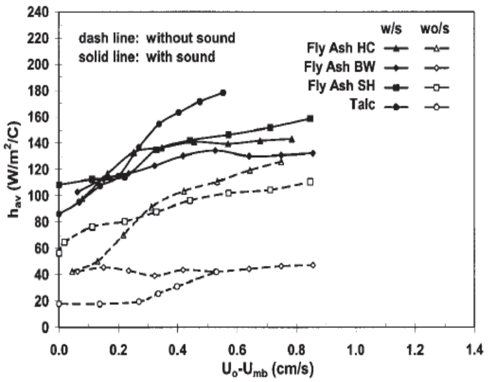

Figure 7: Variation of coefficients of average heat-transfer with velocity of excess air [21].

particles. At the top region of bed, movement was less and also the heat transfer rate. Geldart A and B type powders were found as easy to fluidize without sound but for Geldart C powders, sound field was essential for having fluidization property. It was found that, with increase in the SPL from 124dB to 144dB and with increase in the excess gas velocity, bubbling frequency increased and hence, heat transfer coefficient also was increased.

III. CONCLUSION

Nano powders have unique property of large surface area per unit mass and very small particle size which is necessary in worldwide industrial processes. For having these processes in effective manner, it is importatnt to separate the particles of the nano powder. Gas fluidiztion is the conventional technique for seperating. As discussed previously, gas- solid fluidizing bed gives the results like, high heat and mass transfer rates, the quality to deal various types of the particle properties, the quality of being suitable for the large scale operation and unvarying and controllable temperatures of the bed.

Conferring to the literauture appraised, in case of nano powders, they have much inter-molecular forces that can not be removed with conventional gas fluidization. To overcome this problem and to obtain better fluidization quality, sound assisting method plays an important role. With addition of the sound field of the different intensities and the frequencies to gas fluidization process, breaking of the large agglomerates, movement of particles occur together with bed expansion, reduction in minimum fluidization velocity of the gas, improvement in the degree of mixing and smooth fluidization gives result for the effective heat tranfer rate in the fluidized bed of nanopowders.

The future scope regarding this review, will be the investigation of minimum fluidization velocity, bed expansion ratio, bed pressure drop, heat transfer coefficient at different angular positions for various nano powders in absence and presence of different sound pressure level and frequencies. In presence of sound field, effective replacement of nano powders will be possible and therefore, outcome will be achieved as increase in heat transfer coefficient from heating rod to bed material.

REFERENCES

[1] Jaber shahabanian, Rouzbeh Jafari, Jamal Chaouki,"Fluidization of Ultrafine Powders", International Reiew of chemical engineering, Vol. 4, 2012.
[2] J. Ruud van Ommen, Jose Manuel Valverde, Robert Pfeffer,"Fluidization of nanopowders: a review", J Nanopart Res. at Springerlink.com, 2012.
[3] E.K. Levy, C.A. Herrera,"Bubbling characteristics of sound assisted fluidized beds", Powder Technology 119, pp. 229-240, 2001.
[4] U.S. Wankhede, R.L. Sonolikar, S.B.Thombre,"Effect of acoustic field of heat transfer in a sound assisted fluidized bed of fine powders", International Journal of Multiphase Flow 37, pp. 1227-1234, 2011.
[5] David R. Escuderot and Theodore J. Heindel,"Acoustic field effect on minimum fluidization velocity in a 3D fluidized bed", Proceedings of the ASME 2012, Fluids Engineering Summer Meeting, FEDSM2012, July 2012.
[6] P. Ammendola, R. Chirone,"Aeration and mixing behaviours of nano-sized powders under sound vibration", Powder Technology 201, pp. 49-56, 2010.
[7] S. Kaliyaperumal, S. Barghi, J. Zhu, L. Briens, S. Rohani,"Effect of acoustic vibration on nano and sub-micron powders fluidization", Powder Technology 210, pp.143-149, 2011.
[8] K. Hashizume,"An approach to develop a correlation for liquid-fluidized bed heat transfer", Chemical Engineering and Processing 45, pp. 990-1000, 2006.

[9] Chun-Hua Luo, Hiroyuki Hamano, Shigeyuki Uemiya, Toshinori Kojima,“Fluidization and surface to bed heat transfer coefficient in fluidized beds of very fine Ni and Ni-alloy powders”, Journalof Chemical Engineering of Japan, Vol. 31, No.1, pp. 95-102, 1998.

[10] Edward K. Levy, Ilan Shanitzer, Toru Masaki, John Salmento,“Effect of an acoustic field on bubbling in a gas fluidized bed”, Powder Technology 90, pp. 53-57, 1997.

[11] Qingjie Guo, Jian Zhang, Junyi Hao,“Flow characteristics in an acoustic bubbling fluidized bed at high temperature”, Chemical Engineering and Processing 50, pp. 331 -337, 2011.

[12] Ajbar, Y. Bakhbakhi, S. Ali, M. Asif,“Fluidization of nano-powders: Effect of sound vibration and premixing with group A particles”, Powder Technology 206, pp. 327- 337, 2011.

[13] Federica Rangati, Paol Ammendola and Riccardo Chirone, “Role of acoustic fields in promoting the gas-solid contact in a fluidized bed of fine particles”, KONA Powder and Particle Journal; Reiew paper.

[14] P. Russo, R.Chirone, L. Massimilla, S. Russo,“The influence of the frequency of acoustic waves on sound-assisted fluidization of beds of fine particles”, Powder Technology 82, pp.219-230, 1995.

[15] Qingjie Guo, Huie Liu, Wenzhong Shen, Xianghong Yan, Rugao Jia,“Influence of sound wave characteristics on fluidization behaviours of ultrafine particles”, Chemical Engineering Journal 119, pp. 1-9, 2006.

[16] Chongdian Si, Jing Zhou, Qingjie Guo,“Characterization of pressure fluctuation signals in an acoustic bubbling fluidized bed”, Journal of the Taiwan Institute of Chemical Engineers 42, pp. 929-936, 2011.

[17] Chunbao Xu,Yi Cheng, Jesse Zhu,“Fluidization of fine particles in a sound field and identification of groups C/A particles using acoustic waves”, Powder Technology 161, pp. 227-234, 2006.

[18] Li Wang, PingWu, Jing Yang, Xuezhi Ni,“Modelling of heat transfer between a high temperature fluidized bed and an immersed surface by a surface-particle-emulsion model”, Chemical Engineering Science 62, pp. 503-512, 2007.

[19] Y. Ma, J-X, Zhu, “Heat transfer between gas-solid suspension and immersed surface in an upflow fluidized bed (riser)”, Chemical Engineering Science 55, pp. 981-989, 2000.

[20] DeShau Huang and Edward Levy, “Heat transfer to fine powders in a bubbling fluidized bed with sound assistance”, American Institute of Chemical Engineers, AIChE Journal, Vol.50, No. 2.

[21] Chao Zhu, Guangliang Liu, Qun Yu, Robert Pfeffer, Rajesh N. Dave, Caroline H. Nam,“Sound assisted fluidization of nanoparticle agglomerates”, Powder Technology, 141, pp. 119-123, 2004.

[22] N. Hilal, M. A. Hastaoghu, M.C. Leaper and S.W. Kingman,“ The relationship between particle properties and fluidizing velocity during fluidized bed heat transfer”, Advanced Powder Technology, Vol. 15, No. 5, pp. 583-594, 2005.

[23] Ming-Yen Wey, Chiou-Liang Lin and Shr-Da You,“Fluidized behaviour and heat transfer in a bubbling fluidized bed incinerator”, Journal of Environmental Engineering and Management 17 (3), pp. 169-175, 2007.

[24] Balasim A. Abid, Jamal M. Ali, Ayar A. Alzubaidi,“ Heat transfer in a gas-solid fluidized bed with vaious heater inclinations”, International Journal of Heat and mass transfer 54 , pp. 2228-2233, 2004.