ATTRITION OF BED MATERIAL IN A RECIRCULATING FLUIDIZED BED

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by

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CERTIFICATE

This is to certify that the thesis entitled **"Attrition of Bed Material in a Recircularting Fluidized Bed"**, being submitted by **Ms. Shivali Chourasia**, to the **Indian Institute of Technology Delhi**, for the award of **'Doctor of Philosophy'** in Department of Civil Engineering is a record of the bonafide research work carried out by her under my supervision and guidance. She has fulfilled the requirements for the submission of this thesis, which to the best of my knowledge has reached the requisite standard.

The material contained in the thesis has not been submitted in part or full to any other University or Institute for the award of any other degree or diploma.

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ABSTRACT

The fluidized bed is one of the best known contacting methods used in the processing industry. Recirculating fluidized bed (RCFB) is a conventional gas-solid contactor widely used in process industries for drying, coating, catalytic conversion, combustion and gasification. Attrition is an essential concern in all types of fluidized bed operation. Attrition of solid particles caused by abrasion and fragmentation results in loss of bed material and influences the normal operation, functioning and performance of the fluidized bed reactors.

The objective of this study was the investigation of the attrition of sand particles (Geldart D) in a RCFB. The idea was to investigate the effects of various parameters like superficial air velocity of the fluidizing air, bed inventory and spacing between jet top and draft tube bottom (spacer height) on the attrition of bed material and their size distribution with increasing operation time and to propose a methodology to estimate the attrition of sand particles in a RFCB. The effects of attrition of bed material on the solid circulation rate was also investigated in detail.

Experiments were performed at ambient conditions, with superficial air velocity ranging from 7.13 m/s to 9.16 m/s, bed inventory of 7 kg to 10 kg, spacing of 0.085 m and 0.045 m between jet top and draft tube bottom for an operation time of 40 hours. Bed material was prepared from Indian Standard (IS) Grade I sand using sieves of size 2.2 mm and 1.0 mm. It was found that, with increasing operation time and other parameters (bed inventory, superficial air velocity, and spacer height), attrition of bed material was also increasing. Generation and elutriation of fines were significant at higher superficial air velocity, bed inventory and spacer height. Further, qualitative characterization was done through SEM for the confirmation of mode of attrition of

the particles. Mode of the attrition of particles was found to be abrasion rather than fragmentation.

Particles of the size less than 300 µm were found to be escaping from the reactor with the fluidizing air. This corresponds to the material loss due to the attrition of bed material during operation. The amount of the material lost after 40 hours of operation with the superficial air velocity of 9.16 m/s for 10 kg inventory was around 7.28% of the total bed inventory. For the same scenario, decreasing the superficial air velocity to 8.15 m/s brought down the material loss to about 6.88%.

Effects of attrition of bed material on the solid circulation rate were studied in detail. A mathematical model was developed on the basis of the experimental results to identify the effects of attrition of bed particles on the solid circulation rate incorporating the effects of the various operating and design parameters. To develop the model, dimensional analysis and nonlinear regression were used. The model equation was a nonlinear equation which implies the relationship between the solid circulation rate and the operating and design parameters. The model equation can estimate the solid circulation rate over a range of operation time and other parameters. Decrease in solid circulation rate with increasing operation time can be predicated, using this model equation.

A methodology was proposed to estimate the mass of fines generated in an RCFB by summing up separately the estimated fines generated in the downcomer (bubbling bed attrition) and in the draft tube (jet induced attrition). The total material loss obtained from the experimental results was compared with the mass of generated fines estimated using the models. The proposed methodology can be helpful in the scaling of RCFB reactor and to calculate the total material loss and fines generation in the reactor.

This study provides a detailed analysis of the attrition of sand particles in a recirculating fluidized bed and would help estimate the amount of material loss due to attrition of bed material.

Keywords: Fluidization, Attrition, Elutriation, Material loss, Solid circulation rate, Jet-induced attrition, Bubbling bed attrition

सार

प्रसंस्करण उद्योग में उपयोग किए जाने वाले सबसे प्रसिद्ध संपर्क तरीकों में से एक द्रवीकृत बैड है। द्रवीकृत बैड (आर.सी.एफ.बी.) पुनरावृत्ति एक पारंपरिक गैस-ठोस संपर्कक है, जो सूखने, कोटिंग, उत्प्रेरक रूपांतरण, दहन और गैसीकरण के लिए प्रक्रिया उद्योगों में व्यापक रूप से उपयोग किया जाता है। सभी प्रकार के द्रवयुक्त बेड ऑपरेशन में एट्रिशन एक अनिवार्य चिंता है। घर्षण और विखंडन के परिणामस्वरूप ठोस कणों का घूमना बैड सामग्री के नुकसान में होता है और सामान्य ऑपरेशन, कामकाज और द्रवयुक्त बैड रिएक्टरों के प्रदर्शन को प्रभावित करता है। इस अध्ययन का उद्देश्य आरसीएफबी में रेत कणों (गेल्डर्ट डी) के उन्मूलन की जांच थी। यह विचार विभिन्न मापदंडों के प्रभावों की जांच करना था जैसे द्रव वायु, बैड सामग्री और जेट शीर्ष और मसौदा ट्यूब तल (स्पेसर ऊँचाई) के बीच बैड सामग्री के उन्मूलन और उनके संचालन के समय में वृद्धि के साथ और आकार वितरण के बीच अंतर। एक आरएफसीबी में रेत के कणों के उन्मूलन का अनुमान लगाने के लिए एक पद्धति का प्रस्ताव ठोस परिसंचरण दर पर बैड सामग्री के टूटने का प्रभाव भी विस्तार से जांच की गई।

7.13 एम /एस से 9.16 एम /एस तक की सतही वायु वेग, 7 किलोग्राम से 10 किलोग्राम की बैड सूची, 0.085 मीटर और 0.045 मीटर की दूरी पर जेट शीर्ष के बीच की दूरी और एक ऑपरेशन समय 40 घंटे के लिए ड्राप ट्यूब के तल पर परिवेश की स्थिति पर प्रयोग किया गया। बैड सामग्री 2.2 मिमी और 1.0 मिमी आकार के चलनी के जरिये भारतीय मानक (आईएस) ग्रेड I रेत से तैयार की गई थी। यह पाया गया कि, बढ़ते संचालन के समय और अन्य मापदंडों (बैड सामग्री की मात्रा, सतही वायु वेग और स्पेसर ऊँचाई) के साथ, बैड सामग्री के उन्मूलन भी बढ़ रहे थे। इसके अलावा, कणों के उन्मूलन की स्थिति की पुष्टि के लिए ऐस.इ. म. के माध्यम से गुणात्मक लक्षण वर्णन किया गया। कणों के उन्मूलन का मोड विखंडन की बजाय घर्षण पाया गया।

फ्लूइडिंग वायु के साथ रिएक्टर से 300 माइक्रोग्राम से कम आकार के कणों को भागने में पाया गया। यह ऑपरेशन के दौरान बैड सामग्री के घृणा के कारण सामग्री के नुकसान से मेल खाती है। 10 किलो इन्वेंट्री के लिए 9.16 एम /एस के सतही वायु वेग के साथ ऑपरेशन के 40 घंटों के बाद खो जाने वाली सामग्री की मात्रा कुल बिस्तरों की सूची का 7.28% थी। इसी परिदृश्य के लिए, सतही वायु वेग में 8.15 एम /एस की कमी से सामग्री हानि को लगभग 6.88% कम कर दिया गया।

ठोस परिसंचरण दर पर बेड सामग्री के घृणा का प्रभाव विस्तार से अध्ययन किया गया। विभिन्न ऑपरेटिंग और डिजाइन मापदंडों के प्रभाव को शामिल करने वाले ठोस परिसंचरण दर पर बैड कणों के घृणा के प्रभावों की पहचान करने के लिए प्रयोगात्मक परिणामों के आधार पर एक गणितीय मॉडल विकसित किया गया था। मॉडल विकसित करने के लिए, आयामी विश्लेषण और गैर-रेखीय प्रतिगमन का इस्तेमाल किया गया था। मॉडल समीकरण एक गैर-रेखीय समीकरण था, जिसका मतलब है कि ठोस परिसंचरण दर और संचालन और डिजाइन पैरामीटर के बीच संबंध। मॉडल समीकरण ऑपरेशन समय और अन्य मापदंडों की एक श्रृंखला पर ठोस परिसंचरण दर का अनुमान

लगा सकता है। इस मॉडल समीकरण का उपयोग करते हुए, बढ़ते संचालन के समय के साथ ठोस परिसंचरण दर में कमी की जा सकती है।

डाउनॉमर (बब्लिंग बैड के उन्मूलन) में उत्पन्न अनुमानित महीन कढ़ और मसौदा ट्यूब (जेट प्रेरित उन्मुक्ति) में एक आरसीएफबी में उत्पन्न महीन कढ़ के द्रव्यमान का अनुमान लगाने के लिए एक पद्धति का प्रस्ताव किया गया था। प्रयोगात्मक परिणामों से प्राप्त कुल भौतिक हानि की तुलना मॉडल के उपयोग के अनुमानित जननुमा के द्रव्यमान से की गई थी। प्रस्तावित पद्धति आरसीएफबी रिएक्टर के स्केलिंग में सहायक हो सकती है और रिएक्टर में कुल भौतिक हानि और महीन कढ़ की गणना करने के लिए।

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NOMENCLATURE

ρ_p	Density of the jet gas
n_{or}	Number of orifices in the distributor
U_p	Average velocity of the particle in downcomer
K_j	Constant that characterizes the solids susceptibility to abrasion
D_{p1}	Final diameter of the particle
U_{or}	Jet gas velocity inside an orifice
D_p	Surface mean diameter of the bed solids
ΔP	Pressure drop in downcomer
μ	Viscosity of the fluidizing air
a, b, c	Model parameter
A_d	Area of downcomer
A_r	Area of riser tube
CFB	Circulating Fluidized Bed
C_c	Coefficient of curvature
C_j	Particle-size independent material specific constant
C_u	Coefficient of uniformity
D_0	Diameter of fine particles obtained after collision
d_{or}	Diameter of the orifices
d_p	Diameter of particle
D_{p1}	Diameter of initial sand particles in the bed
e	Voidage
e_d	Operating voidage in downcomer
Ep	Young’s modulus of sand particle
e_r	Operating voidage in riser tube
FCC	Fluid Catalytic Cracking
f_p	Collision frequency of the particle
H_{dt}	Operating height of spout for respect to perforated plate

H_s	Height of the bed in the riser when the air flow was suddenly cut off
i	Bed inventory
k	Coefficient of restitution for particle-particle collision
K_b	Attrition rate constant of bubbling fluidized bed
L'	Height of solid bed in downcomer
M	Constant
$m_{att,b}$	Mass attrition in dense zone
$m_{att,total}$	Material loss after operation time t
RCFB	Recirculating Fluidized Bed
SEM	Scanning Electron Microscope
t	Operation time
U_{fd}	Actual velocity of air in the downcomer
U_{pd}	Particle velocity in the downcomer
U_{pr}	Particle velocity in the riser tube
v	Superficial air velocity
W_s	Solid circulation rate
w_i	Weight of particles retained on i^{th} sieve
x	Spacing between jet top and riser tube bottom (Spacer height)
x_i	Diameter of i^{th} sieve
η	Proportion of dissipation energy cumulated to give rise to attrition
σ_p	Yield strength of sand particle
ϕ_p	Sphericity factor for sand particle

Greek Symbol

ρ	Density
л$_1$, л$_2$, л$_3$	Dimensionless variables
λ, ϕ	Functions

Subscript

D	Downcomer
p	Particle
r	Riser tube
s	Solid