PERFORMANCE CHAR… …TOR DESIGNS IN A

FLUIDIZED BED

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LIST OF SYMBOLS

A	surface area, m^2
d	diameter, m
$\bar{d}$	mean particle diameter, m
D	fluidized bed diameter, m
f	friction factor, [-]
F	kinetic force, $\frac{1}{2}mv^2$
H	length, m
K	a characteristic kinetic energy per unit volume, $\frac{1}{2}\rho v^2.m$
l	slot diameter, m
M	mass of bed materials, kg
N	number of orifices [-]
n	number of inclined slots, [-]
ΔP	pressure drop, Pa
p	pressure, Pa
Q	flow rate, m^3/s
Re	Reynolds number, [-]
Re_m	modified Reynolds number, [-]
Re_1	modified Reynolds number, [-]
S	surface area per unit volume, m^{-1}
t	distributor thickness, m
T	temperature, °C
U	air velocity, m/s
V	tangential air velocity, m/s

LIST OF SYMBOLS

$\bar{V}$	volume of bed, m^3
x	length, m
Δz	plate thickness, m
ε	void fraction, [-]
μ	air viscosity, $Pa.s$
ρ	density, kg/m^3
θ	distributor inclination angle, [-]
$\emptyset$	sphericity, [-]

LIST OF ABBREVIATIONS

CFD	Computational Fluid Dynamics
CI	Confidence Interval
DEM	Discrete Element Method
FBC	Fluidized Bed Combustion
FVM	Finite Volume Method
MRI	Magnetic Resonance Imaging
PEPT	Positron Emission Particle Tracking
PBM	Population Balance Model
PVC	Polyvinyl Chloride
RSM	Response Surface Methodology
SEM	Scanning Electron Microscope
SFBC	Swirling Fluidized Bed Combustor
SIMPLE	Semi-Implicit Method for Pressure Linked Equations
SMD	Sintered Metal Distributor
SSV	Solid Stack Volume
SVF	Solid Volume Fraction
UI	Uniformity Index

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ABSTRAK

Perbezaan tekanan tinggi yang dihasilkan oleh pengedar udara untuk mengalirkan udara ke dalam relau pembakar terbendalir adalah suatu masalah pada rekaan pengedar udara masa kini. Selain itu, alat pengacau mekanikal dan pengedar udara berpusing digunakan untuk meningkatkan pergerakan di dalam relau. Oleh itu, untuk mengurangkan kos dan tenaga dari penggunaan pembekal angin berkapasiti tinggi, rekaan terbaru pengedar udara yang mempunyai perbezaan tekanan yang rendah adalah diperlukan. Kajian ini bertujuan untuk menyiasat kitaran angin dan hidrodinamik di dalam relau terbendalir secara simulasi dan eksperimen. Rekaan pada pengedar udara yang konvensional diolah supaya sesuai digunakan bersama pembekal udara bertekanan rendah. Enam pengedar udara –konvensional dan baharu; diuji di dalam gelas relau terbendalir yang berdiameter 108 mm untuk tujuan eksperimen dan simulasi. Pengedar udara konvensional adalah terdiri daripada pengedar berlubang sekata dan berlubang jet. Manakala pengedar udara yang baharu mempunyai bilah kecondongan pengaliran udara yang berbeza pada sudut: 90°, 67°, 45° and 30°. Ujikaji bersama pasir dijalankan untuk menguji interaksi antara pasir dan udara yang dihasilkan dari pengedar udara. Dalam ujikaji ini, pasir dari kumpulan B *Geldart* jenis alumina bersaiz 177 μm and 520 μm dan pasir sungai bersaiz 543 μm and 756 μm digunakan. Simulasi menggunakan model *RNG k-ε turbulent* menunjukkan apabila bilah kecondongan pengedar udara berada pada sudut 67°, 45° and 30°, pusaran angin berpusar dihasilkan oleh pengedar udara. Pusaran angin yang dihasilkan dalam simulasi ini menunjukkan ruang udara tidak aktif yang dihasilkan oleh pengedar udara konvensional, berjaya disingkirkan. Pada kadar *H/D*= 0.4 dan 0.5, perbezaan tekanan yang dihasilkan oleh kehadiran pasir didalam gelas relau terbendalir menunjukkan penurunan apabila menggunakan pengedar udara 90°. Sebaliknya perbezaan tekanan tinggi dilihat pada pengedar udara konvensional berlubang sekata. Sementara itu, peningkatan perbezaan tekanan dilihat sedikit tinggi pada pengedar udara bersudut 67°, 45° and 30° jika dibandingkan dengan pengedar udara 90°. Selain itu, kelajuan minimum udara untuk menjadikan pasir terbendalir didalam gelas relau dilihat berlaku awal pada pengedar udara 30° dan 67°. Ini menunjukkan ketebendaliran berlaku pada kadar angin yang rendah dengan menggunakan pengedar udara ini. Pusaran angin berterusan dan pergerakan berbuih didapati berlaku di bahagian bawah dan juga bahagian atas gelas relau dengan menggunakan pengedar udara 67°, 45° and 30°. Kadar pergerakan pasir didalam relau dilihat bergantung kepada saiz dan bentuk pasir dimana kadar pergerakan yang laju terhasil dengan menggunakan pasir yang halus manakala pergerakan pasir yang lebih stabil terjadi jika pasir yang lebih kasar digunakan. Keseragaman penyebaran udara dihasilkan oleh semua pengedar udara kecuali pada jenis pengedar berlubang sekata. Selain itu, kecekapan pengedar udara diuji dengan kebolehan kesamarataan penyebaran suhu. Korelasi baharu dicipta berdasarkan korelasi *Forchheimer-Ergun* dengan mengambil kira bentuk dan rekaan pengedar udara. Jangkaan dengan kadar ralat 9% dihasilkan antara korelasi baharu dan data ujikasi. Oleh itu, dengan kelebihan yang ditunjukkan oleh pengedar udara 67° berbanding pengedar konvensional, pengedar udara 67° dicadangkan untuk digunakan didalam relau terbakar terbendalir kerana beroperasi pada perbezaan tekanan yang rendah dan terbukti meningkatkan pergerakan pasir di dalam relau.

ABSTRACT

High pressure drop across the distributor for fluidizing air supply to the bed is one of major draw backs of the current air distributor designs. Besides, the mechanically assisted agitator and rotating distributor were installed to improve mixing inside the bed. Therefore, in order to minimize the cost of using high capacity blower as well as to reduce the energy, viable design of air distributors that can contribute to low pressure drop and improved particulate mixing in fluidized bed are essential. The present study aims to numerically and experimentally investigate the flow patterns and hydrodynamics in a fluidized bed operated with different configuration of distributors. The optimum mode of operation and the parameters that contribute to low pressure drop and improved particulate mixing in a fluidized bed is identified. The commonly used distributor designs are modified to suit in the fluidization operation with a low pressure blower. A fluidized bed column of 108 mm in diameter with six different air distributors; conventional perforated plate, multi-nozzles, and newly proposed slotted distributors with inclination angles of 90°, 67°, 45° and 30° are used in the simulations and experiment. In this study, 177 μm and 520 μm alumina and, 543 μm and 756 μm river sands categorized in Geldart Group B particle are used to investigate the hydrodynamics of gas-solid fluidization. The numerical simulations by using the Re-Normalisation Group (RNG) k-ε turbulent model show that when the inflow direction of the fluidizing air is inclined at 67°, 45° and 30° through the distributor slots, air flow pattern inside the bed is shown to produce swirling motion in a vicinity of the distributors. Also, the induced swirling air motion eliminates major dead zone regions. Experiment with bed materials show that at aspect ratio H/D=0.4 and 0.5, the bed pressure drop is observed to be the lowest in the fluidized beds operated by 90° distributor and highest by the perforated plate distributor. Considerable increment of bed pressure drop is observed by 67°, 45° and 30° distributors as compared to 90°. Interestingly, the minimum fluidization velocity is observed to take place promptly in a fluidized bed operated by 30° and 67° distributors. In other words, the fluidization occurred at low air flow rate in a bed operated by these inclined distributors. A continuous swirling bottom layer and a vigorously bubbling top layer are visible in a fluidized bed operated by 67°, 45° and 30° distributors. The degree of mixing is found to be influenced by the size and shape of bed materials in which intense mixing is observed by the fine bed and more stable mixing is spotted by the coarser bed. For all distributors, the distributor to bed pressure drop ratio is found to fall within the range of uniform operation of fluidization; except for the operation by using perforated plate distributor. The performance of the distributors is further assessed in terms of temperature distribution in the bubbling fluidization regime by using 67° and perforated distributors. Finally, a new pressure drop correlation is developed based on the Forchheimer-Ergun equation that takes into account the design parameter of the distributors with different inclination angles and different types of bed materials. The constants obtained through the regression analysis provided excellent predictions to the experimental data with maximum average error of 9%. In conclusion, a novel inclined 67° distributor is proposed as a new distributor for FBC due to lower pressure drop operation and improved particulate mixing as compared to conventional type distributors. This research finding could contribute to higher application of the fluidized bed technology, particularly in Malaysia where fluidized bed technology is still not popularly used in power generation plant using biomass as solid fuel.

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