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Mechanical Impact Erosion Evaluation of Fluidized Bed Reactor: Oil Shale Particle Case

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ABSTRACT

In this paper, we are interested in experimental evaluation of particle attrition due to mechanical impact by solid particles in laboratory bubbling fluidized bed reactor. An experimental methodology is presented to estimate the erosion in fluidized bed reactor due to mechanical impact. The fluidized bed erosion power by this impact was evaluated by integrating all the contributions of measured particle mass loss inside the bed. The case of oil shale particle was used to undergo silica sand particles impact in laboratory fluidized bed system.

Keywords: attrition, shale, impact, fluidized bed, erosion

INTRODUCTION

The fluidized bed reactor performance is closely linked to the physical and chemical operating parameters. The issue of solid particle attrition has surfaced as serious problem.The multiple particles collisions enhance these undesired phenomena. Generations of small particles and dust particles causes fluidized bed structure modification and disturbs the fluidization regime. Attrition process generally referred to the mechanisms that produce small size particle from the parent particles. Erosion of particles by impact is a complex process sensible to bed velocity, shape and particle size, mechanicals properties of target and solid particles. Chemical reactivity of the solid particles increases or decreases the hardness and the fragility of the bed material. Several studies D. Merrick and J. Highley (1), W.G. Vaux (2), U. Arena et *Al.* (3) have concentrated their search on this problem and have set out models in order to account the estimation of the attrition and fragmentation. Y. Ray et *Al.* (4). Fluidization technology was used successfully in combustion of solid particles. In energy conversion systems using particulates as the primary fuel, the combustion of particle flows is critical to the development of these systems. Actual industry utilization of oil shale concerns mainly burning as power fuel in fluidized bed boiler A, Martins (5) and Xiangxin Han *et al* (6) and X.M. Jiang, *et al*. (7). In such reactor the interaction between solid particles generates fragments (chipping and splitting) and fines during the process of combustion and pyrolysis. Fluidized bed combustion (FBC) can efficiently utilize solid fuels like oil shale which are difficult to burn if using other combustion technology. In FBC system the shale particle fragmentation and attrition occur and their proportion depend on their chemical reactivity and on the reacted shell formed on the particle surface, A. Bouhafid and J.P Vantelon (8). The literature shows various discrepancies regarding the origin of fine particles formation in fluidized bed combustor. In order to achieve a good understanding of the oil shale attrition process, a particular concern in this study is the distinctness of the erosion due mechanical impact in fluidized bed which is a relevant to the design of FBC boiler. The impact effect is measured experimentally in the case of oil shale particle processed in fluidized bed filled with silica material. The experimental test allows the evaluation of operating conditions (fluidized bed velocity and material, target material, temperature..) on the total power of bed erosion by direct impact.

EXPERIMENTAL METHOD

Apparatus

A circular Pyrex glass atmospheric bubbling fluidized bed column with 4.8 cm in diameter and 100 cm in height was used for all the experiments as depicted in Fig. 1. A perforated steel plate with 118 perforations disposed in triangular pitch was used as distributor. Air was used as gas of fluidization. It was dried in a glass tube filled with zeolith to avoid humidity adsorption by bed material. Experiments were performed at ambient temperature. The air flow rate was measured by volumetric flow meter. Bed material consists of 200 g of granular silica particle with 0.5 – 0.63 mm in diameter. Density of sand material is 2.3 g/cm^3. At the start of each experiment, the solid shale particle (diameter 2.5-3 mm) was weighed and attached in the extremity of rigid stainless thin rod and positioned at different positions inside the fluidized bed. Another set of measures of shale particle moving freely in the silica bed were performed. The corresponding mass loss is compared to mass loss by mechanical impact inside the bed. Minimum fluidized bed velocity U_{mf} was measured by the pressure drop method: U_{mf} = 27.6 cm/s. Fluidized bed velocity varies from 1.5 U_{mf} to 2.5 U_{mf}. Measurements were made for the following radial positions: 0, 0.7, 1.4 and 2.1 cm.

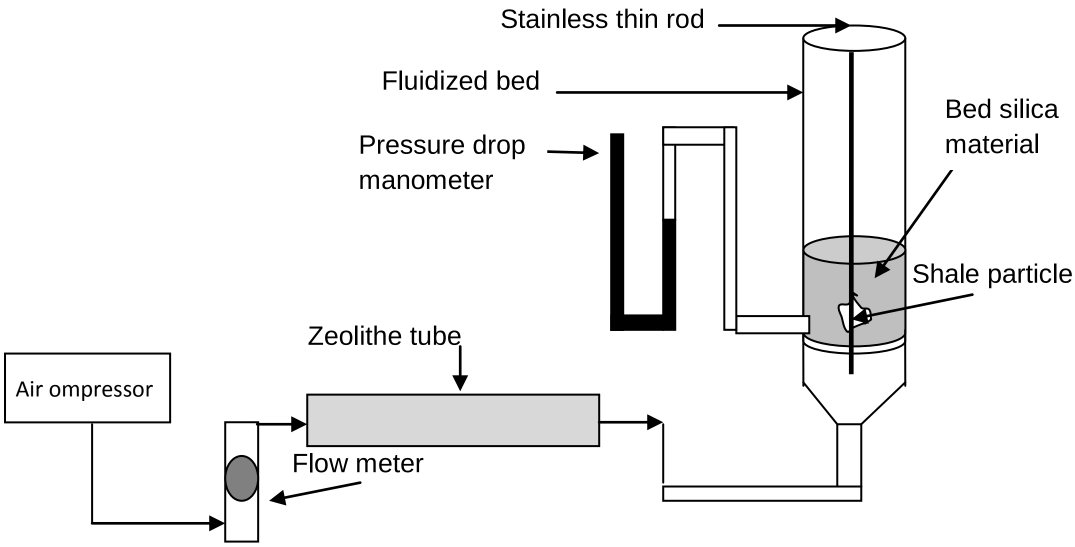


Fig.1. Schematic diagram of impact test system

Material

The R2B2 oil shale seams was ground and sieved to prepare the initial size fractions. The ultimate analyses (wt.) give carbon 15.5, hydrogen 1.17, nitrogen 0.28, oxygen 23.65, and sulphur 1.6. The lower heating value of the oil shale is 3386 kcal/kg, and the shale density 2.1 g/cm^3. Mineral matter and organic matter represent 15% and 85% of weigh respectively. Total CO_2 evolved at 900°C is approximately 22% of total solid particle weigh. Oil shale and ash analysis of Tarfaya oil shale R2B2 deposit is presented in table 1. Calcite and dolomite are the main minerals in the carbonate constituents of oil shale.

Composition analysis	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	SO_3	K_2O	Na_2O	P_2O_5	TiO_2	Others
Shale chemical analysis	6.25	0.83	0.54	40.42	0.41	3.43	0.05	0.10	0.08	0.05	1.67
Ash chemical analysis	11.61	1.55	1	75.08	0.76	6.38	0.09	0.19	0.15	0.09	3.10

Table 1: Oil shale and ash analysis, (wt.%) Tarfaya R2B2 deposit

EXPERIMENTAL RESULTS

In all the figures we report the instantaneous particle weight loss caused by silica particles impact for the distances along the bed axis. This representation describes better the flow pattern of bed behavior. Figures 2-5 Show the extent of particle mass loss (wt.%) in different positions inside the bed for different processing times. (wt.% = $(m_0 - m)/m_0$, m_0 is the initial particle mass and m the particle masse at time t). All the shale particles tested were rounded and abraded on their external surface and no fragment was formed. Only gradual wearing away of particle's surface occurs. Theses illustrations give a response and information about what occurs in the sense of erosion by impact at an instant t at a fixed point in the bubbling medium in the reactor. As it can be seen the impact effect is more pronounced for bed velocity of $2U_{mf}$. The %wt. of particle shale loss due to repeated impact by small solid particles varies inside the fluidized bed. Each plot of these figures is divided into two or three regions. At low fluidized bed velocity, U=1.5 U_{mf}, bed height 13.1 cm, the axial region is more active if compared to the region near the wall of the reactor.

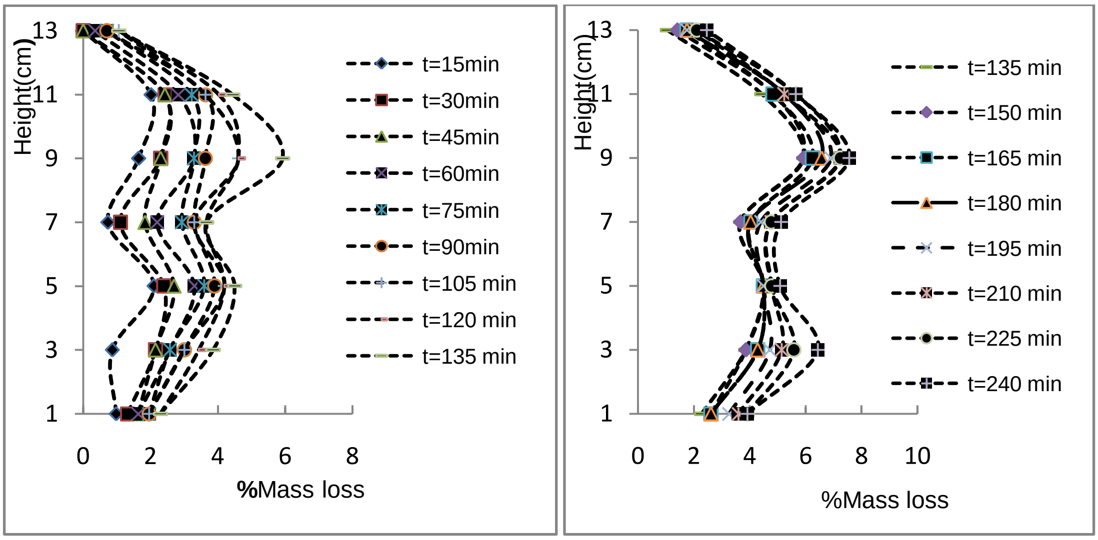


Fig. 2: Shale particle mass loss along the bed axis, r = 0 cm, at different fluidization times (U= 1.5 U_{mf})

There are two zones along the bed axis where the maximum erosion by impact takes place: at distance of 3 cm and 9 cm from the distributor. A low emission levels is observed a long the bed axis in zones at 3 cm and 7 cm above the distributor. Near the bed wall the mass loss lies between 1.5% to about 4.5% for all the experienced times. The largest amount of material emitted by abrasion was obtained from the experiment in the case where fluidized bed velocity is 2 U_{mf} and bed height of 21.2 cm. The impact effect is more detectable and the fluidization behavior of the bed material is more turbulent. At the top of the central bed axis, the fluidize bed impact trend to decrease in the case of 1.5 U_{mf} bed velocity unlike the case of 2 U_{mf} where the impact is more relevant. Away from the bed axis the impact activity is more pronounced over the entire fluidized bed top area which suggests that dispersion of solid bed material by mixing occurs in the entire fluidized bed.

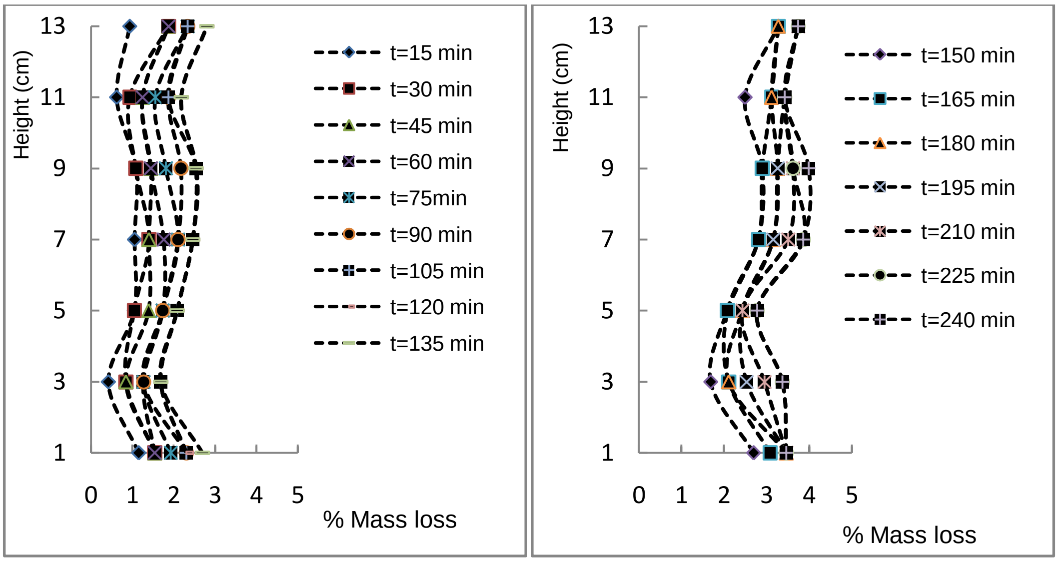


Fig.3: Shale particle mass loss along the axis r = 2.1 cm for different fluidization times and U= 1.5 U_{mf}

The mass loss by impact by collision can exceed by a factor of two the mass loss of freely moving shale particle in the bed Fig.6 (a) and (b).

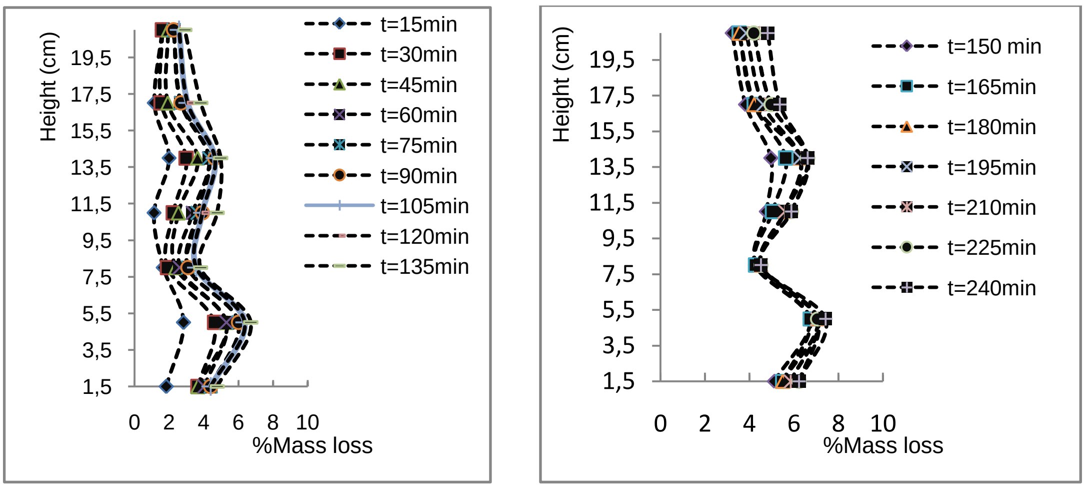


Fig.4: Shale particle mass loss along the bed axis r = 0 cm for different fluidization times and U= 2 U_{mf}

Morphology of the outer surface of the solid shale particle changes with time and the irregularities on the surface were abraded away.

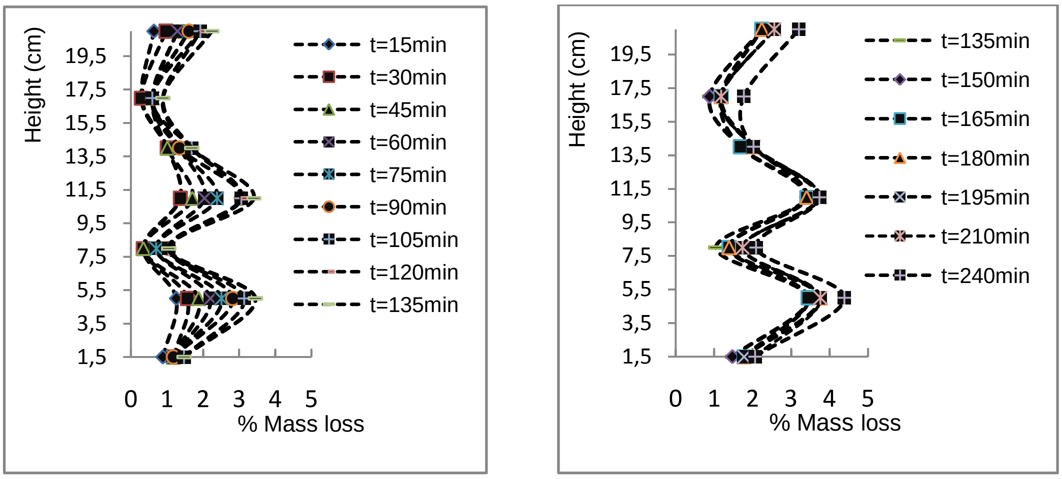


Fig.5: Shale particle mass loss along the axis r = 2.1 cm for different fluidization times and U= 2 U_{mf}

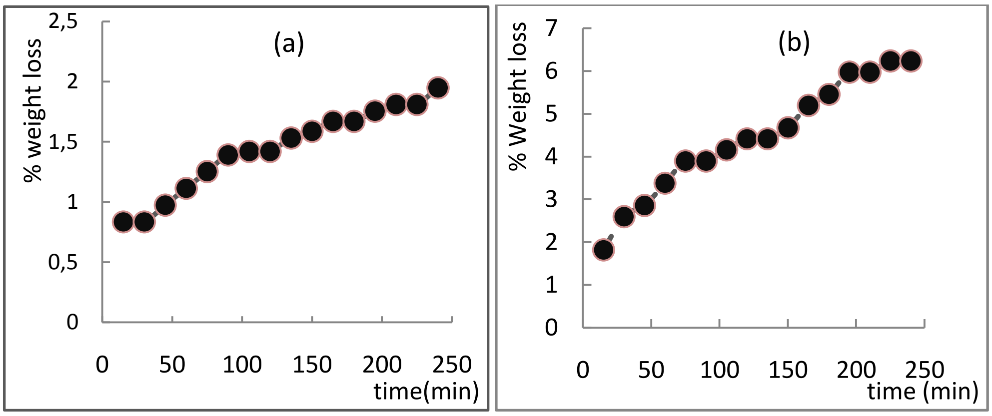


Fig.6: Shale particle weight loss moving freely in the bed, (a): U= 1.5 U_{mf} and (b) U=2U_{mf}

MECHANICAL IMPACT POWER EROSION EVALUATION

Let $P^{(t)}$ denote the total mechanical impact erosion power of the fluidized bed at time t. It is related to the total fraction mass loss in the fluidized bed by impacting process. By supposing the cylindrical symmetry the evaluation of $P^{(t)}$ is as follow for a fluidized bed velocity U .For each circle with radius r_j and located at height h_i the number of solid particles with average diameter d that can be ranged along the circumference of the circle is$2\pi r_j/d$. The number of particles that can be lined along a height H is $2\pi r_j/H$. The mass lost due to impact at time (t) in this position (r_j, h_i) is $\delta P_{ij}^{(t)} = X_{ij}^{(t)} = m_0 - m_{ij}^{(t)}$. The initial particle mass m_0 is related to the mass loss $m_{ij}^{(t)}$ by the extent mass loss defined by: $\varphi_{ij}^{(t)} = \frac{m_0 - m_{ij}^{(t)}}{m_0} = \frac{X_{ij}^{(t)}}{m_0}$.

For a cylinder C with radius r_j we can evaluate the impact effect of the bed material by summing all the mass detached of each particle in this circle with rayon r_j:

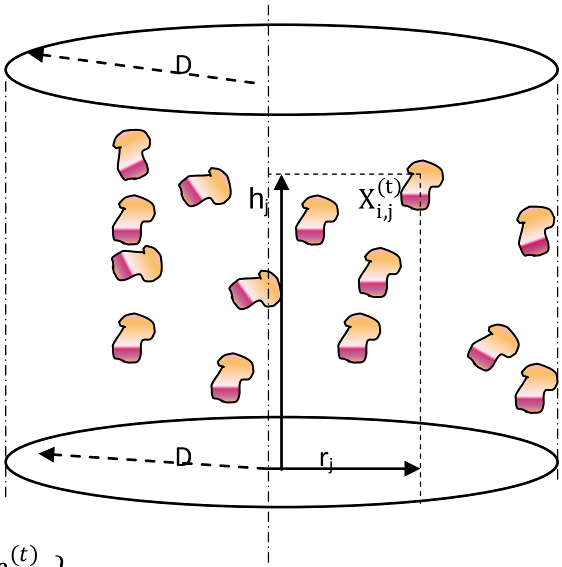
$$\xi_{rj} = \iint_C \delta P_{ij}^{(t)} = \sum_{i=1}^{i=n} X_{ij}^{(t)} \frac{2\pi r_j}{d} = \frac{2\pi r_j}{d} \sum_{i=1}^{i=n} X_{ij}^{(t)}$$

For r = r_1 , $\xi_{r1} = \sum_{i=1}^{i=n} X_{i1}^{(t)} \frac{2\pi r_1}{d} = \frac{2\pi r_1}{d} \sum_{i=1}^{i=n} X_{i1}^{(t)}$ and for r = r_2 ,$\xi_{r2} = \frac{2\pi r_2}{d} \sum_{i=1}^{i=n} X_{i2}^{(t)}$

and for the radius r_m = D/2 – d/2 with D fluidized bed diameter:

$\xi_{rm} = \frac{2\pi r_n}{d} \sum_{i=1}^{i=n} X_{im}^{(t)}$.

Therefore, if the volume of the operating fluidized bed is V**,** the total erosion bed capacity at time t is:



$$P^{(t)} = \iiint_V \delta P_{ij}^{(t)}$$
$$= \xi_{r1} + \xi_{r2} + \dots + \xi_{rn} = \sum_{j=1}^{m} \xi_{rj}$$

$$P^{(t)} = \sum_{j=1}^{j=m} \{ (\frac{2\pi r_j}{d})(\sum_{i=1}^{i=n} X_{ij}^{(t)}) \}$$

$$P^{(t)} = \iiint_V \delta P_{ij}^{(t)} = \sum_{j=1}^{j=m} \{ (\frac{2\pi r_j}{d})(\sum_{i=1}^{i=n} m_0 \varphi_{ij}^{(t)} \}$$

The contribution of particles which are on the surface of cylindre with radius r_j to the total bed erosion by mechanical impact is:

$$Q_{rj}^{(t)} = \frac{\xi_{rj}}{P^{(t)}} = \frac{\iint_C \delta P_{ij}^{(t)}}{\iiint_V \delta P_{ij}^{(t)}} = \frac{\frac{2\pi r_j}{d} \ m_0 \varphi_{ij}^{(t)}}{\sum_{j=1}^{j=m} \{ (\frac{2\pi r_j}{d})(\sum_{i=1}^{i=n} \ m_0 \ \varphi_{ij}^{(t)} \}}$$

All calculations were made using spreadsheet software (Microsoft EXCEL). Fig. 7 reports the total bed power erosion during the process of fluidization. Such process generates a steady rate of mass loss after 75 minutes of fluidization. It is a typical profile of attrition reported in literature and proves that the measurements presented by impact effect contribute to the effective mass loss by attrition process. The share of particles which are on a cylinder with radius r to the total power erosion is presented on Fig. 8 and Fig.9 for the fluidized bed velocity tested in these experiments. It can be seen in Fig.8 that during the first time of fluidization (t<15 min.), the contribution is more relevant by the vertical surface of the cylinder with radius 1 cm. The minimum impact is measured near the lateral reactor surface (r ≈ 2.1cm). After this time the maximum contribution comes continuously from the particle located inside the volume delimited on the outside by the cylinder r=1.6 cm and on the inside by the cylinder r= 2.1 cm.

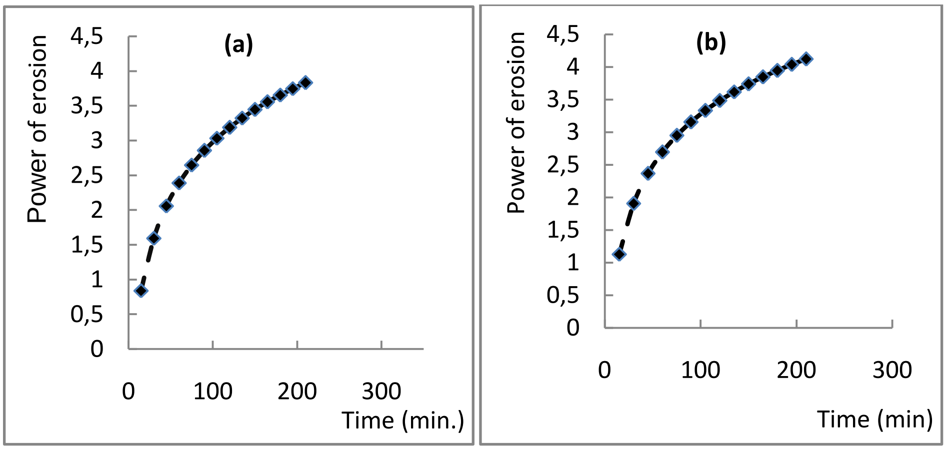


Fig. 7: Evolution of power impact erosion of fluidized bed at different times, (a) U= 1.5U_{mf} and (b) U=2 U_{mf}

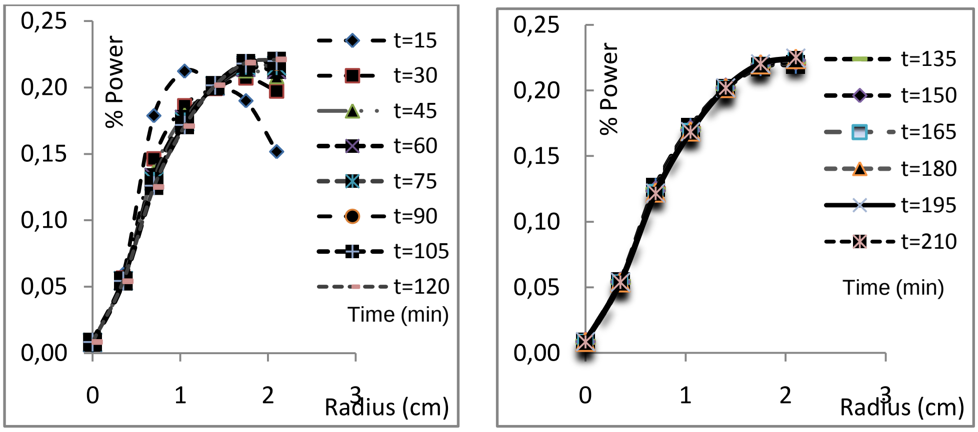


Fig.8: Contribution of particles on surface of cylinder with radius r to the total power of erosion during the fluidization process, U = 1.5Umf

In Fig.9 we can see that the contribution is the same for all the inners cylindrical surfaces of the bed. The part of the overall surfaces remains constant during the time of fluidization. The more active region is in space around the cylinder with radius 1.4 cm. Turbulence emanating from solid particles movement is the source of the uniform impact distribution inside the bed. However impact effect is reduced near the bed wall by a factor of 20% if compared to the maximum mass loss. The low impact activity is found around the bed axis in a volume with radius of 1 cm.

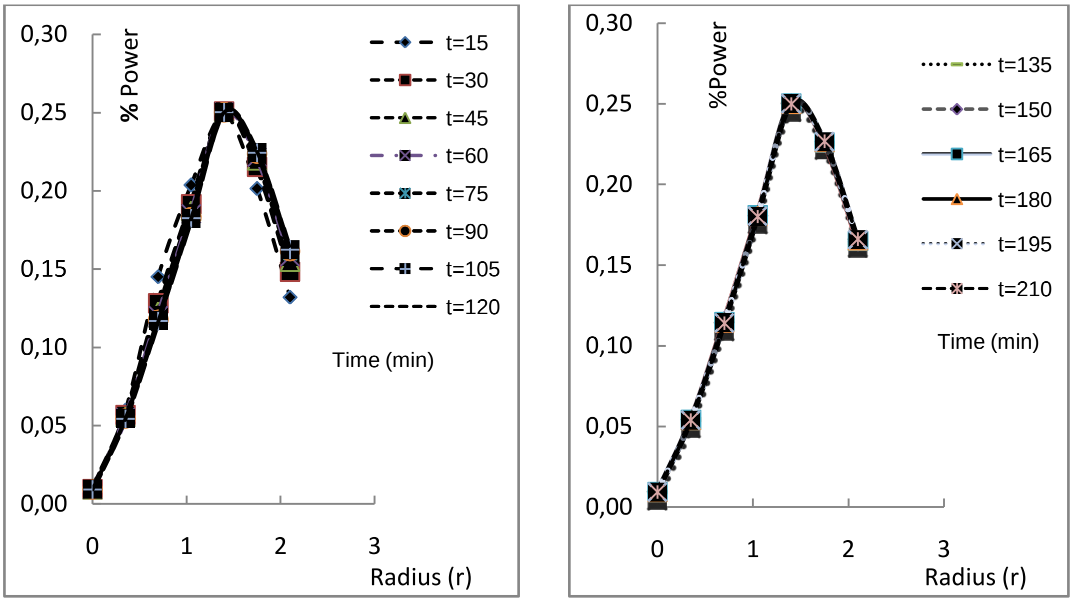


Fig.9: Contribution of particles on surface of cylinder with radius r to the total power of erosion during the fluidization process, U = 2Umf

CONCLUSION

The following conclusions can be made from this work to evaluate the erosion caused by mechanical impact in fluidized bed reactor operated at 0.44 m/s and 0.55 m/s. Impact effect varies with the local position inside the bed. Erosion by only impact exceeds global particle attrition in the case of oil shale particle. This is not to say that other factors do not influence the particle surface abrasion. It can act as determining factor once the solid particle is submitted directly to mechanical impact. Perspective of this work is to show the chemical reaction and temperature effect on the erosion by impact, work on which we are also conducting experiments and will be finished shortly. The experimental test for erosion by impact developed will be used to improve our knowledge on fluidized bed attrition. Next model development will take into account the effect of particle size distribution inside the bed.

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