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AN INVESTIGATION OF GRANULAR MATERIAL MOVEMENT DUE TO INSTABILITY POST IMPINGING UPWARD FLUID

Granular is a form of material that is widely used in the industry. To move the granular material, energy is needed to form a flow of granular. Granular instability can be utilized to move granular material. Prevention of jamming and clogging is done by breaking down the parts of the granular, which are locking. Impinging fluid in the granular is used to create granular instability. An observation was made using the experimental method. The granular in the Hele-Shaw cell is shot with fluid in the granular body and results in instability motion. Fluid impinging breaks granular bonds and forms fluid cavities. Furthermore, the fluid cavity moves upward due to unstable conditions. Granular with a strong bond is loose in the form of the agglomerate. Agglomerate is destroyed in the process of moving because there is a drag force. Granular with weak bonds tries to maintain individually form fingering. Granular moves down in the settling process to find a stable position. Instability is affected by the bonds between the grains. A comparison between the cohesion force and the mass weight of the particles is expressed as a granular Bond number B_{og}. In glass sand material, strong granular bonds occur at granular sizes below 100 μm. Granular bonds affect the movement of instability in groups. The value of the granular Bond number is greater than 1. At sizes of 100 to 230 μm, the granular bond still affects the granular instability with the fingering pattern in the granular motion. The value of the granular Bond number is close to 1. Granular sizes above 230 μm indicate the presence of non-dominant bonds between the grains. The individual granular mass is higher than the cohesion force that occurs at the interface between the granular, and the granular Bond number value is less than 1

Keywords: granular material, instability, impinging, upward flow, Bond number, fluidization, cavity fluid

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1. Introduction

Granular is a form of material that is very widely used in various industrial processes. The handling of granular material is needed to produce various products in the industry. The lack of standardized work for the industry according to the flowability assessment of powders and grains indicates the need for a methodology capable of observing actual handling conditions. Material flow ability needs to be observed to support the work process [1]. The flowability of granular materials plays an important role in production and processing because it defines the quality of the product [2]. Although widely used, a complete description of granular systems and property dynamics is still largely not yet explained. The industry needs a method that can be done that is simple and reproducible. Industrial practitioners and academics undertake studies to seek a more precise fundamental understanding of the physical mechanisms that govern the flow [3]. A better understanding of granular flow makes a valuable contribution to many industrial applications. The handling of granular material includes transportation, mixing, separation, filtering, and chemical reactions. The material handling process often requires conditions of granular instability to move the granular. Stability must often be eliminated, as in the case of jamming and clogging in the transportation process so, the material can run. To open the clogging is often done by mechanical vibration. The granular instability process can be carried out by the method of providing granular or fluid material with the Rayleigh-Taylor instability concept.

Rayleigh-Taylor instability is an instability that occurs at the confluence of two fluid surfaces that have different densities. The instability process occurs when two fluid surfaces rush in the interface and form fingering. High-density fluid drives low-density fluid so there is movement in the interface area of the two fluids to create certain stability. The granular fluid interaction produces a concentration. Low viscosity suspensions replace high concentration, and high viscosity suspensions and are unstable because of the instability mechanism [4]. The instability in interactions between fluids can develop in several forms [5]. The granular movement process is started with internal fluidization. Localized fluidization in a moving granular medium is affected by the flow rate of the fluid [6].

The research is needed because granular behavior varies, every type of granular has different characteristics. Designing granular handling equipment requires a thorough understanding of the mechanical behavior of grains. Knowledge of granular motion dynamics is required to handle industrial processes.

2. Literature review and problem statement

Research on granular instability motion develops to take advantage of natural phenomena in industrial processes. Researchers have studied the motion of granular instability. The mixture between granular material and fluid which forms the fluidization produces a density that is different from static granular material. The meeting of two different densities can cause instability conditions. One of the problems of granular material transportation that often occurs in industrial processes is the occurrence of clogging and jamming in the channel. This paper presents the results of research on the motion of granular materials due to unstable conditions. Instability is created by injecting fluid from the bottom granular. The phenomenon of instability can be used as a method of creating motion that prevents jamming or clogging. Research on granular instability to solve jamming and clogging problems is rare. Instability research needs to be developed as an energy-saving to solve industrial problems.

Researchers observed the development of granular movements. To prevent blockage, the researcher adds a helical groove to the inner wall of the pipe. This leads to a homogeneous distribution of particle motion in the pipe and results in a stable flow [7]. Barriers were investigated for the effect of resistance in granular flow. The results showed that the resistance greatly affected the velocity distribution and compaction fraction around the inhibiting object [8]. The observation of the pipe position was carried out by the researcher to show the occurrence of clogging. An experimental study of the flow of particles through vertical pipes was carried out. Research shows that the distribution of time taken to show blockage is growing exponentially [9, 10]. Observation of the particle types got attention related to clogging because each particle has different properties. Experiments of oil particles in the water and hydro-gel were carried out to determine the blockage that occurred [11]. Jamming and clogging problem-solving is mostly done mechanically by the vibration process. The vibrations cause changes in the position and velocity of the particles in the granular bad [12]. The clogging of silos due to arch formation is often avoided in practical utilizing vibrations. The vibration is likely to impose incompatible stresses on the arch [13]. Frequency and channel geometry need to be determined to prevent clogging [14]. Vibration conditions were also observed for clogging prevention. A diagram is constructed based on the value of a flow parameter that characterizes the intermittent flow observed in a discrete system. However, this condition simply cannot be used in a static silo because the requirement to break a clogged arch requires an external or internal energy supply [15]. Forced vibrations are used to destabilize the connections between particles that form stable bridges, and show that it is easier to prevent bridge formation than to destabilize an already formed bridge [16]. Instability in the granular material can be done by utilizing differences in particle density. The high-density particles push downward to form the RT instability developing during the flow [17].

The mechanism results in the formation of structures in fluidized grains because the grains are suspended by fluid motion. Granular does not have a significant cohesive force to create surface tension. The difference in density between the granular bulk and the fluid causes suspension motion as well as deformation structures in the saturated granular. The high effective viscosity of the granules acts to stabilize the interface. It causes certain fingering characteristics according to granular properties. Particle phase viscosity arises due to friction between particles and has been used to explain the formation of fingerings when granular particles are deposited in a liquid [4, 6, 18].

Granular bond affects the formation of fingering. Each granular tries to maintain the bond between the granular. Gravity resists granular bonds and creates instability. In very fine granules, the interactions of particulates depend on the strength of the molecules due to differences in chemical composition, capillaries, electrostatic and Van der Waals forces [19]. Very fine grain particles, less than 100 μm, have a strong granular cohesive bond compared to the weight of individual particles. The influence of the cohesive forces in granular decreases when the diameter is greater than 100 μm [20]. The smaller particles in the assembly have the maximum force when compared to the bigger particles. The effect of particle size on the distribution of the contact force decreases as the size difference between the particles decreases [21]. To determine the overall cohesiveness, forces of object surfaces must be considered along with the strength of cohesion. The contact force is influenced by the size of the granular diameter. To explain the strength of the granular bond, a dimensionless parameter known as a granular Bond number (B_{og}), which is described as the ratio of cohesive forces to non-cohesive forces, is used to measure cohesion between particles [22, 23]. To predict granular bonds, particle size analysis is the procedure used in the investigation. Individual particle size can be described in several different ways and using various measurement methods, so the granular type is determined according to the size classification [24].

From many studies of granular instability, there are unresolved problems related to the handling of granular flow. The objective difficulty associated with granular handling is the different properties of the granular. The fundamental possibility is to conduct experiments as an approach to industrial problems. Operational research using factory equipment is costly, so it makes the relevant research impractical. Empirical research in the industry is conducted for a granular behavioral approach. Thus, the development of granular instability is a promising aspect to solve the problem of self-locking or jamming and clogging in granular flow. Instability is created by impinging the fluid upwards from the bottom of the granular.

3. The aim and objectives of the study

The aim of the study is to investigate movements due to instability in the granular post upward injection in the bottom granular bed.

To achieve this aim, the following objectives are accomplished:

– study of the effect of injection pressure on granular instability after upward injection;

– study of the effect of granular diameter on granular instability after upward injection;

– study of the process of movement due to instability after upward injection into the granular bed.

4. Materials and methods of research

In this experiment, the granular medium used is glass material. The granular material diameter is 80 µm, 100 µm, 140 µm, 230 µm, 290 µm. The size represents very fine granular (VFG) and fine granular (FG) [24]. The granular density is 2,600 kg/m^3. To ensure the size of the granular material, all granular material is sifted according to size. The grain shape of the glass particles was observed with the Dino-Lite digital microscope. The particle shape and porosity can be seen in Fig. 1.

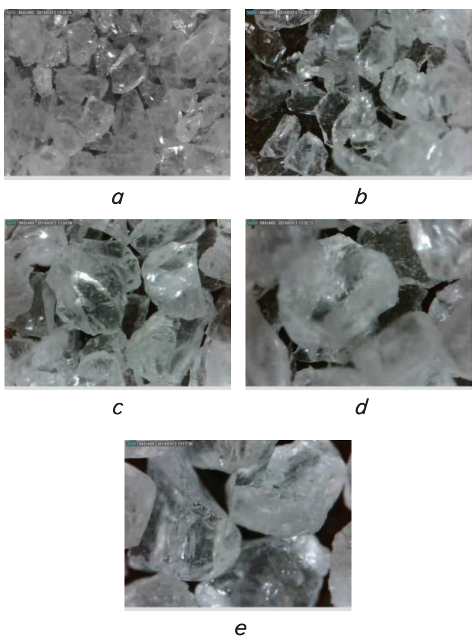


Fig. 1. Material granular: *a* – 80 µm; *b* – 100 µm; *c* – 140 µm; *d* – 230 µm; *e* – 290 µm

Experiments were carried out by injecting water into granular beds with varying pressures of 0.5 kg/cm^2, 1.0 kg/cm^2, 1.5 kg/cm^2, 2.0 kg/cm^2, 2.5 kg/cm^2, 3.0 kg/cm^2. Water is injected rapidly for 0.1 s. The pressure is varied to determine the shock effect on the granular material. The experimental process produces a visualization of the granular material's movement when it is subjected to shock flow. The arrangement of the equipment used in the granular motion observation process can be seen in Fig. 2.

Data collection is carried out by injecting fluid into the granular particles from the bottom of the Hele-Shaw cell, a computer regulates the incoming pressure and velocity. Motion instability is observed by taking motion videos when the fluid is injected. Videos were extracted to get an image of each motion condition with Video to JPG software.

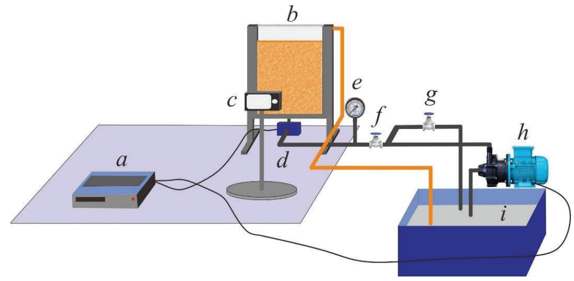


Fig. 2. Equipment of experiment: *a* – computer; *b* – Hele-Shaw cell; *c* – camera; *d* – valve controlled for impinging; *e* – pressure gauge; *f* – valve to control debit; *g* – valve to control pressure; *h* – pump; *i* – reservoir tank

5. Dynamics of fluid cavity formation and instability

The instability of the granular material begins with the presence of a fluid cavity in the granular body. The gravity of the granular material pulls the granular downward. The bonds between the granules withstand gravity, so the granules move down slowly. Fig. 3 shows the change in the shape of the fluid cavity pattern due to the instability of motion in very fine materials.

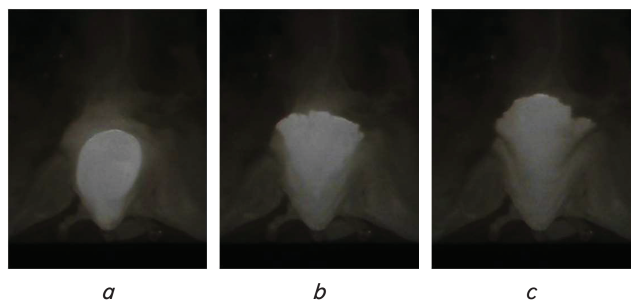


Fig. 3. Evolution of granular motion post jet impinging 0.1 s, pressure of 3.0 kg/cm^2 at granular 80µm: *a* – 0.2 s; *b* – 10.0 s; *c* – 20.0 s

The pattern of motion evolution of each size of granular material has a difference. In Fig. 3, the motion is running slowly and widening. In Fig. 4, the instability of moving upwards and forming a length upwards is due to the force acting on the bonding of the particles.

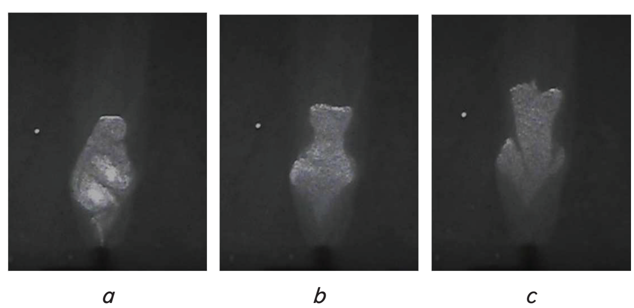


Fig. 4. Evolution of granular motion post jet impinging 0.1 s, pressure of 3.0 kg/cm^2 at granular 100 µm: *a* – 0.2 s; *b* – 5.0 s; *c* – 10.0 s

The ability of long fluidization affects the granular arrangement in the area through which the instability fluidization motion passes. The granular position moves to look for a stable position so the force acting on the particle is equal to zero.

5. 1. Effect of impinging pressure on granular instability

The formation of the fluid cavity is caused by the pressure impinging fluid on the nozzle tip. The impinging process is a fluid flow shock event with a certain discharge and high speed. Fluid impinging in a granular bed produces a deformed area. Deformation in the granular bed occurs due to the momentum of fluid flow into the bed. Fluid momentum results in the kinetic energy that pushes the granular material. Fluid momentum occurs when fluid flow with a certain mass enters the granular media at the beginning of fluid injection. The incoming fluid has the momentum of the mass flow times the mass of the fluid. Fluid momentum can be calculated with the principle of conservation of momentum for volume control. Fluid momentum can be described by the equation:

$$M_f = m \cdot U_f = \rho_f \cdot V_f \cdot U_f, \qquad (1)$$

where M_f is the fluid flow momentum with mass flow m expressed as the amount of mass flowing in the granular media. Momentum is the velocity vector U_f, and mass m is a scalar quantity. Fluid mass is the volume of fluid V_f with density ρ_f. The momentum flux vector is defined as a momentum flow per area. The particle dynamics that occur informing of the fluid cavity are calculated using Newton's Law II approach so the equation obtained can be approached as follows;

$$P \cdot dA_n = \rho_g \cdot dV_{fc} \cdot g + \sum F_c + \int \sigma_t \cdot \mathrm{d}A + F_y, \qquad (2)$$

where P is the impinging injection pressure, dA_n is the area of the nozzle, dV_{fc} is the volume of the fluid cavity, and ρ_g is the granular density. The equation states that the pressure P acts on the surface and is the force that moves the granular volume into a fluid cavity. Fluid cavities occur when the displacement of the fluid with a force must be greater than the granular weight displaced, the inter-particle contact force is F_c, tangential stress between fluid and wall of the bed σ_t, and the friction force between the particle and the wall is F_y. The inter-particle contact force results in shear thickening in the granular. An illustration of the components that affect fluid dynamics is shown in Fig. 5. Interaction occurs between the fluid and the granular material when the fluid is injected into the granular bed at high velocity. The pressure of the fluid injected into the granular bed moves the granular. The size of the fluid cavity depends on the volume of the fluid that enters and passes from the granular bed.

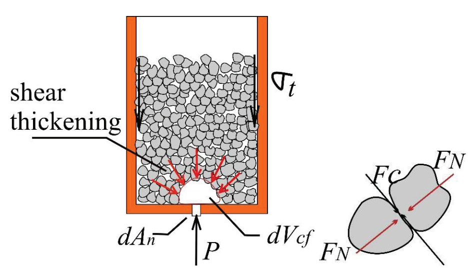


Fig. 5. Dynamics of a particle: *a* — component of force acting on the Hele-Shaw cell; *b* — contact force of particles

Granular instability movement is affected by impinging pressure. The amount of pressure applied during impinging affects the size of the fluid cavity. Fig. 6 explains that different impinging pressures cause different fluid cavity heights. The fluidization of instability is slow at the same rate. The graph shows the increase in the height of the fluid cavity when an impinging pressure is added. At low to high pressures, after impinging, the granular material experiences a slow settling motion. Granular agglomerate is decreased so the upper side of the fluid cavity forms a fingering. With the addition of pressure, it can be seen that the initial area of the fluid cavity has an even greater impact.

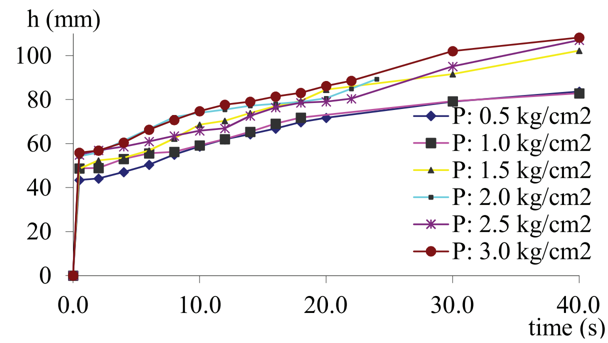


Fig. 6. Movement of granular instability at varying impinging pressure t=0.1 s at granular 80 μm

The time required for the fluidization process at 80 μm granular can be seen in Fig. 6. The graph shows that during the impinging process, the formation of a fluid cavity is marked with a vertical graph, followed by the fluidization instability process. The breakdown process of granular agglomerate occurs shortly after the granular agglomerate deposition process. From the graph, this condition is shown in a horizontal graph. The fluidization process works after a time gradient concerning the height moves inclined. The fluidization process stops when the granular stops moving and reaches a stable state.

The impinging pressure greatly influences the growth of the fluid cavity. The fluid impact on the granules promotes rapid cavity formation. Weak cohesion bond makes it easy for fluid to enter the granular body. Fig. 7 shows that a pressure of 0.5 km/cm^2 does not form a high fluid cavity. The process of erosion over the cavity does not occur. With increasing pressure, the growth of the fluid cavity increases because fluid pressure can move the granules.

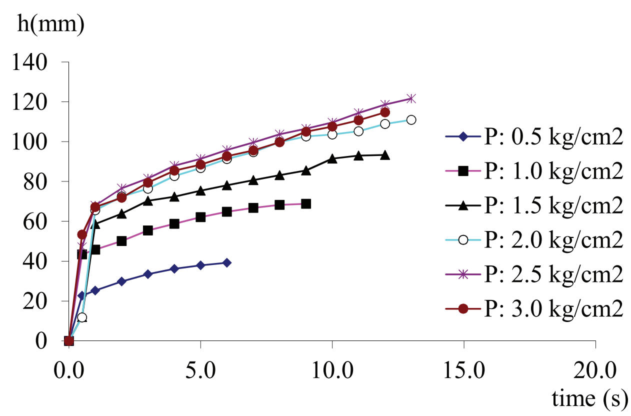


Fig. 7. Movement of granular instability at varying impinging pressure t=0.1 s at granular 100 μm

The granular diameter influences the time required for the fluidization process. The more granular roughness used in the observation process results in a shorter time. The fluidization height is influenced by the size of the granular material and the pressure. Fig. 8 describes fluidization of the granular material at 140 μm at 0.1 s impinging time and various pressures. At 140 μm granular height of 0.1 s post impinging fluidization process with 1 mm diameter nozzle, resulting in a fluid cavity of 130 mm at a pressure of 3.0 kg/cm^2. This condition is almost the same as for smaller granular materials. However, what is different is the time required for the fluidization process to take place and is very fast. Fluidization at a pressure of 3.0 kg/cm^2 lasted only 6 s. As for the lower pressure, it lasts less than 6 s.

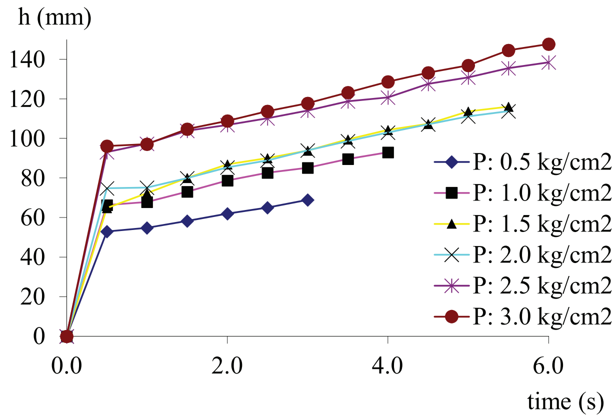


Fig. 8. Movement of granular instability at varying impinging pressure t=0.1 s at granular 140 μm

The height of fluidization in granular 140 μm occurs at each time change, as can be seen in Fig. 8. The graph shows that pressure affects the height of the fluidization process.

The big granular diameter makes the inter-granular cohesion bond less influential. It causes instability to take place quickly. Fig. 9 shows that the granular diameter of 230 μm undergoes unstable motion for 3 seconds to reach a stable condition. The graph explains that the instability towards stability is fast. The granules stop moving and form a new granular arrangement when conditions are stable.

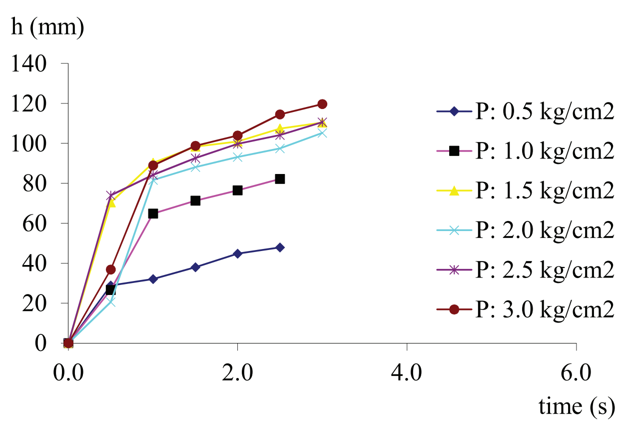


Fig. 9. Movement of granular instability at varying impinging pressure t=0.1 s at granular 230 μm

Granular material of 230 μm can move without the resistance of cohesion bonds. This results in a fast granular motion and is not hampered by the binding force between the particles. The motion that occurs is influenced by the pull of gravity and buoyancy resistance of the particles so, the particles experience a stable condition.

5. 2. Effect of granular diameter on instability after upward injection

The granular size affects the movement behavior of the granular material after fluid injection from the bottom of the bed. The height of the fluid cavity indicates the ability of the granular material to break the bonds of particles and seek a stable position for each particle. Fig. 10 shows the movement of granular material to form a fluid cavity with several variations in granular diameter, 80 μm, 100 μm, 140 μm, and 230 μm. The movement of the granular material flow differs in each differentiating diameter. In very fine materials, a suspended fluid cavity appears. This movement occurs in very fine granular materials experiencing shear thickening behavior. The granular viscosity also increases and interlocks as the shear rate increases. This condition occurs because of the relationship between the particles that bind each other when under pressure. This causes the behavior to become solid by bonding to each particle. Due to the properties, the viscosity of shear thickening fluid depends on the shear rate. The presence of particles often affects the viscosity of fluidization. The presence of particles can cause Newtonian fluid behavior to change to non-Newtonian fluid behavior. Parameters that influence shear thickening properties are particle size and particle size distribution, particle shape, particle volume fraction, particle-particle interaction, fluid viscosity, particle type and deformation time [25].

In 100 μm and 140 μm particles, the granular material undergoes fluidization motion and forms a fluid cavity with a small size, but has a wide fluidization motion. At this size, the force between the particles as a granular bond does not affect the fluidization motion. Fluidization movement is a depositional motion that is influenced by gravity but to be able to settle, and each particle must be separated from the granular bond. In 230 **μm** granular, after impinging fluidization occurs immediately. At size, the particles are not much affected by the bonds between particles. In a granular bed, the particles tend to move on their own to adjust the flow rate through the granular. The impinging pressure pushes the granular material; the particles move upward and fluidize. When the impinging energy has run out, all fluidized particles move downward following the particle's gravity.

The ability of fluid to pass through is influenced by the size of the gap between the granular materials. The big gap between the granules can be easily penetrated by the fluid. The large pressure can increase the force of the fluid through the gap. Fig. 10 explains the effect of diameter on the height of the fluid cavity. The greater the pressure injected into the granular bed, the greater the size of the fluid cavity. However, until a pressure of 2.5 kg/cm^2, the size of the fluid cavity does not develop. This happens because granular material has shear thickening properties. This property causes the fluid-pressed granular particles to lock together rapidly. The granular forms bonds and the fluid cavity does not develop at the pressure above it.

The impinging fluid results in the fluid cavity because the granular material is displaced by the momentum of the impinging. Fig. 10 shows from the experimental results that the granular size of material influences the height of the fluid cavity (hc). The effect of the granular diameter on the height of the fluid cavity can be seen in the experiment. The size of the gap between the particles causes the fluid to escape from the granular bed or obstruct its flow. At 100 μm diameter, it has a high fluid cavity. When the granular diameter is reduced, the effect of the granular bond affects the fluid cavity. This condition causes the ability to form the fluid cavity to decrease. The 100 μm granular is capable of producing a higher fluid cavity height than 80 μm. However, for particles larger than 100 μm, the fluid cavity has decreased. The larger diameter produces a smaller fluid cavity. This condition appears at a diameter of 290 μm, producing the lowest fluid cavity. The phenomena that can be observed from these conditions are as follows: (1) In the VFG, the formation of granular heights is influenced by the granular bond, thickening shear, and water's ability to pass through the gaps between the granules. (2) In the FG, the ability to escape the fluid is high, but the granular bond does not affect, so the fluid cavity develops. In big granules, the ability of the fluid to pass through the granular is greater. This condition causes the ability to form a fluid cavity to be small.

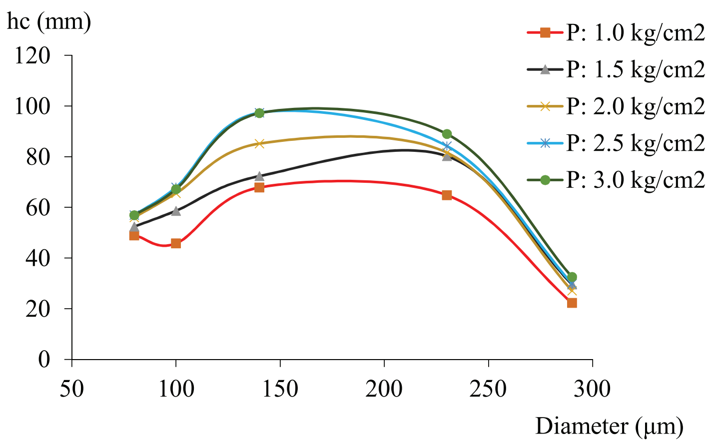
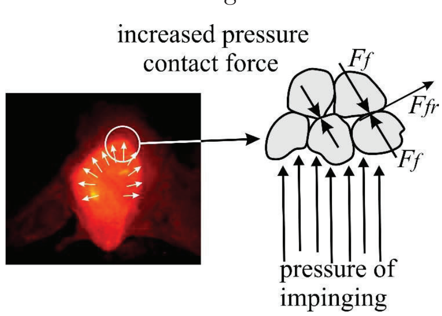


Fig. 10. Fluid cavity post injecting of fluid t=0.1 s

Particles of VFG have bonds that are affected by the impinging pressure. After fluid injection, the development of fluid cavities moves quickly due to the rapid flow of fluids that hit granular particles. The kinetic energy of the flow can break the bonds between the granules, forming a fluid-filled cavity. The cohesion between granular bonds is strengthened by the pressure exerted by the fluid that forces the cavity walls. The compressive force of the fluid F_f between the particles forms a stronger friction force F_{fr}. This condition causes the impinging process, the particles are pressed, but nothing is released. By observing Fig. 11, it can be explained that at the time of impinging and forming the fluid cavity, the granules are firmly attached to the cavity wall. Strong granular cohesion force binding force.



a *b*

Fig. 11. Impinging dynamic stress adds strength to the contact force between the particles: *a* — the force pressing the granular wall, *b* — the impinging force results in the particle contact force

The increased pressure in the impinging process pushes the walls even stronger. The inter-granular bonds are not separated, but the area of fluid entering the granular body increases. The impinging pressure forces the granular body to create a wide cavity. When the fluidization of the fluid cavity looks clean, there is no granular loss because the contact force between the particles is getting stronger with the compressive force of the impinging fluid.

In VFG, the impinged shock flow produces a specific form of instability in the granular bed. When the dynamic fluid pressure dissipates, the fluid cavity has the same pressure as the hydrostatic pressure. This condition triggers the instability of the granular array. The binding force between the particles tries to form bonds that maintain the granular arrangement. However, the weight of the particles is pulled downward. The particles bind to each other with cohesion forces to maintain the arrangement of particles. The forces are acting to form a bond between the granular with the equation:

$$F_{coh} = F_{vdw} + F_{cap} + F_{asp}, \tag{3}$$

where F_{vdw} is Van der Waals binding force, F_{cap} is the capillary force, and F_{asp} is the contact force. Van der Waals is the attractive force between molecular particles or between groups in molecular entities due to the formation of bonds or electrostatic interactions of ions or ionic groups with each other or with neutral molecules. The capillary force is the force that is formed due to the surface stress of the fluid acting on the granular. Asperity contact force is the bonding force related to the surface roughness of the particles. The granular Bond number expresses the relationship between the bonding force and the attractive granular force. The granular Bond number is defined by:

$$B_{og} = \frac{F_{coh}}{W_g}, \tag{4}$$

where F_{coh} is the cohesion force, and W_g is the gravity of the granular particle [10]. When the binding force between particles (cohesion force) is greater than the particles' weight, the particles form their stability. The presence of a fluid cavity does not affect the granular arrangement. However, the release is granular due to gravity in the form of an agglomerate. When there is a granular crack gap, the bonding of particles in the gap releases, the impact is the weight of the agglomerate pulling off the agglomerate group. The movement of the cracks starts from the outside and forms agglomerates which are then released due to gravity. The process of breaking granular bonds is described in Fig. 12.

Fig. 12 illustrates the creepage cracks in the granular bonds causing agglomerate deposition. The existence of creepage cracks causes the inter-granular bonding force cannot withstand the weight of the granular agglomerate. Consequently, the granular agglomerate undergoes sedimentation.

The cohesion force in working granular material is influenced by the granular size. FG has a smaller binding force than VFG. The Van der Waals force acts when the electrostatic bonds of ions act on the interactions of granular grains. The Van der Waals force is effective on small particles because the contact between the surfaces is more dominant than the force, giving the dimensions interference. The contact force is a force due to the contact properties of the surface properties of the particles. The surface properties of the granular influence this force. In 100 μm granular material, the binding force between the particles does not have much effect. This can be observed in the formation of the fluid cavity that occurs, at the time of impinging, the fluid impacts the particle tip and opens the granular body. The weak bonds between particles cause the particles in the fluid cavity walls to experience partial erosion. Most of the erosion is at the top because the particles' gravity helps the release of granular material. The loose granular material causes the impinging fluid flow to occur. The mass of loose particles to form different densities causes the flow to move to find a position with a low density. This condition causes a fluid swirl in the cavity. Fluid whirls increase the erosion of the cavity walls. In this condition, the fluid cavity has undergone initial fluidization. The fluidization energy comes from the impact of the fluid during impinging. The impinging fluid flow motion can be seen in Fig. 13.

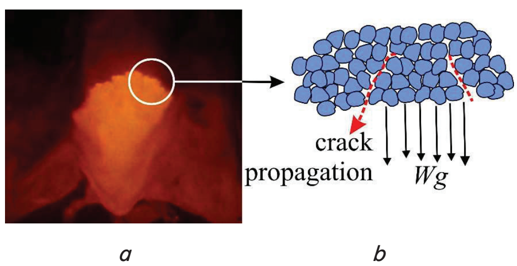


Fig. 12. Cracks in the granular bonds lead to agglomerate settling at granular 80 μm

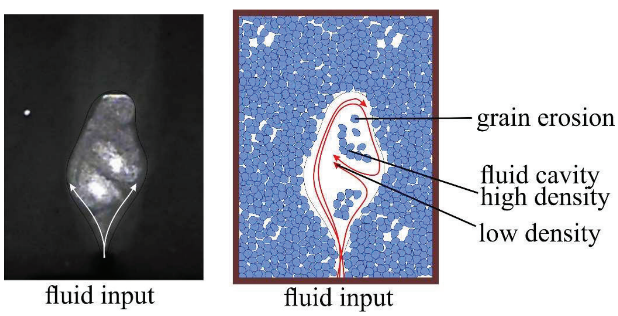


Fig. 13. Vortex flow and erosion granular in the fluid cavity at the impinging granular 100 μm

Fig. 13 shows the movement pattern of the fluid that enters the fluid cavity, at the beginning of impinging, the fluid moves to push the granular. The walls of the fluid cavity are exposed to the flow experience erosion. The loose granules move with the fluid flow. The presence of granularity causes the density in different fluid cavities. It causes a vortex in the fluid cavity. The condition occurs when the bonding of particles is not strong enough to hold the flow.

Granular size causes differences in granular bonding and instability behavior. The ability of the binding force to maintain the position of the particles causes different forms of instability. The instability of particles moves to determine the position of stability. The fluidization process at 100 μm granular can be seen in Fig. 14. The fluidization of the FG movement forms the fingering. The binding force between particles tries to maintain the form and relationships between granules. Meanwhile, the gravity of the particles attracts the particles to move down. When the force that is moving down is greater, the particles move down. The effect of cohesion between working particles is due to the form of the fingering in the fluidization settling process. The cohesion force holds the particles individually, so the form of the fingering is random. The upper part will grow faster. This fluidization occurs because of erosion at the beginning of the formation of the upper cavity. Fig. 14 shows the strong cohesion force between particles holding the position of the particles to form a fingering.

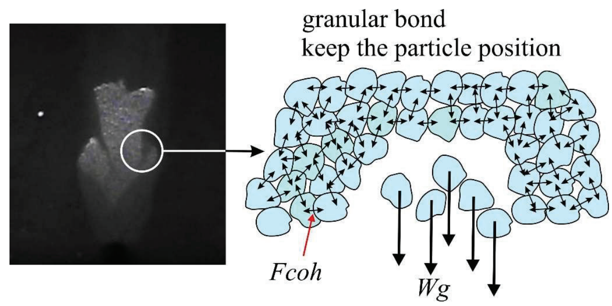


Fig. 14. Cohesion force between the particles and forming fingering at the instability of FG

Fingering that occurs when the motion of individual particles settling moves leaving granular assemblages. Granular by moving due to gravity with an initial velocity of 0 mm/s. Settling velocity is influenced by the drag coefficient and Reynolds number [26]. The analysis shows that the destabilization of the submerged bed depends primarily on the initial stabilizing density contrast when the grains are heavier than the surrounding liquid [27].

5. 3. Process of movement instability after upward injection

The process of movement instability after upward injection results in areas of deformity instability. The velocity of instability motion correlates with granular diameter. The granular binding energy determines the time of the granular fluidization process. Fig. 15 shows the time the granules are settling instability concerning the granular diameter. The smaller particles also have a longer settling time.

From the behavior of the fluidized motion, a division of different behavior areas can be made. In VFG, the granular bond's effect is powerful, so the fluidization begins with the fall of the granular agglomerate. A strong granular bond indicates that the value of the granular Bond number B_{og} is much greater than 1. As B_{og} approaches 1, the bonds are not strong enough to hold the bond. The settling fluidization movement will immediately occur under the influence of the granular bond. These conditions have an impact on the form of the fluidized fingering. When the diameter is increased, the fluidization takes place without the influence of a granular bond, so it mixes with the fluid and moves in the direction of the flow.

The fluidizing motion due to instability is affected by the granular diameter. In VFG, it has a strong granular bond in the form of fluidization agglomerate settling. The condition is called region 1. In FG, the granular bonds are equivalent to the grain weight, which causes individual adjusting motion. The VG represents region 2. In coarse granularity, the bonds between particles do not affect. Fluid permeable granular crevices and it is called region 3. The division of the region can be seen in Fig. 15.

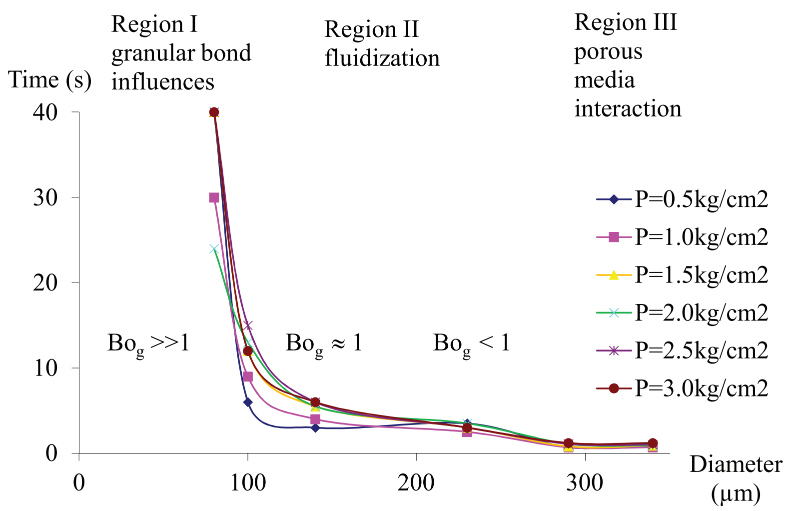


Fig. 15. Effect of granular diameter on fluidization time and area of instability

Fig. 15 shows that the diameter in the granular glass, silica, results in a change in behavior conditions. In very fine 80 μm granules, the impinging fluid creates a fluidizing instability over long periods. This form of fluidization occurs when the agglomerate of granular is destroyed. In FG, fluidization takes place more rapidly. In this area, there are individual fingering and granular patterns. The coarse granular size has a large gap. The relationship between particles is not dominant, so the granular moves quickly to reach a stable position. For coarse granular fluid can pass directly without deformation of the granular position, which is porous media.

6. Discussion of the results of investigation of instability of granular post impinging upward fluid

Impinging fluid in a granular bed body produces areas of deformation. Fluid momentum generates kinetic energy that pushes granular materials. The height of the fluid cavity indicates the ability of the granular material to receive the impinging kinetic energy and release the bond particles. Fig. 5 describes the dynamics of pressure pushing and releasing granular bonds. The granular resists pressure due to the contact force. Post cavity formation, the granular position becomes unstable. The movement of the granular material is different at different diameters. In the VFG, a suspended fluid cavity appears. This movement occurs in fine granular materials that have shear thickening behavior. Fig. 11 describes the occurrence of a resist incident due to thickening shear. The granular viscosity also increases and interlocks as the shear rate increases. The pressure applied during impinging affects the size of the fluid cavity. At the VFG instability, the fluid cavity has the same pressure as the hydrostatic pressure. The cavity triggers a granular instability. The binding force of the particles forms bonds that maintain the granular arrangement, and the weight of the particles pulls them down. To maintain the arrangement, the particles bind to each other by cohesion to create bonds between the particles. Granular is loose due to weight in the form of a lump. The cohesion force in granular material works according to the granular properties. Fig. 12 describes agglomerate settling due to cohesion forces. In FG, the granular binding force is balanced compared to the gravity, so that the fluidization motion occurs individually granularly. Fig. 14 describes individual settling. The binding force between particles tries to maintain the shape and relationship between the granules. Meanwhile, the gravity of the particles attracts the particles to move down. When the force that is moving down is greater, the particles will move down. The effect of the cohesion binding force between working particles is due to the shape of the fingering

The velocity of the instability motion correlates with granular diameter. The granular binding energy determines the time of the granular fluidization process. The smaller particles will also experience a longer settling time. From the behavior of the fluidized motion, it can be divided into the difference in behavior. At the VFG, the effect of the granular bond is very strong, so that the fluidization begins with the fall of the granular agglomerate. The binding ability of the particles is expressed by the granular Bond number in equation 4. The strong granular bond has the value of the granular Bond number B_{og} much greater than 1. As B_{og} approaches 1, the granular bonds are not strong enough to hold the weight. Fig. 15 shows the fluidizing behavior area. The direct fluidization settling movement occurs under the influence of the granular bond. These conditions have an impact on the fluidized area in the form of fingering. Deformation and instability motions break down clogging and jamming.

The change in instability with an increasing granular diameter is an interesting finding. The phenomenon is used as the basis for the design of the equipment being developed. Equipment follows the properties of the material to be handled. The data of research can be used as a calculation for designing clogging parsing equipment. Impinging and the resulting instability motion are alternative methods for unraveling jamming and clogging. Compared to mechanical vibration methods, decomposing the jamming and clogging of the impinging can take advantage of the instability conditions experienced. Using low energy, the impingement process of instability motion can change the position of the granular arrangement. The change in granular arrangement causes the granular arrangement to cause the clogging to come off and unravel. Controlled impinging pressure provides a predictable area of fluidization.

Granular material is a mixture of solid and flowable substances. The two substances have different properties. Contact between granular particles has a different character as well. The combination of two different properties causes many changes in the granular properties of the material. Granular materials of different types have different characteristics. This causes this study to be limited to the properties of granular glass materials. To design equipment to release jamming at the other granular, research is needed to observe granular characteristics. Research on the characteristics of granular instability is still very broad according to the type of granular and its processing.

Different granular characters make it difficult and challenging for researchers to develop studies of granular instability. Granular instability movement is a natural phenomenon that can be developed in an effort to save energy. Instability motion is created with less energy, producing a wide range of motions and affecting granular positions. It can be proposed in the anti-clogging design process. Limited information about granular properties is a problem in industrial applications. Several dimensional changes need to be made for research in industry. This fact becomes a challenge for researchers to study granular instability in industrial applications with different variable dimensions.

7. Conclusions

1. The impinging pressure against granular instability after upward injection results in disruption of the granular stability and forms a fluid cavity. The pressure difference results in the area of the fluid cavity. The effective impinging pressure affects very fine granules less than 100 µm. The granular has small gaps between particles and, it creates high viscosity, to push the granules and form a fluid cavity. In the course granular gap between the granules, it is easier for the fluid to pass. The formation of fluid cavities is limited by the thickening shear when the granular gets impinging pressure. At diameters above 100 µm, impinging pressure is reduced by passing fluid through the granular gap. The pressure does not affect the movement of fluid cavity formation in 290 µm coarse granular.

2. The effect of granular diameter on granular instability after upward injection impinging differs between fine granular and fine saint granular. Strong granular bonds occur at granular sizes less than 100 µm. Granular bonds affect the movement of instability in groups. The value of the granular Bond number is greater than 1. At sizes of 100 to 230 µm, the granular bond still affects the granular instability with the fingering pattern in the granular motion. The value of the granular Bond number is close to 1. Granular sizes above 230 µm indicate the presence of non-dominant bonds between the grains. The individual granular mass is higher than the cohesion force that occurs at the interface between the granular, and the granular Bond number value is less than 1.

3. The process of instability movement after upward injection impinging into the granular bed shows a change in the form of the pattern in instability motion in very fine and fine materials and medium granular. The pattern of motion evolution of each granular material size has a different form of motion. The form of stability is divided into 3 regions. The region of granular bond influences occurs in very fine granules<100 µm, and the pattern of motion is slow and wide. The region of fluidization occurs in fine granular instability. The upward movement and length of the form of the motion are caused by the force acting on the bonding of the particles. The long fluidization ability will affect the granular arrangement in the area through which the instability fluidization motion passes. The granular position moves to find a stable position so the force acting on the particle is equal to zero. The region of porous media interaction occurs when the fluid can pass through the granular gap and does not change its granular position.

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