



Agglomeration and sizing of rolling particles in the sago sizing mechanism

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ABSTRACT

Discrete particles with the moisture in a rotating system tend to form themselves as lumped mass granules of different sizes. This paper depicts the agglomeration of the particles using batch and continuous system through the mathematical modeling. The liquid bridge formation, coalescence and breakage are essential steps in the agglomeration process of continuous system. The combination of two effects, namely, binder viscosity and surface tension will govern the bridge formation. In case of batch system of granulation, a regime map of granulation behaviour has been developed for the particulate system of sago powder–water mixer. This regime map predicts the granule growth behaviour and it is possible to assist in designing and controlling the granulation systems. In these processes, mass of the granules varies continuously with respect to time. According to the conditions of coalescence and breakage behaviour, the agglomeration is maximum during three to six minutes of granulation due to the maximum percentage of granule breakage. After six minutes the granule breakage and growth is gradually reduced and after 10 min there is no granule growth due to minimum or no breakage. The number of granule breakage increases with the Stokes deformation number.

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1. Introduction

Cassava is mostly used as a staple food in the Africa and in the South America. Industrial utilization of cassava is common in the South Asian countries in the form of starch, sago, dried chips, flour etc. In these industries the sago (product from cassava) sizing is the key process to acquire the globe size. Hence to acquire globule form of sago particles an automation mechanism model is devised [1]. In the previous contribution the dynamics of granules inside the bowl is analyzed. The result shows that the rotational speed of the bowl is high then the granule residence time gets reduced and the preferred range for inclination angle of the rod is 60°–64°. In this paper the process of liquid bridge formation, coalescence, breakage and mass build up of the granules is presented.

The overall view of the granulation technique is originally derived by Ennis [2], Ennis and Litster [3]. Sastry and Fuerstenau [4,5] proposed the basic mechanisms of granulation are nucleation, shatter, coalescence, breakage, attrition, abrasion transfer and layering for size changes which occur during granulation. Kapur and Fuerstenau [6] divided the granulation process in three regions: nuclei growth region, transition region and the ball growth region. Linkson et al. [7] addressed the

apparently conflicting results of earlier studies concerning the type of growth mechanism. The weaker and smaller granules are then crushed and their fragments are picked up by the larger ones. Capes and Danckwerts [8] reported that when two granules of different sizes collide, the smaller granule is crushed and the fragments are formed. The fragments are then layered onto the surface of the remaining granules.

In the study of binder role, Rynhart [9] states that the over wet condition resulting in the formation of cohesive mass. Chansataporn and Nopharatana [10] experimental results indicated that the growth of cassava pearl is very sensitive to binder content. Srinivasakannan and Balasubramaniam [11] studied the fluidized bed granulation in which an increase in the flow rate or an increase in the concentration of the spray solution increases the granule growth rate. Levin [12] states that, during the wet massing stage, the granules may increase in size to a certain degree while the intra granular porosity goes down. Iveson and Litster [13] investigated that a decrease in binder surface tension decreased the dynamic yield stress of granules. Based on this, water would be a good choice of binder as it has a higher surface tension. Salman [14] studied that, binder properties are significantly accountable for granular strength and breakage behaviour.

The other parameters such as particle size, rotational speed, mass conservation and yield of granulation studied by the following researchers. Gluba et al. [15] clearly states that during the wet drum granulation of silica flour, an increase of bulk density of the bed during

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Nomenclature

a	acceleration of the granule
D	diameter of the bowl
e	coefficient of restitution
F_a	force applied to the particle or granule through the bowl rotation
F_i	inter-particle force
F_{cap}	capillary force between the particles
F_{vis}	viscous force between the particles
2h	separation distance in the liquid bridge formation
h_a	minimum half separation distance
k	mass transfer of powder particle into granule
m_p	particle or granule mass at the time t
Δm_p	mass addition at time (t + Δt)
M (t)	radial component of momentum of granule at time t
M (t + Δt)	radial component of momentum of granule at time (t + Δt)
n	powder and water mixing ratio or binder content
ΔP	pressure difference caused by the water droplet
R	initial particle radius
r_1	radii of curvatures lie in the plane z-x
r_2	radii of curvatures lie in the plane z-y
r_p	radius of the sago granules
$\dot{r}$	radial velocity of the granule with mass m_p
$\Delta \dot{r}$	radial velocity of the granule with mass ($m_p + \Delta m_p$)
$\ddot{r}$	radial acceleration of the granule with mass m_p
S_{max}	maximum granule pore saturation
St_c	capillary Stokes number
St_v	viscous Stokes number
St_c^*	critical capillary Stokes number
St_v^*	critical viscous Stokes number
St_{def}	Stokes deformation number
t	time
Δt	change in time
V_{lb}	volume of liquid bridge
v_p	total velocity of granule
v_r	relative velocity between the particles or granules
V_s	volume of the particle or granule
x, y, z	coordinate of the particles in liquid bridge formation
ψ	sector angle or filling degree
δ	contact angle
ε	dimensionless gap distance (porosity)
ε_{min}	minimum porosity
γ	surface tension
ρ_b	bulk density of materials
ρ_s	density of the solid particles
ρ_t	true density
ρ_w	water density
θ	inclination angle of the rod with horizontal plane
σ_t	Tensile strength of granule required to deform and break
μ_v	liquid viscosity
ω_1	precession of the rod
ω_2	spin of the bowl
ω_b	rotational speed of the particle

granulation depends on the wetting liquid droplets and size of raw material particles. Kastner et al. [16] performed the granulation runs with variations in impeller speed, massing time and binder addition rate. They are found that, the input parameters which describe the initial particle size distribution are found to significantly affect the

distribution of the end product. Paiva et al. [17] proposed that the agglomerate is formed when the normal relative velocity is not larger than the critical velocity. If the agglomeration occurs, the momentum and mass conservation is taken into account since the new particle diameter is determined by mass conservation of the particles. Gluba and Obraniak [18] results showed that at constant rotational speed of the plate, constant mass of the fine-grained material and increasing the supply height of droplet; results in increased quantitative and mass fraction of nuclei of smaller size. Irshad et al. [19] studied the pan granulation and concluded that the pan speed is inversely proportional to the rate of granulation, granulation yield directly proportional to the granulation time and yield is not affected by the inclination angle of pan.

2. Mechanism of sago agglomeration

The mechanism exists in the sago granulation process in which the moist powder masses are tumbled in rotating bowl until the granules have grown to the required size. The agglomeration can be defined formally by the nucleation, coalescence, breakage, layering and abrasion transfer [4]. The nucleation is typically applied to the initial coalescence of primary particles in the immediate surrounding area. In a batch system, the nuclei have been formed by first few rotations of bowl which leads to occurrences of well formed granules [6]. The coalescence events cause discrete changes in agglomerate masses and contribute to an overall decreases in the number of granules, but does not change the total mass of the system [20,21]. The breakage leads to collection process of small and fractured fragments and hence enhances to change in mass of formed species without affecting total mass. The fragments due to breakage are redistributing on the surviving granules called layering [22].

The binders are typically included water, ethanol and isopropanol; used either alone or in combination [11]. Water is commonly used for sago like food products, inexpensive and environmental reasons. The primary role of water in this system is to provide the cohesiveness that essential for the bonding of the powder particles under compaction to form sago granule. At low concentrations, water may act as a plasticizer under low deformation conditions and as an antiplasticizer under high deformation conditions [23]. Water in starch material has generally been regarded as the universal plasticizer, implying that it serves always to soften or make less brittle. Addition to that, all commercial starches contains minor quantities of uncombined inorganic material and normally processes using the water.

3. Mathematical models

3.1. Liquid bridge and growth formation

In the continuous system of granulation, when two particles are approaching each other the outer liquid binder layers will make the first contact and the liquid is sucked into the inter particle gap and enhances the formation of liquid bridge. The liquid bridges cause various effects on the particles due to the adhesion force caused by the capillary effect, the shearing force caused by the viscosity of the liquid and relative displacement of the particles [24]. The total force acting between the particles is induced majorly by the sum of these two forces only. Hence, the inter-particle force can be described by applying Newton's second law of motion using these is given by [25],

$$F_i = F_{vis} + F_{cap} = m_p \frac{dv_r}{dt} \quad (1)$$

3.1.1. Static bridge

The static strength of a liquid bridge consists of two components namely, capillary suction pressure caused by the curvature of the liquid

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