CHAPTER 6

SIMULATION OF FERTILIZER GRANULATION PROCESS

6.1 Introduction

If engineers try to operate a fertilizer plant without good understanding of the granulation process, it could produce large amount of off-grade fertilizer during start-up or grade switchover or even during process disturbance. A suitable realistic model to describe the performance of each major component in the fertilizer granulation process could enhance the understanding and reduce losses due to off-grade fertilizer.

Up to now the author has translated Adetayo's mathematical model for the drum granulator into computer code and carried out its validation and sensitivity analysis. Then he has done the same thing to the selected screen and crusher models. Now simulation of the granulation process can be carried out by linking the relevant units to complete the circuit.

In this chapter the granulation circuit simulation will be carried out for fertilizer grade 16-16-8. Since the author cannot obtained any actual operating data for the screen and crusher performance on this grade of fertilizer, their performance will be assumed the same as the two units modeled by Lister (1989) based on his plant data. Only the model parameters of the drum granulator will be estimated from the actual plant data.

6.2 Estimation of the Coalescence Constants for Grade 16-16-8

Figure 6.1 shows the collected data on the granulator feed stream (recycle stream plus fresh feed) and the granulator outlet stream in terms of its particle size distribution.

Depending on the value of S_{sat} of fertilizer grade 16-16-8, the coalescence kernel should be in the form

$$\beta_{i,j} = \begin{cases} k_1 & t \leq 2\min \\ \left.\begin{array}{ll} 0 \; ; & 0.044 < S_{crit} \\ k_2(v_i + v_j), & 0.044 > S_{crit} \end{array}\right\} & t > 2\min \end{cases} \tag{6.1}$$

Based on Adetayo's experiences it is assumed here that $t_1 = 2$ minutes is the time required to complete the first stage of granulation and switch the form of the growth kernel.

By trials and errors, it is found that the set of values $k_1 = 1.49$ and $k_2 = 0$ gives a reasonably good fit to the actual plant data after 2 minutes, at which time $S_{crit} = 0.044$. In the words, the fertilizer grade 16-16-8 is shown to reach an equilibrium rather quickly (after 2 minutes).

In other words, the model reveals that 16-16-8 grade fertilizer essentially has only the first-stage granulation and the final granule size distribution is narrower than the size distribution of the granulator feed stream, resulting in almost total removal of the fines. Since the second stage coalescence rate constant k_2 is nearly zero ($k_2 = 0.0001$), it is reasonable to use $k_2 = 0$.

To accurately estimate the parameter k_1 from plant data, it is necessary to vary the liquid phase content by making a plot between $k_1 t_1$ and S_{sat}. The slope of the straight line is A.

$$k_l\, t_l = A\, S_{sat}$$

In the case of fertilizer 16-16-8, the author does not have enough data to re-estimate the value of A for grade 16-16-8. So the same value given by Adetayo for DAP (A$\approx$39.0) will be used.

6.3 Simulation of a Fertilizer Granulation Process to See the Effects of the Solution Phase Ratio

6.3.1 Scaling-up criterion

If full-scale plant data are not available for modeling it would be necessary to estimate the full-scale granulator model parameters from the lab-scale or pilot-scale model parameters based on batch data. What follows is an approximate guideline on how to do the parameter estimation.

At steady state, the population balance equation for the drum granulator is given by

$$V_{space} \frac{dNi}{dz} = \left[\frac{dNi}{dt}\right]_{batch} \tag{6.2}$$

$$V_{space} = \frac{L}{t_r} \tag{6.3}$$

where L = drum length

t_r = particle mean residence time

$\left[\frac{dNi}{dt}\right]_{batch}$ is the same as that given by equation (3.21)

Lister and Water (1990) postulate that an equivalent rolling distance is required to achieve the same degree of granulation in drums of different diameters but geometrically similar. They suggest that dynamic similarity requires that the Froude number, F_r, must be constant in both drums.

$$F_r = \frac{D\omega^2}{g} \qquad (6.4)$$

Here g = acceleration due to gravity (length/time^2)

ω = drum rotational speed (rev./time)

D = drum diameter (length)

Adetayo (1993) concludes that the conservation of the Froude number, F_r, is just one useful indicator .Then

$$\omega_l = \omega_s\sqrt{\frac{D_s}{D_l}} \qquad (6.5)$$

Subscripts l and s refer to the large and small drums, respectively. The total distance, Z, traveled by a representative particle is proportional to the product of the drum size, D, the time spent in the drum, t, and the rotational speed of the drum, ω .

$$Z \;\alpha\; D\omega t \qquad (6.6)$$

The postulation of equivalent rolling distances requires that

$$D_s \omega_s t_s \; = \; D_l \, \omega_l \; t_l \tag{6.7}$$

Combining equations (6.2) and (6.4) gives

$$\frac{t_l}{t_s} \; = \; \left(\frac{D_s}{D_l}\right)^{\frac{1}{2}} \tag{6.8}$$

This simple criterion may be used to scale up model parameters obtained from laboratory granulation drum for use in modeling a full scale granulation drum .

As an example, consider the following specifications of an actual fertilizer plant:

Length of the drum	=	8	m.
Drum diameter	=	3.6	m.
Particle residence time	=	5	min.
Space velocity	=	1.5	m./min
Fertilizer feed	=	2,000	kg./hr.

First-stage coalescence rate constant k_1

Adetayo (1993) utilizes a 0.31 m. diameter laboratory granulation drum in which the first stage lasts approximately 2 minutes.

From equation (6.5), for the full-scale drum

$$t_l \; = \; 2\left(\frac{0.31}{3.6}\right)^{\frac{1}{2}} \; = \; 0.5869 \text{ min} \tag{6.9}$$

Let l be the equivalent length traveled by the granules before the second stage of granulation occurs. Then

$$l = t_l v_{space} \tag{6.10}$$

$$l = 0.5869 \quad v_{space} = 0.8803 \text{ m.} \tag{6.11}$$

To achieve the same extent of granulation $k_1\, t_1$ in both drums,

$$k_{1,s}\, t_{1,s} = k_{1,l}\, t_{1,l} \tag{6.12}$$

Then for the full-scsle drum

$$k_{1,l} = \left(\frac{2}{0.5869}\right) k_{1,s} \tag{6.13}$$

Second stage coalescence rate constant k_2

Similarly

$$\frac{k_{2,l}}{k_{2,s}} = \left(\frac{D_l}{D_s}\right)^{\frac{1}{2}} \tag{6.14}$$

In summary, the coalescence kernels for the full-scale drum are given by

$$\beta_{i,j} = \begin{cases} k_{1,l} & l \leq 0.8803\, m \\ \left.\begin{array}{ll} 0\ ; & S_{sat} < S_{crit} \\ k_{2,l}(v_i + v_j) & S_{sat} > S_{crit} \end{array}\right\} & l > 0.8803\, m \end{cases} \tag{6.15}$$

6.3.2 Simulation results of the present granulation process

Before embarking on the simulation, assumptions should be made to simplify the present process .

- The dryer only acts to reduce the liquid content of the fertilizer granules.
- The effect of rotating dryer drum on the particle size distribution exiting the drum is insignificant.
- The granulation drum is 8 m long, internal diameter 3.15 m. and the particle mean residence time in the drum is 5 min.

All simulations will be performed on the same inlet size distribution to the drum while the solution phase ratio is changed. The inlet particle size distribution of fertilizer grade 16-16-8 is as shown in Fig. 6.1.

After the granulated granules come out of the granulator, the average particle diameter is characterized by the median granule diameter D_{50}. Figure 6.2 illustrates the variation of the median granule diameter as a function of the solution phase ratio, y. The fertilizer grade 16-16-8 is found to have a median granule diameter of approximately 2 mm. The median granule diameter varies only slightly as the liquid content increases. This confirms the observation of Van der Leek (1976) that the average granule size varies slightly when the granulation mechanism does not consist of two stages of granulation.

Figures 6.3 to 6.4 shows the effect of the solution phase ratio on to the mass flowrate of the oversize and undersize stream. As expected, the oversize stream increases with increasing moisture content to the granulating fertilizer while the undersize mass flowrate decreases. A lot of fines smaller than the product size are found at low liquid contents,

Figure 6.5 shows that the recycle ratio goes through a minimum as the liquid phase ratio increases. Obviously, bigger granules are granulated as the recycle ratio increases.

Figure 6.5 shows that the recycle ratio goes through a minimum at a relatively low liquid phase content.

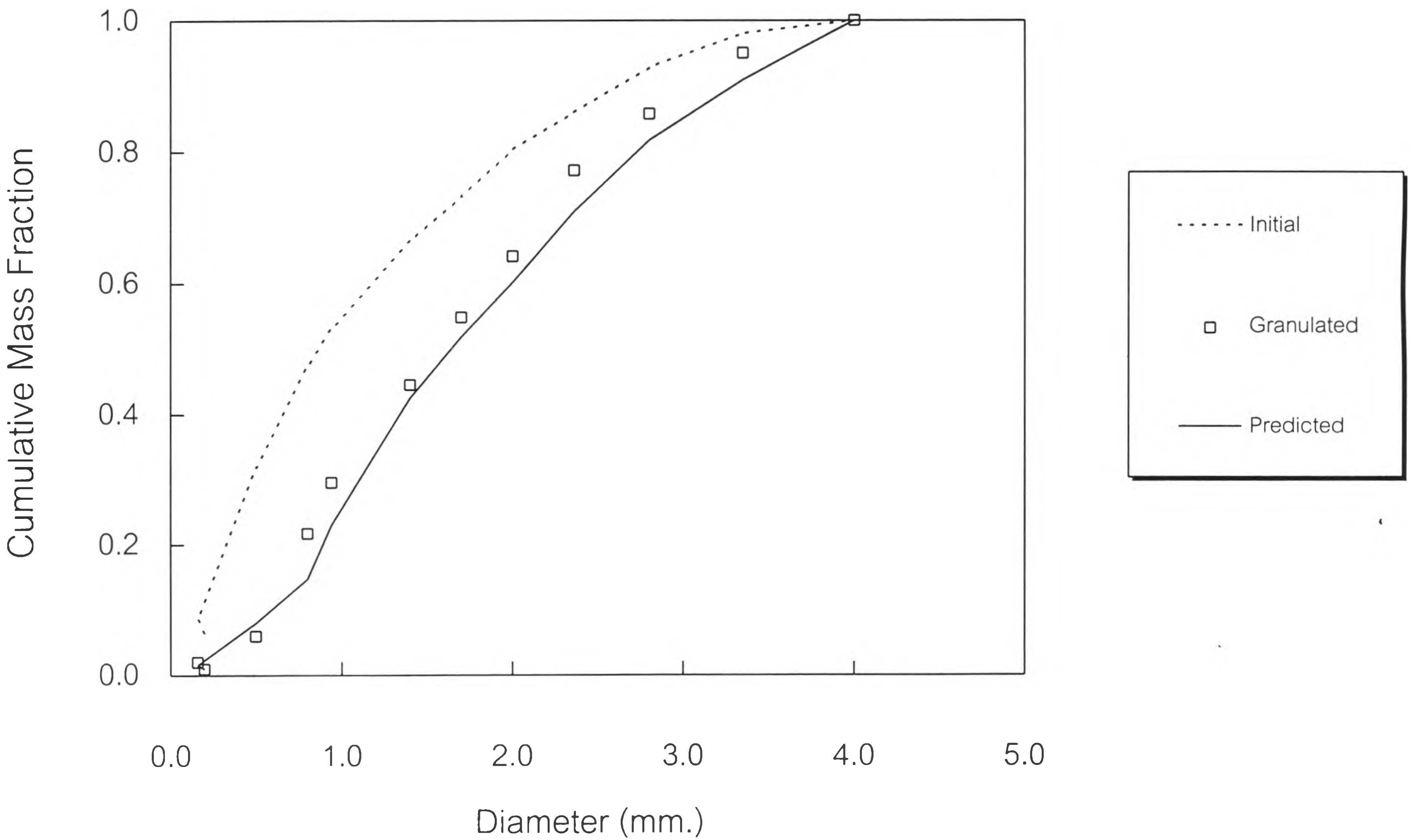

Figure 6.1 Simulation result and NFC plant data for fertilizer grade 16-16-8

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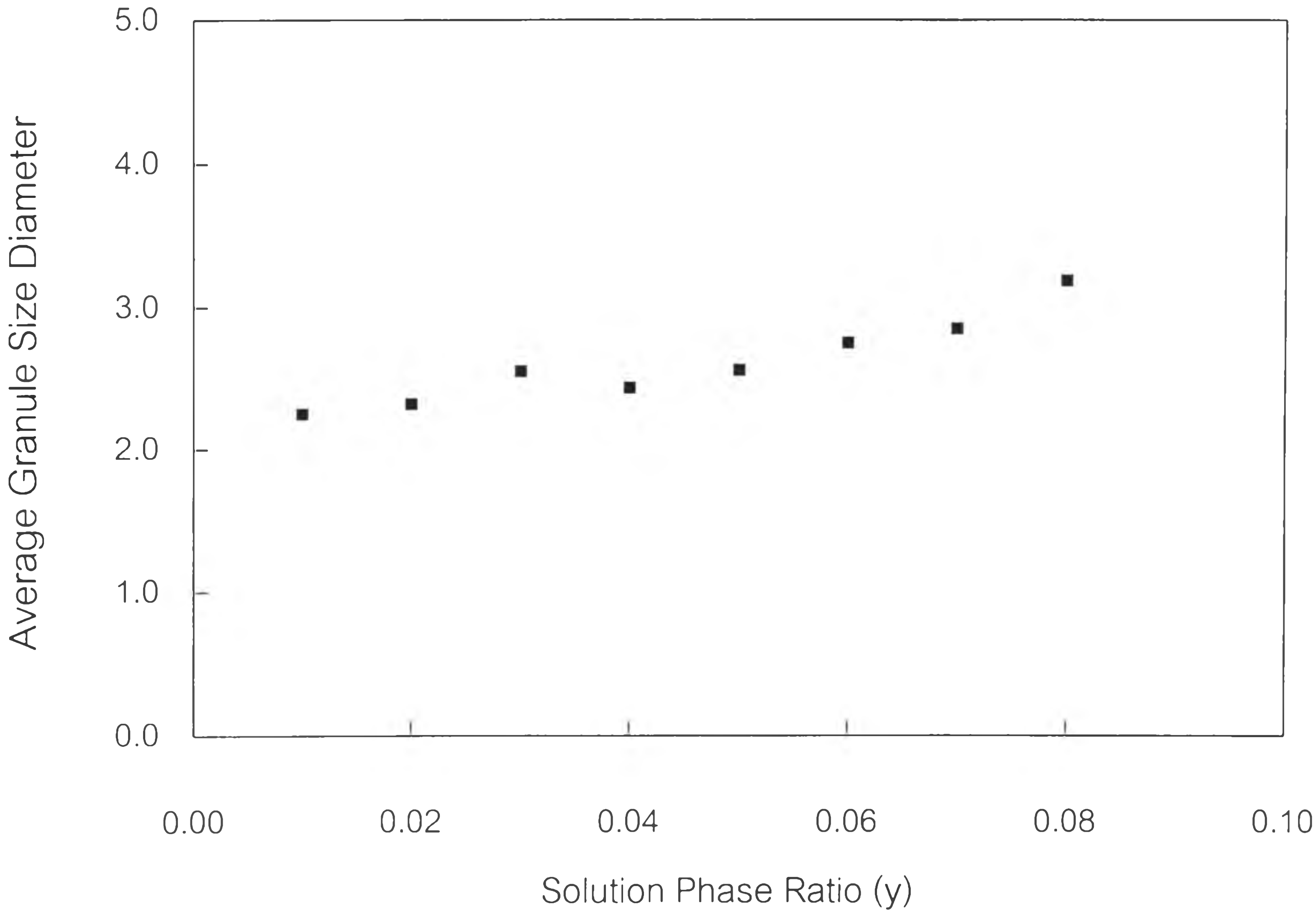

Figure 6.2 Simulation result shown the variation average granule diameter with liquid phase content

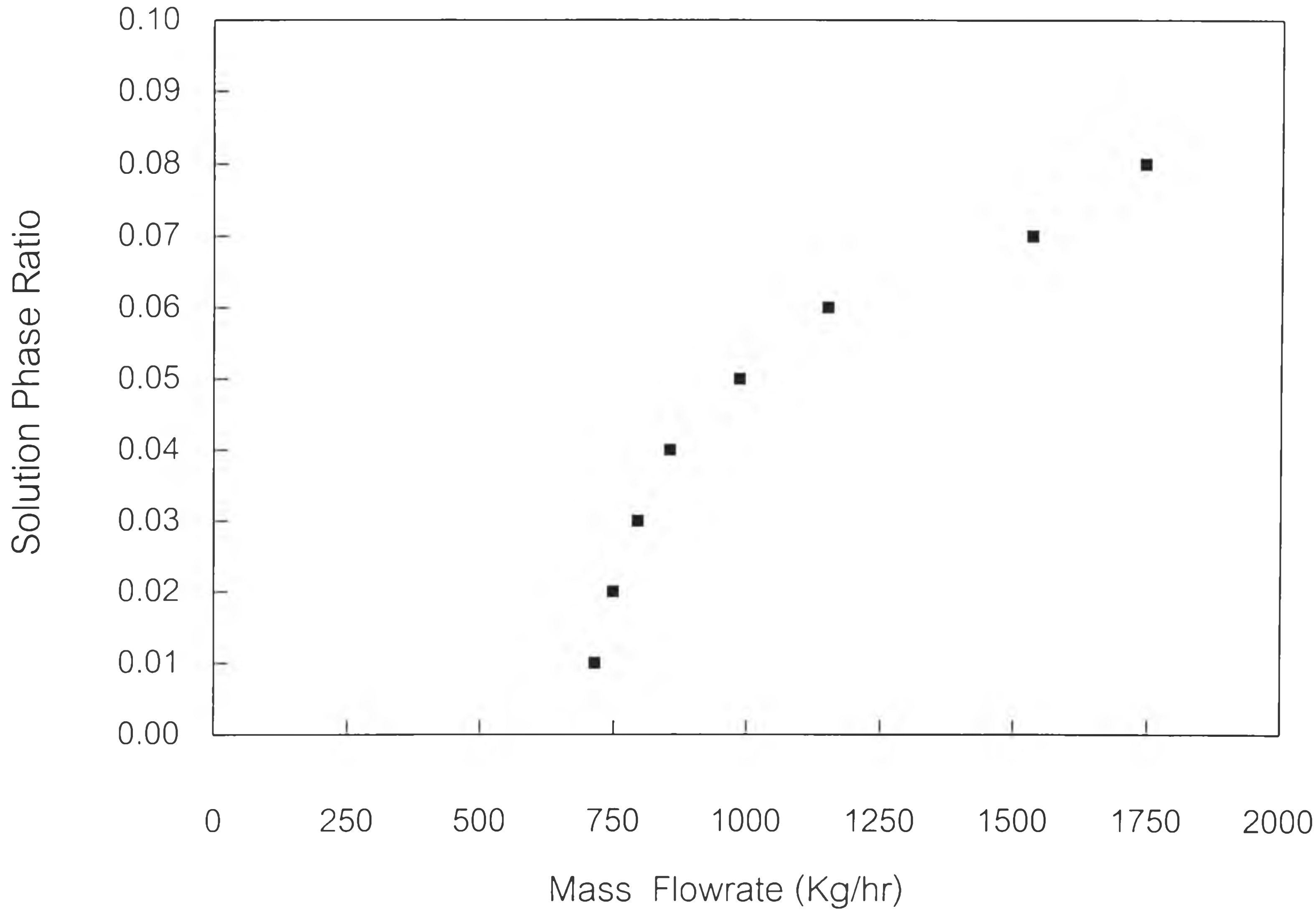

Figure 6.3 Efeect of solution phase ratio on the oversize mass flowrate to fertilizer grade 16-16-8

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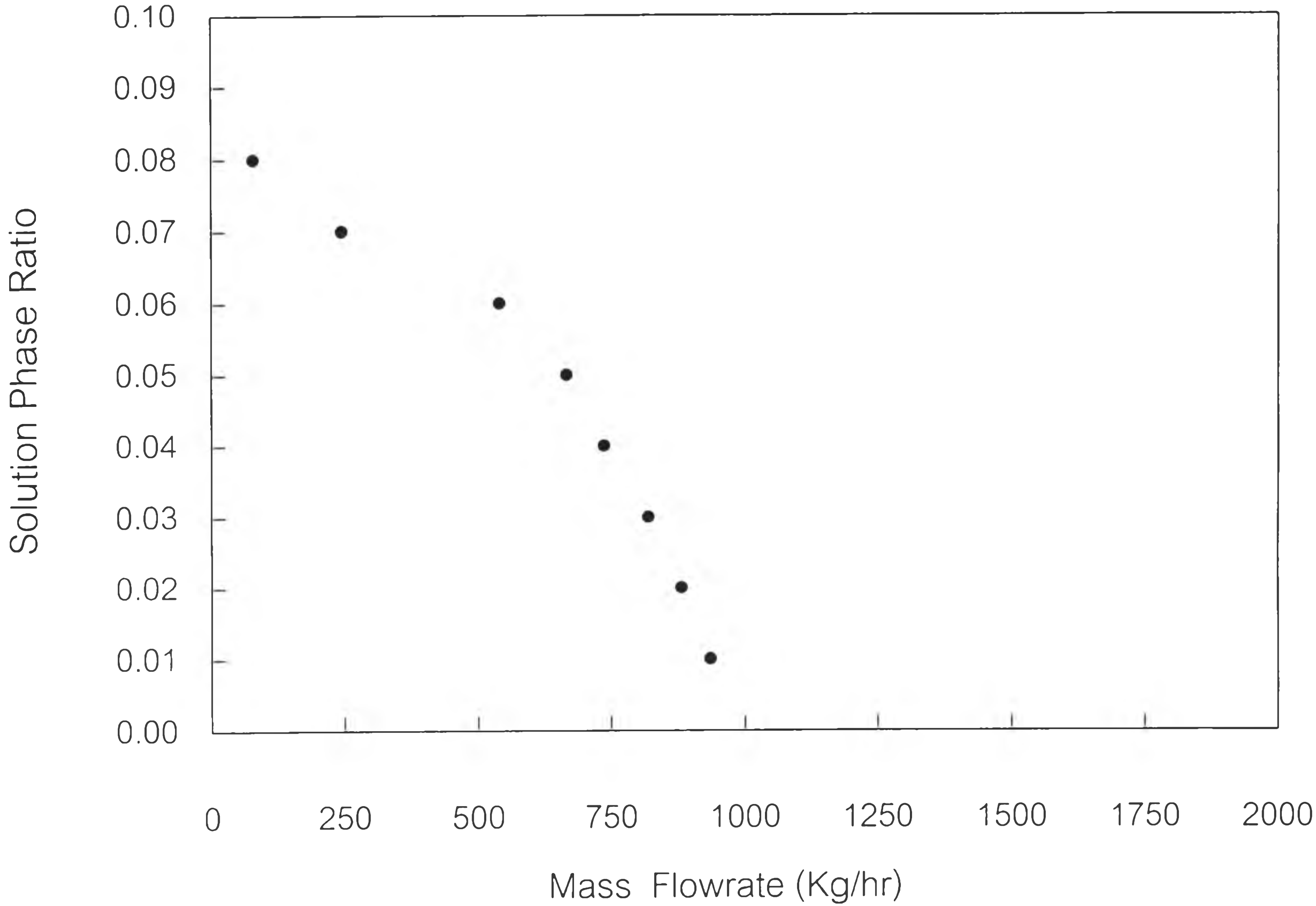

Figure 6.4 Efeect of solution phase ratio on the undersize mass flowrate to fertilizer grade 16-16-8

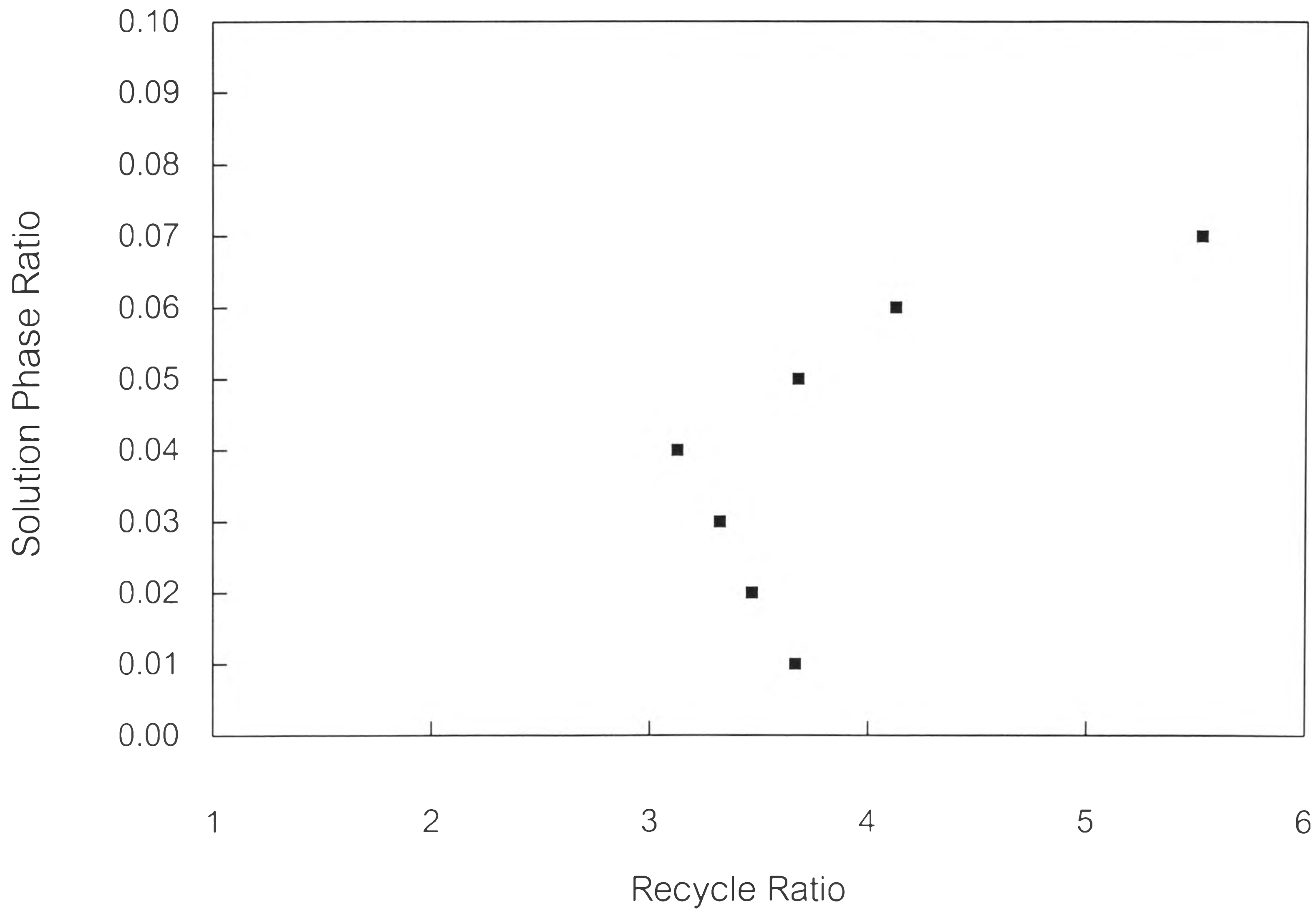

Figure 6.5 Efeect of solution phase ratio on the reycle ratio of fertilizer grade 16-16-8