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International Fertilizer Industry Association - Secretariat: 28 rue Marbeuf - 75008 Paris - France
Tel. +33 1 53 93 05 00 - Fax +33 1 53 93 05 45/47 - ifa@fertilizer.org - www.fertilizer.org

COMPUTER SIMULATION OF FERTILISER GRANULATION PLANTS

TA/84/20

By I.K. Watson, UKF Fertilisers Ltd/Stamicarbon b.v., Netherlands

1. INTRODUCTION

This presentation is an abridged version of the paper written by Mutsers, Slanger, Rutten and Watson, presented to the Fertiliser Society in London in April 1983. Those wishing for fuller details should refer to that paper (Proceedings n° 215).

The computer model described is based on two similar models made for two of UKF's fertiliser plants : the CAN plant at Geleen, Holland and the NPK plant at Ince, England. A flow diagram of one of these plants is shown in figure 1.

2. WHY USE A COMPUTER ?

In fertiliser granulation plants (from which prilling plants are excluded) generally a considerable part of the material leaving the granulator is eventually fed back to the granulator. This recycled material usually consists of screened-off fines, crushed over-size, and fine dust from the cyclones. In some cases also on-size product, as such or after being crushed, is recycled. The fraction of the flow from the granulator that is recycled can vary considerably ; in most processes it exceeds 50 % and in some cases it may even reach up to 90 %. When the plant is in equilibrium the amount of on-size product leaving the plant equals the total amount of liquids and solids fed to the plant. Further, the sieve analyses of all the flows remain constant in time.

The recycling of material, nearly always an indispensable element in the granulation process, makes the behaviour of granulation plants much harder to understand. The characteristics of the recycle, which are themselves the result of what has happened previously in the granulator, influence in their turn what will happen later on in the granulator. As a result of this a certain interference in the process can have an effect upon the equilibrium state which is markedly different from its effect after one pass. Further, in some cases an unstable, i.e., time-dependent behaviour of the granulation loop is caused. The large periodical oscillations which may result in this case, are unfavourable for plant capacity as well as product quality. It is evident that, both in optimising the static equilibrium state as well as in finding causes of instabilities, the effects of the solid recycling have to be taken into account. The concepts of equilibrium and granulation stability are important to the understanding of the granulation process.

The mechanism through which the solids recycle works has been discussed by Van der Leek (Ref. 1). By means of his equilibrium theory of the so-called V/G and L/G Lines it is possible to explain most of the observed phenomena.

Fortunately the modern computing techniques that have arisen since then offer new opportunities. In principle an exact computational elaboration of the van der Leek theory is now possible. The technique to be used consists essentially of making mathematical characterisations of the size enlarging action of the granulator, the separating action of the screens and of the size reducing action of the crushers, followed by computing the equilibrium state of the solids loop. When the granulation occurs through agglomeration , the amount of liquid phase has to be calculated and in order to do so a heat and water balance over the granulator has to be set up. The models only give information about the magnitude and the size distribution of the various flows. The quality of the granules (roundness, mechanical strength, etc.) is not considered.

Process flow scheme Granulation plant

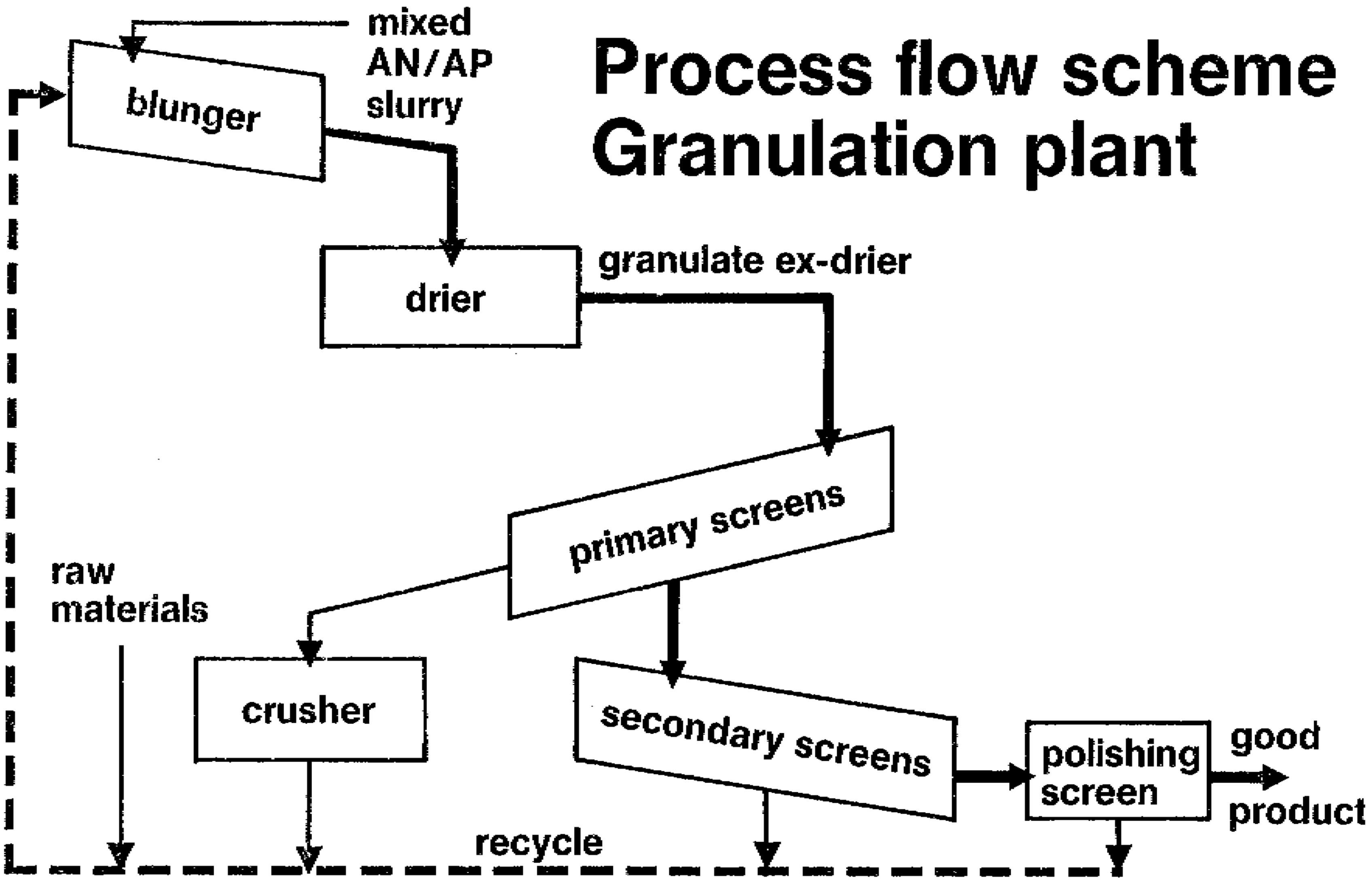

FIGURE 1

3. THE COMPUTER MODEL

3.1. Basis

The model concerns itself with the flow of solids throughout the plant, and how the characteristics of solid flows change.

The characteristics of the solid flows are quantified in terms of the following parameters :

a. Mass flow rate, tonne hr
b. Sieve analysis[*] for a specified set of sieves[+]

In a fertiliser plant (and thus in a model) four changes can occur to a solid flow stream :

a. A separation process, where larger particles are separated from smaller ones (screening)

b. A size reduction process, where particles are made smaller (crushing)

C. A size enlargement process where particles are made larger (granulation)

D. A combination process where two different streams are added together (mixing)

In terms of the two parameters given above (mass flow, sieve analysis) changes of both occur in granulation, screening and mixing. In the case of crushing a change only occurs in sieve analysis.

In a computer model there are three basic building blocks ;

- the screens
- the crushers
- the granulator

The process of mixing is one of simple arithmetic, and will thus not be considered further.

3.2. Screens

The basic concept is that of the probability P, of a particle, sized, passing through a sieve mat, size d_s.

For a particular sieve installation the following sort of curve can be made.

Figure 2 : Probability curve for a particle passing through a screen.

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[*] Sieve analysis can be either fractional (as in Ince model) or cumulative (as in Geleen).

[+] These can be in regular intervals, e.g. every 0.05 mm, or each ISO sieve fraction sub divided into a number of equal fractions. These values are used as a standard throughout the whole programme.

Probability curve for a particle passing through a screen

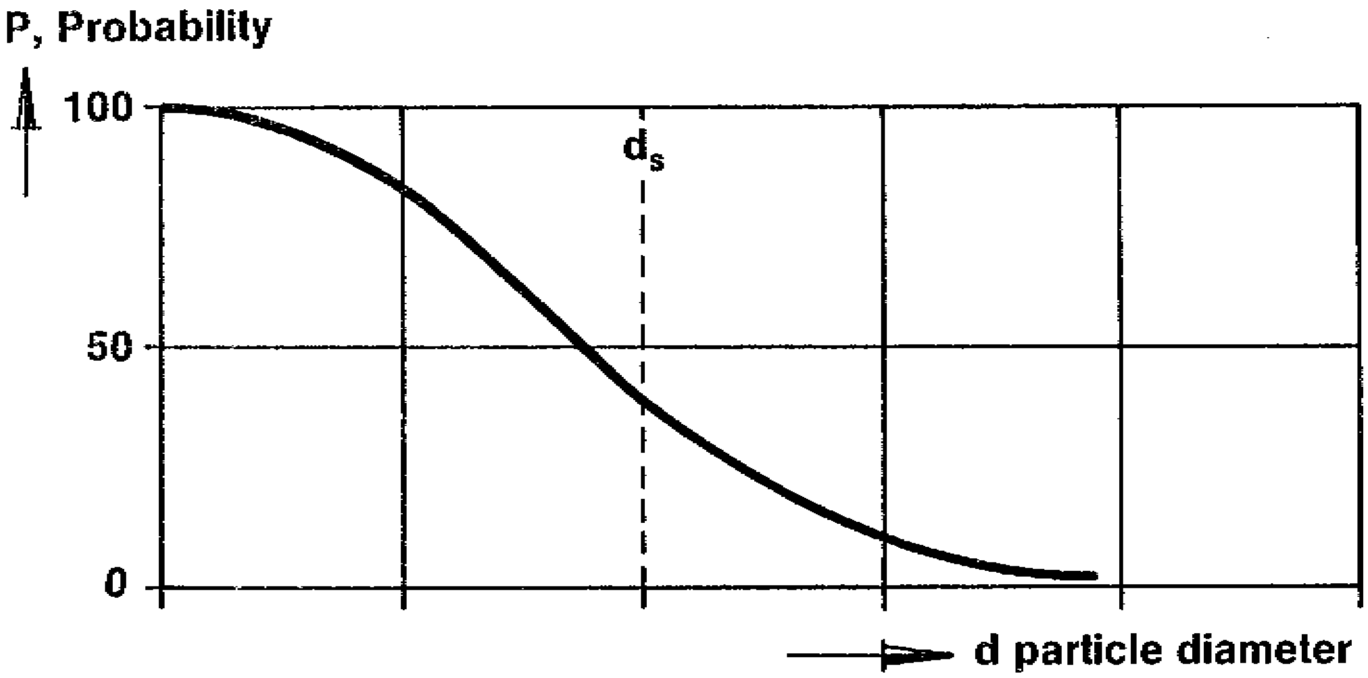


FIGURE 2

With an ideal screen of course, the picture would look like this :

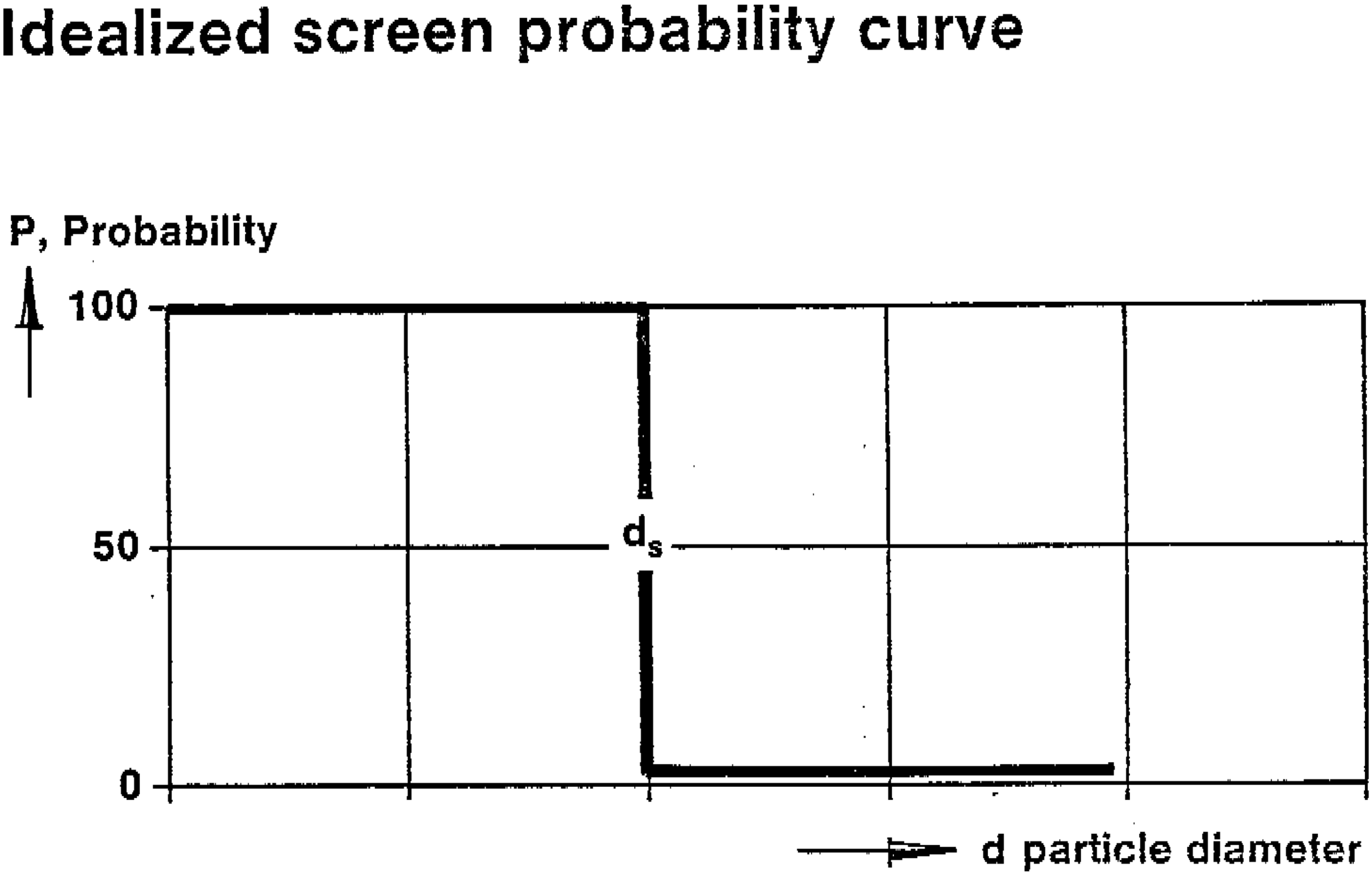


FIGURE 3 : Idealized probability curve for a particle passing through a screen

This picture is never realised.

Also where the curve actually crosses the d_s-line (either below or above the theoretical 50 %) is dependent on the working of the screen. Blinding will give a figure lower than 50 %, whereas worn sieves, or the combination of slotted screens with unround product may give figures above 50 %.

In a computer model the probability curve can either be defined as a data array of, say, 10 probability values at certain d- values, or alternatively, three probability points can be defined at e.g. d_s+0.5 mm. On the basis of these, the probability curve can be built up from two "straight lines" on a log-probability plot.

3 Models of Crushers

Three types of crushers were modelled :

- chain mill
- roll crushers
- cage mill

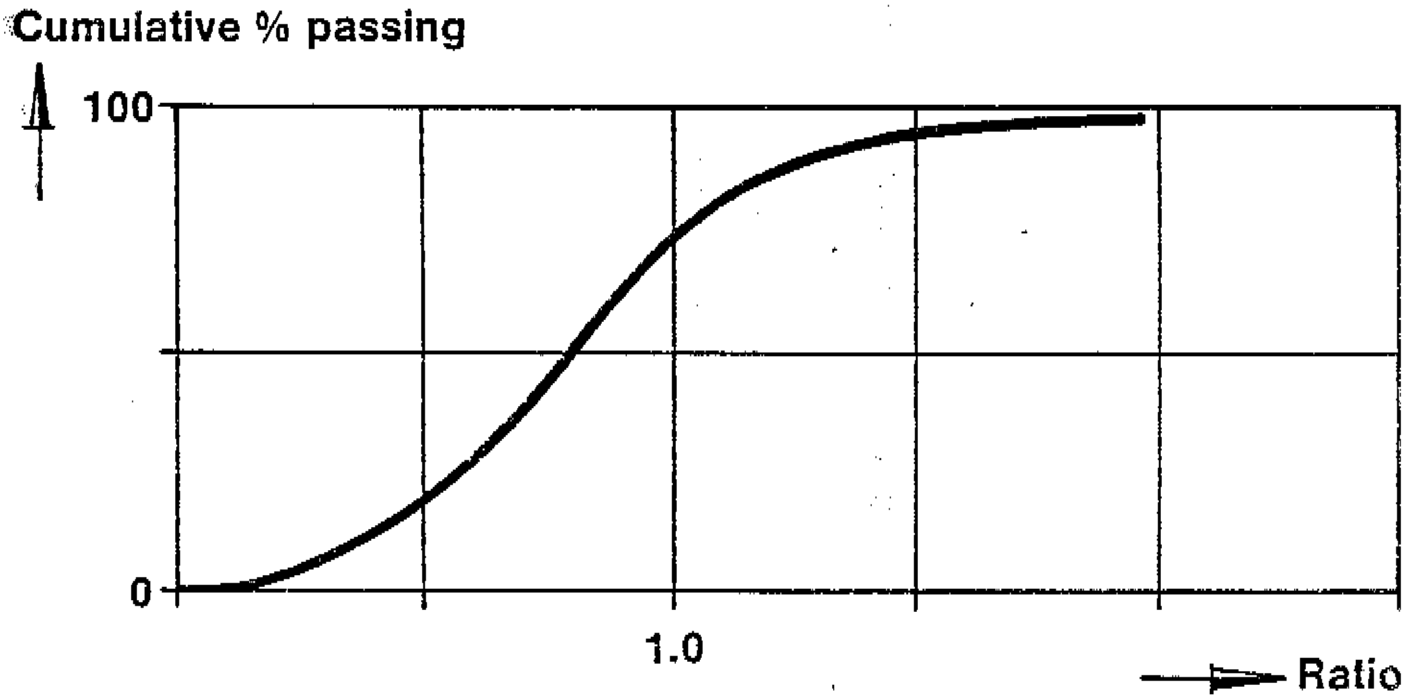
For the sake of brevity only the roll crusher model is described here.

Roll Crusher

After analysing a lot of plant data for different values of d_{rolls} (= distance between the rolls) it appeared that the particle size distribution of the roll crusher outlet was approximately proportional to d_{rolls}, i.e. all our measurements could be described by the same function of d/d_{rolls}.

In figure 4 this function is shown :

Ratio particle diameter / roll crusher gap wid
vs. sieve analysis crushed material



This same function has been used throughout all our calculations, independently of the mass flow to the crusher and the size of the particles in it.

3.4. Model of the Granulator

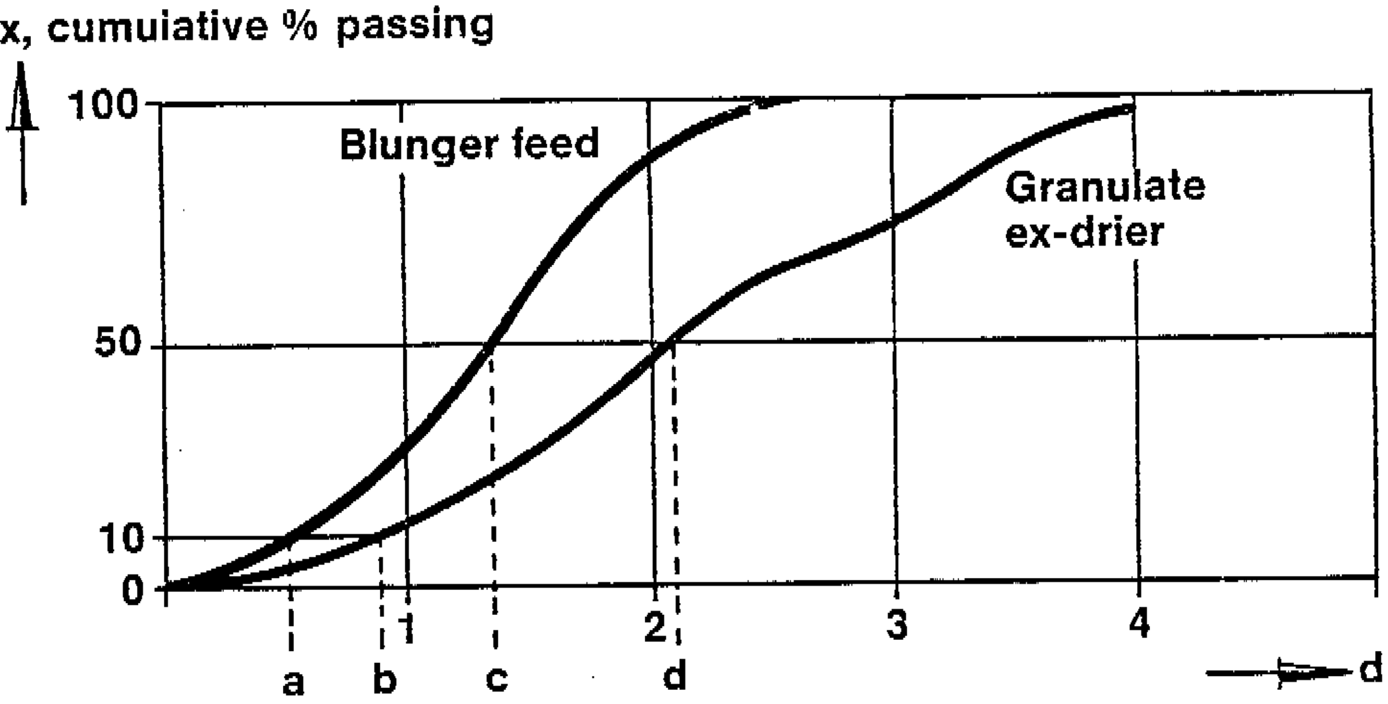
3.4.1. ß-Curve

For the sake of clarity the derivation of a normalised ß-curve is illustrated graphically. The bases are the cumulative sieve curves of the blunger feed and the granulate ex-drier. We use the convention of a cumulative undersize (passing) anal sis. (Thus d_{10} is a smaller diameter than d_{90}).

Figure 5 : Cumulative sieve analysis granulator feed and granulate.

Cumulative sieve analysis blunger feed and granulate

Fig. 5



$$\beta_{10} = \frac{d_{10} \text{ blunger feed}}{d_{10} \text{ granulate}} \text{ , etc}$$

from the cumulative curves above, a β-curve is derived.

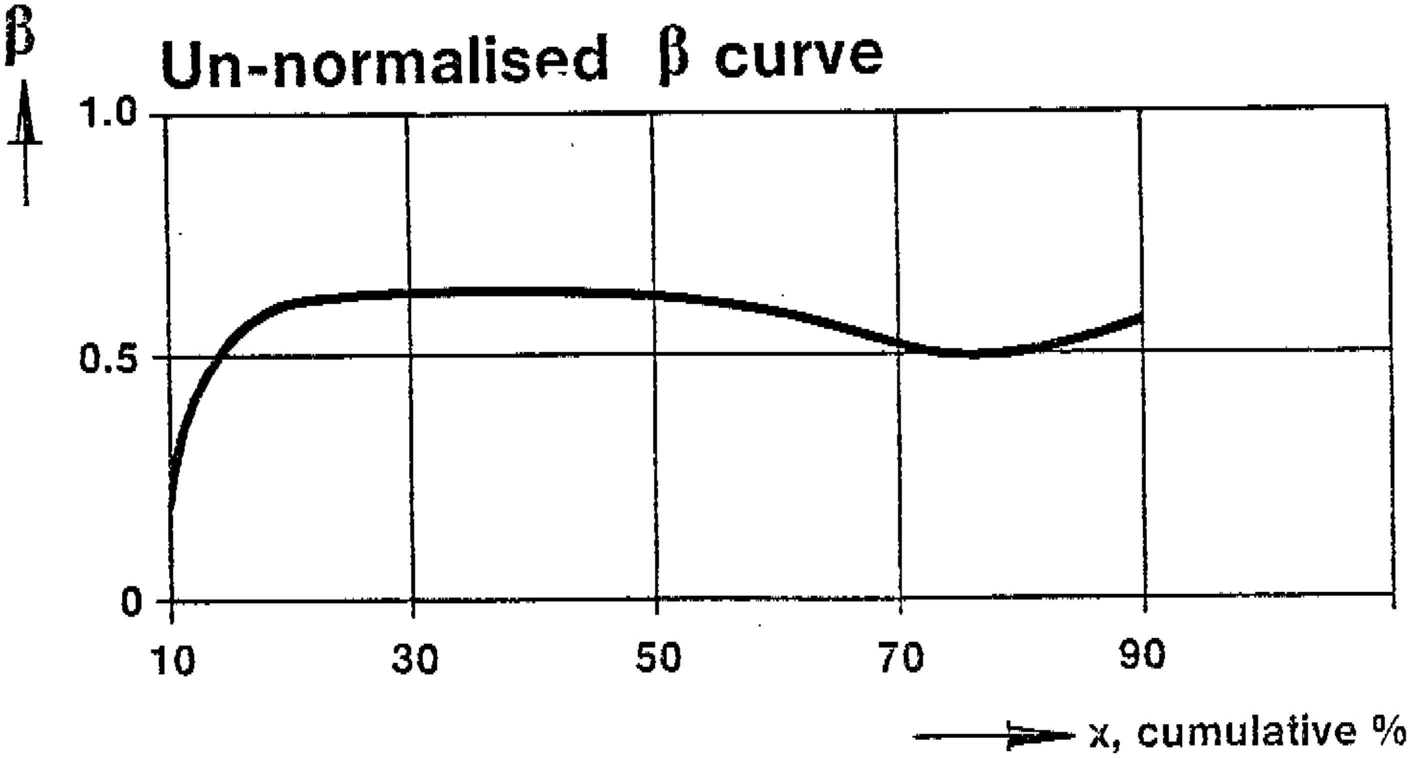


Figure 6 : Un-normalised β curve.

In practice a β-curve can be defined either in terms of deciles, or a particle diameter (granulate or feed); the form of the β-curve differs little whichever method is used, and for practical computing reasons, the decile method was chosen.

A normalised β, $\bar{\beta}$ is derived as follows:

$$\bar{\beta}_X = \frac{\beta_X}{\beta_{50}}$$

It follows thus that $\bar{\beta}_{50}$ is unity.

It has been found in practice that for a particular fertiliser grade, a normalise β-curve retains its shape independently of β_{50}.

In the computer model the normalised β-curve is treated as if it were a property of the blunger. Whether this is in fact so, is considered later.

3.4.2. The Sherrington Equation

In our computer models we assume that the Sherrington agglomeration model holds. The Sherrington equation (Ref. 2) is :

$$y = k\ (1 - 3\beta t)$$

where k = voidage fraction
t = contraction ratio
y = volume ratio of liquid to solid phase

From this the following relationship is derived

$$\beta = \frac{k - y}{3kt}$$

In our model we assume that β is in fact β_{50}, and that k and t are constants. Thus if y, the fluid phase ratio, is known β_{50} can be calculated.

Thus knowing β_{50} and having a normalised β-curve (stored in a data-array), the value β_{10}, β_{20}, etc. can be calculated. From the cumulative sieve analysis of the blunger feed, the cumulative sieve analysis of the granulate (ex-drier) can be calculated.

3.4.3. "y", the fluid phase ratio

Hunter & Hawksley (Ref.3) show that y can be calculated from the granulator water content and the solubility of the formulation.

$$y = \frac{w(1 + s)\ \phi s}{(1 - ws)\ \phi_1}$$

where $w = \frac{\text{weight of water}}{\text{unit weight of dry solids}}$

$s = \frac{\text{weight of solids dissolved}}{\text{unit weight of water}}$

ϕ_s = density of solid phase

ϕ_1 = density of liquid phase

3.4.4. Water content

In our models we suppose that the liquid phase which is present in the solid particles fed to the blunger does not contribute to the capillary forces causing agglomeration, the water content of these solid particles is therefore counted as solid phase.

A complication arises in the calculation of effective granulation water content, and this is the moisture loss through evaporation. We can consider granulation to be largely complete before evaporation begins, or the opposite. Either case is a simplification since we are treating dynamic processes in the model as if taking place instantaneously.

The Ince model considers that water evaporation takes place after granulation, and the Geleen model vice versa. In practice the difference is compensated for by the use of different k and t values. In the case of the Ince model two granulator water contents are thus calculated by the computer:

- granulation water content; exclusive of water from the recycle also no evaporation loss ;
- ex blunger water content; inclusive of water from the recycle and also corrected for evaporation loss.

The first is used for calculation β, and the second for comparison with plant measurements.

3.4.5. Solubility

For the CAN Model, the data for pure ammonium nitrate are used. Measurements have shown that the $Ca(NO_3)_2$ content has no significant influence on the amount of liquid phase which is present under granulation conditions, and can therefore be ignored. In the case of NPK's the solubility is measured experimentally using a hydraulic press.

The solubility data are stored in the computer as a quadratic function of temperature. (In the case of NPK's the equation constants can be changed).

Thus in order to calculate solubility we need to know granulation temperature.

3.4.6. Granulation temperature

A heat balance over the blunger has to be made, the main processes are:

- Mixing of slurry and recycle; the recycle warms up and the slurry cools down until a combined mixed temperature is reached.
- Cooling through evaporation of water and passage of air through the blunger.

Further in both models the effect of heat losses from the blunger, and energy dissipation are taken into account.

4. COMPUTER MODEL: COMPUTER/MATHEMATICAL ASPECTS

4.1. Basic principles of calculation procedure

The calculation procedure is iterative, each iteration for example being one residence time period round the recycle loop.

Before the calculation begins all the various process conditions must be known, together with details of the equipment performance. These are read in from an input list or data array in the programme.

The calculation begins with the recycle: in order to start two assumptions have to be made:

- the recycle screen analysis
- the recycle quantity

Thereafter the calculation proceeds through the following steps:

- addition of solid raw materials to recycle and calculation of granulator feed sieve analysis.
- heat and mass balance over the granulator; calculation of granulation temperature and water content; calculation of solution phase ratio.
- calculation of granulation over granulator plus drier.
- calculations over screens and crushers-

thus - end product quantity and sieve analysis
  - recycle quantity and sieve analysis.

In the Ince model the quantity of end product is compared to the quantity of raw materials, and the calculated recycle sieve analysis and quantity is compared to the assumed start values. If all three of these values are the same then the equilibrium situation exists.

4.2. Types of model, and methods of determining equilibrium

Basic model types:

The two principal model types are:

- a static model
- a dynamic model

4.2.1. Static model

The static model concerns itself exclusively with the determination of the equilibrium situation for a particular set of operating conditions. The manner in which the equilibrium is reached is ignored: in other words the granulation stability is not considered at all.

The model only seeks the granulation equilibrium, whatever it is, and does not consider whether in real life such an equilibrium is attainable and/or usable. In the static model, at the beginning of each new iteration, new assumed recycle conditions are made. The value of these assumptions is derived from the old value and the difference between calculated and assumed value.

4.2.2. Dynamic model

In contrast to the static model, the dynamic model considers how the plant behaves. Not only what the equilibrium is, but how it is reached, and how quickly.

The Ince model is dynamic, and for Geleen both a static and a dynamic model have been made.

In the Ince dynamic model the end recycle quantity and recycle sieve analysis from one time-step become the start situation for the next time-step.

In the dynamic model of the Geleen-plant the residence-time distribution in the rotary-drier is taken into account. Here no start-assumption has to be made. The equilibrium, calculated by the static model is the start point for the dynamic model. For a given disturbance (in the AN-temperature for instance) the computer programme calculates the effect of this disturbance as a function of time.

The advantages of a dynamic model are that it can see the effects of disturbance to the process. If an incorrect start assumption is made then sometimes no equilibrium conditions can be reached. This is purely a reflection of real life - if for instance the recycle loop is burdened up with dust, then by setting normal feed rates it is indeed unlikely that a granulation equilibrium would be reached - or certainly one which has any practical significance.

An example of a calculation with the Ince model is given in Appendix 1 where the effect of a change in plant throughput is demonstrated.

5. COMPARISON OF COMPUTER PREDICTIONS WITH PLANT OBSERVATIONS

Generating data from a computer model is not very difficult. However, collecting reliable data from the plant is: we all know the problems of obtaining representative samples coming from the discharge of a bucket elevator.

Similarly collecting reliable heat and water data over the blunger so that good k and t values can be found is not simple.

Even allowing for these difficulties, the model and plant situation appear to be in fair harmony. Table 1 presents the average value of six measurements on six different days, compared with the results obtained via the model.

TABLE 1

	Difference between measurement and calculation
Granulation temperature (°C)	+ 0.3%
Size enlargement β_{50}	+ 4.4%
d_{50} of granulated product	+ 1.3%
Amount of recycle	+ 1.5%

6. THE USE OF THE MODEL TO PREDICT PLANT CONDITIONS

6.1. Effect of AN melt water content

Appendix 2 shows the effect of changing AN melt water content on medium particle size of the granulate (d_{50}), the granulation temperature (T_6), and the relative amount of product size material in the granulate ($\Delta\eta$: relative to normal plant operation).

There are no surprises in this graph: as more water is added, d_{50} increases, whilst the other two decrease.

6.2. Effect of recycle temperature

See Appendix 3.

The kink in the lines is caused by the AN crystal phase (II/III) latent heat. If the recycle is colder than 84°, then the melt in warming up the recycle also has to provide latent heat.

6.3. The effect of Cage Mill speed

See Appendix 4.

As one would expect, speeding up the mill decreases granulate d_{50}. However, not so obvious is the fact that it has minimal effect on the amount of product size material in the granulate.

7. CONCLUSIONS

1. Computer models work give within limits, good agreement with plant conditions.

2. They can be used to investigate process conditions, and so

   - define bottlenecks
   - predict effects of changes
   - optimise plant operation. (At UKF Ince the production rate of one major production was considerably enhanced as a result of studying with the computer).

3. Computer models are a useful training aid.

4. The weak point is the model of the granulator

   - use of βcurves
   - granulation is often not only by agglomeration

8. REFERENCES

1. J. van der Leek; Proc. ISMA Technical Conference, The Hague, 1976 p.p. 94-114; "Agglomerate Granulation as an Equilibrium Process".

2. P.J. Sherrington; Chem. Eng. (London). July/Aug. 1968, pp. CE 201-CE 215: "The granulation of sand as an aid to understanding fertilizer granulation"

3. G. Hunter & J.L. Hawksley; Proc. ISMA Spec.Dev.Conference, New Delhi, December 1975: "Some developments aimed at reducing recycle ratios of high analysis NPK process".

This shows an iterative calculation to determine granulation equilibrium in a dynamic manner. At the start equilibrium exists with feed rates at 35 tph. The feed rates are instantaneously dropped to 25 tph. After 22 passes of the recycle loop a new equilibrium is reached.

The column headings have the following meanings:

GWS - effective granulation water content at start of iteration;
GWE - ditto, end
GTEMP - effective granulation temperature
SOLN - "y" = solution phase ratio
BETA - β50
PROD - production rate - amount of on-size product leaving the plant in tph
GRAN - recycle ratio
D50 - d50 of granulate mm

The step change disturbance results in an oscillation of plant conditions - granulate d50, production rate and so on.

(N.B.: Sometimes the oscillations increase rather than diminish, and no stable situation is reached).

The equilibrium appears in practice to have been reached after 16 passes of the loop. In the last six passes (17 to 22) little change occurs. These last cycles are dependent on the convergence test limits used for testing for equilibrium. In this example one of the equilibrium test criteria is the difference between production rate and feed rate which must not be greater than 0.1 tph.

```
GIVE PROD-N RATE BASED ON RAW MATERIALS FEEDS (T/H) (35.0000)
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Results from iterative calculation: Dynamic model

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I LN    GWS    GWE   GTEMP    SOLN    BETA  PROD  GRAN    RR    D50
1  2  1.806  1.394   95.5    .136    .695  28.6  136.3   3.8   3.37
1  3  1.394  1.393   95.1    .135    .696  33.6  132.7   3.0   3.09
1  4  1.393  1.427   96.4    .141    .684  34.9  124.1   2.6   2.94
1  5  1.427  1.522   98.2    .154    .655  18.9  114.2   5.1   2.89
1  6  1.522  1.657   97.1    .168    .625  28.2  120.3   3.3   3.07
1  7  1.657  1.571   97.6    .159    .644  21.8  117.1   4.4   3.04
1  8  1.571  1.616   97.1    .163    .635  27.7  120.2   3.3   3.10
1  9  1.616  1.572   97.6    .159    .644  22.7  117.5   4.2   3.07
1 10  1.572  1.610   97.2    .162    .636  26.7  119.8   3.5   3.11
1 11  1.610  1.578   97.5    .159    .643  23.6  118.2   4.0   3.08
1 12  1.578  1.601   97.2    .161    .638  26.1  119.5   3.6   3.10
1 13  1.601  1.582   97.4    .160    .642  24.2  118.5   3.9   3.09
1 14  1.582  1.597   97.3    .161    .639  25.6  119.3   3.7   3.10
1 15  1.597  1.585   97.4    .160    .642  24.5  118.7   3.8   3.09
1 16  1.585  1.594   97.3    .161    .640  25.4  119.2   3.7   3.09
1 17  1.594  1.587   97.3    .160    .641  24.7  118.8   3.8   3.09
1 18  1.587  1.593   97.3    .161    .640  25.2  119.1   3.7   3.09
1 19  1.593  1.588   97.3    .160    .641  24.8  118.8   3.8   3.09
1 20  1.588  1.592   97.3    .160    .640  25.1  119.0   3.7   3.09
1 21  1.592  1.589   97.3    .160    .641  24.9  118.9   3.8   3.09
1 22  1.589  1.591   97.3    .160    .640  25.1  119.0   3.7   3.09
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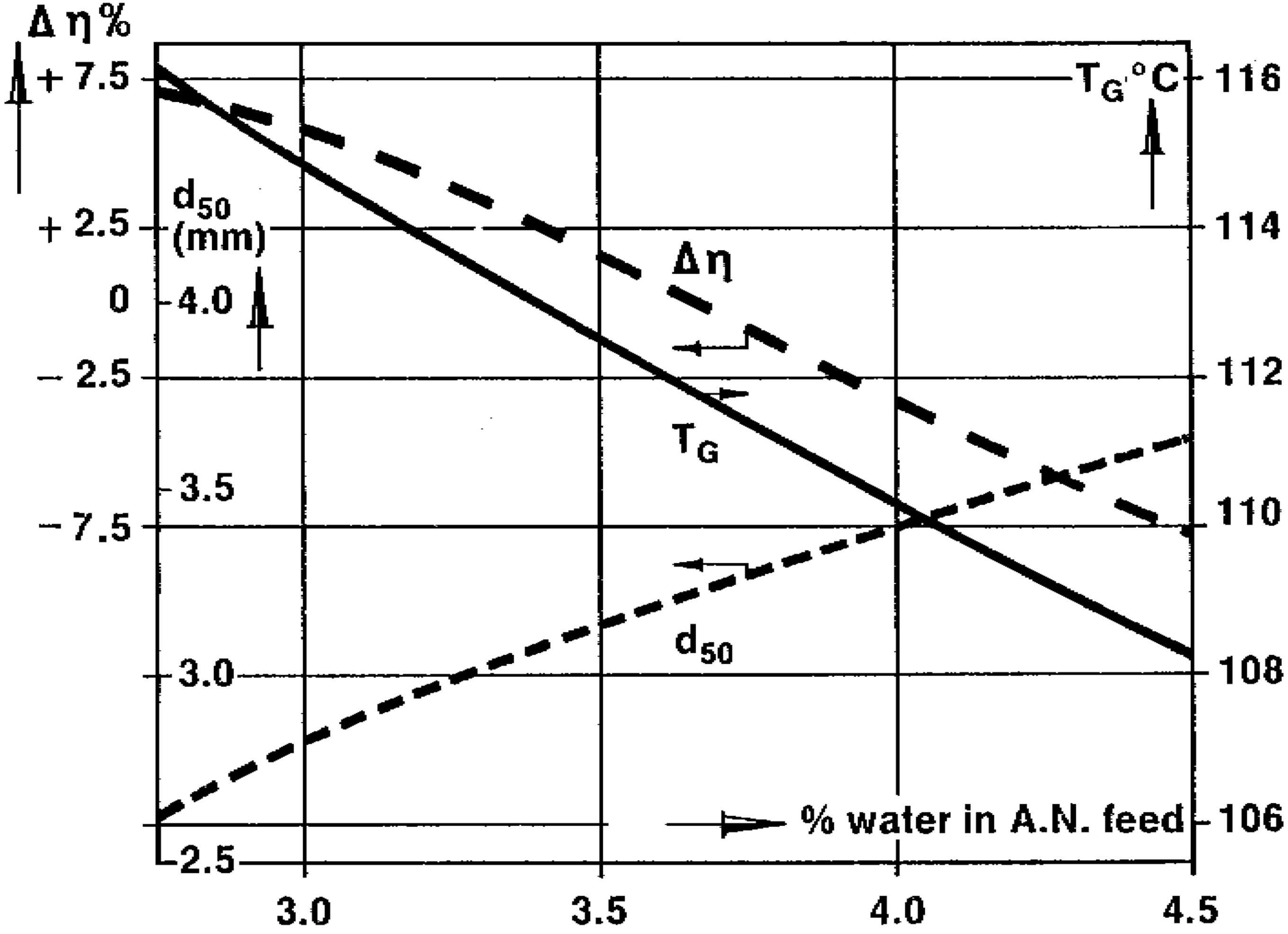
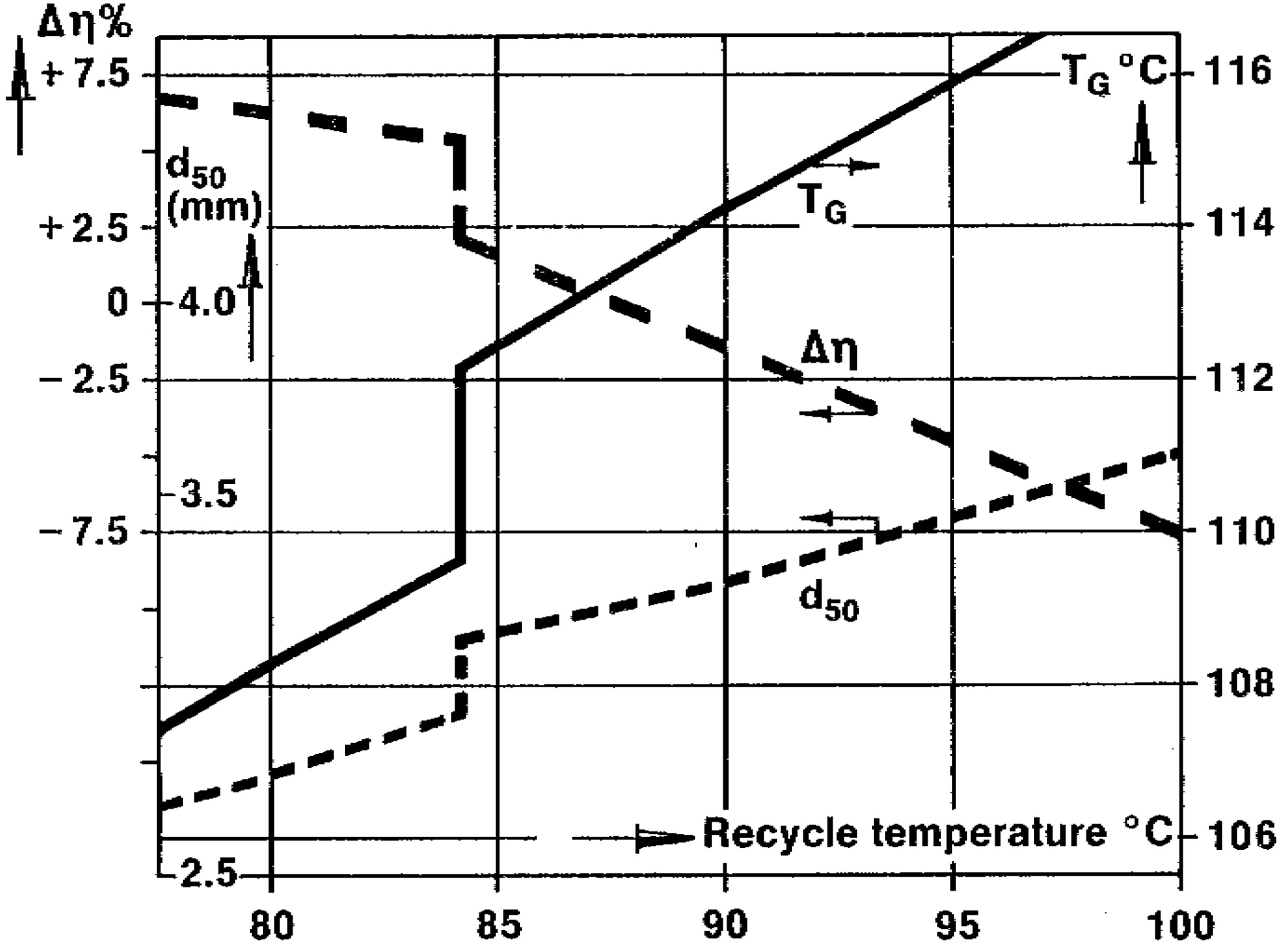
The effect of A.N. melt water content

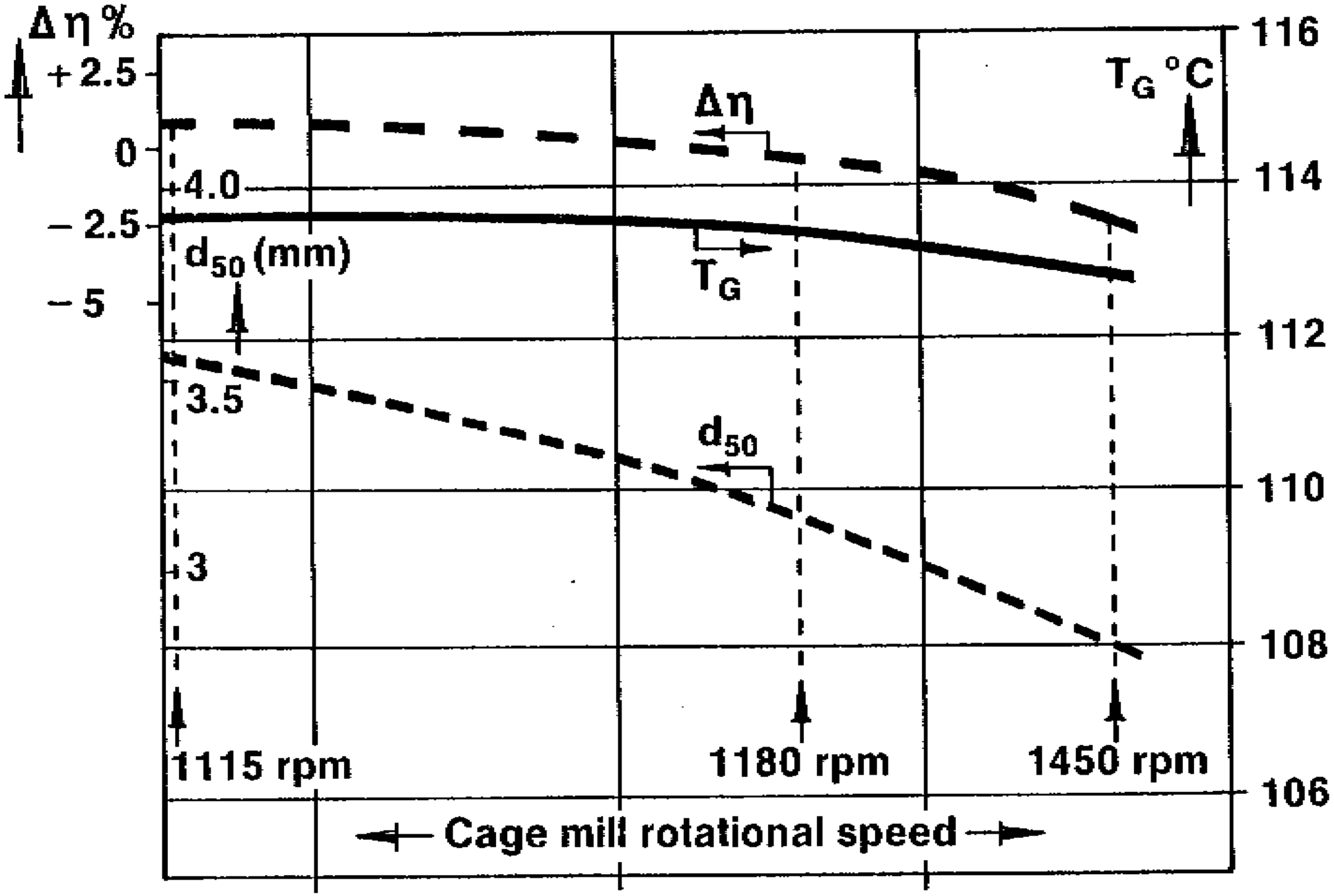


The effect of the recycle temperature



APPENDIX 3

The effect of rotational speed of primary crusher (cage mill)



TA/84/20 Computer simulation of fertilizer granulation plants by I.K. Watson, UKF Fertilizers Ltd/Stamicarbon BV, Netherlands

DISCUSSION: Rapporteurs L.K. RASMUSSEN, Superfos AS, Denmark and B. PERSSON, SUPRA AB, Sweden

Q - Mr. R. MONALDI, Fertimont SpA, Italy

From your paper the computer is used to simulate the plant conditions to optimize the process. Do you intend next time to apply a computerized system on-line to operate the plant?

A - Not yet. The reason for this lies in the last conclusion I gave about the model; that is, the accuracy of simulating the granulator itself is not yet good enough. I think we have only got to go back to one of the earlier papers from Mr. Handley, who was talking about the effects of different phosphoric acids upon granulation to see that to build a reliable model of the granulation step is very difficult indeed. Our approach would therefore be to use the computer model off-line in the manner described in the paper to develop a control philosophy for particular products under particular conditions, and develop this philosophy through to guidelines for operating the plant.

Q - How do you propose to obtain reliable samples of the solid recycle?

A - Earlier I mentioned something about computer models being only as good as the information upon which it is based. As you imply, it is difficult to obtain reliable samples and reliable sieve analysis for recycle and granulate materials. We did obtain large numbers of samples both to determine the sampling variance and also a number of series of samples over short time periods to find out how variable our plant is.

Q - Have you studied an automatic method to obtain sieve analysis on a real-time basis?

A - Several plants in UKF have continuous on-line sieve analysis. One of these works by taking a sample actually of the granulate before screening, in which case the sample is fed to a small screening and weighing system. The problems with this system is that you only need one lump of say 20 millimeters in size, and it makes obtaining a representative sample very difficult. Another plant tries to get round this problem by doing continuous size analysis of the product after screening, and using the indirect correlation between product sieve analysis and granulate sieve analysis. This is also not an entirely adequate method and a better one is to put a number of weighers on the recycle conveyor and so get a continuous indication of fines, on-size and over-size in the recycle. This is the method that I personally favour, though it is potentially more expensive than the other two.

Q - Is it the same with moisture in the slurry?

A - That has been thought about but we do not do it because in our process the slurry is nearly always under boiling conditions, in which case there is a very good correlation between the water content and the temperature. Knowing the temperature and the mole ratio is therefore sufficient.

Q - How much would a complete on-line automation of an NPK plant cost?

A - John Markham is going to answer that partly when he comes to talk about chemical analysis in the next paper.

Like a lot of other people we are going down the route of putting most of our plant data on to computers. We have been doing this for a number of years via an off-line system and we are now moving to a system of doing it directly on line so that we have got up to date information available on a computer terminal and people can see the trends in process conditions; also statistical techniques can be applied to current data giving suggestions to the operator what action he ought to be taking.

Q - Mr. N.D. WARD, Norsk Hydro Fertilizers Ltd, United Kingdom

On the basis of your model would you say it is essential to include a recycle hopper in the recycle loop?

A - I would not say it is essential, and further there are problems with the practibility of actually doing this. Our own plant for instance was built with a recycle hopper because years ago this was the philosophy of Dorr Oliver. It never worked and has since been removed. In any case, if you have good information on your recycle screen analysis and the required flexibility to control it, e.g. a splitter valve or an adjustable crushing system, then such a recycle hopper is not necessary.

Q - Mr. E. SEUNA, Kemira Oy, Finland

How do your models take different rheological properties of ammonium phosphate slurries into account (e.g. due to different phosphoric acids or varying N/P ratio, etc...)?

A - They don't directly, they do it in an indirect fashion very crudely. If you look at the model, what we have in there is a thing that we call Beta-curves, and we have different Beta-curves for different conditions. I accept that it is extremely simplistic but that part of the model is being worked out, and hopefully one of these days we will come to the situation where we can say we know enough about viscosity or other properties of AP slurry to put in as a variable in such a computer model.

Q - Do you actually use the model for creating strategies for handling process disturbances?

A - Yes. See my answer to the first question from Mr. Monaldi.

Q - If the recycle loop is burdened up with dust, could you take that into account?

A - Yes. You can use it in any situation where plant is potentially out of control, or is actually out of control (for example, the recyle D50 has gone down to 1.5 mm). To look at potential ways of getting out of that situation you will discover fairly rapidly that some have no chances of success at all, but others show some promise. However, you may come to the conclusion, in practice, that it would be a lot quicker and easier to dump the whole recycle and start again.

Q - How did you collect the data for the models? Was it done manually or by automatic measurements?

A - All the sieve analysis data was collected manually, and let me say once again that to build a reliable model requires the collection of a very large amount of data. This is in effect an advantage of the computer model; it forces you to collect a lot of information which otherwise would probably not be collected. For example, if I take a sample of the granulate, how representative is that? if I take another one in two minutes time, am I going to get the same result or not?