Granulator Performance for Urea Granule Quality: A Study on Material Balance and Recycle Seed Ratio

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***Abstract*— Granulation is a critical process in quality of urea fertilizer, particularly their size distribution, significantly affects the product's performance and marketability. Urea synthesis begins with the reaction between ammonia and carbon dioxide, where ammonium carbamate is decomposed to produce urea by granulation process. This research aims evaluate the performance of granulator on urea granule size product quality based on material balance and recycle seed ratio (RSR). The granulator performance in the urea granulation process was evaluated for a production capacity of 3,500 tons/day. The methodology involves data collection from operational records in six days respectively, followed by mass balance analysis and product quality evaluation based on particle size distribution. The analysis revealed a significant deviation between design and actual data. Specifically, the design mass balance indicated a total inlet of 236,726 kg/h and a total outlet of 230,575 kg/h, resulting in a mass deficit of 6,151 kg/h attributed to dust formation and water evaporation. The measured on-size product yield was approximately 98.50% at the outlet, with the desired particle size range of 2–4.75 mm. These findings provide critical insights for process optimization and resource management in urea granulation, emphasizing the need for precise operational control to minimize material losses and ensure product quality compliance with specifications.**

Keywords—granulator, mass balance, optimization, quality, recycle seed.

I. Introduction

Urea production is one of the crucial aspects of the fertiliser industry, acting as the main source of nitrogen for plants. The process involves the reaction between ammonia (NH_3) and carbon dioxide (CO_2) to produce urea through complex chemical conversion stages [1], [2]. Urea (NH_2CONH_2) is a compound that has an important role in the agricultural sector, providing essential nutrients that support plant growth [3], [4]. One of the critical stages in urea production is the granulation process, where a highly concentrated urea solution is converted into urea granules of a specific size [5]. Granulators play a central role in this process by spraying the urea solution onto the surface of seed particles under fluidised conditions. The success of the granulation process not only determines the quality of the final product but also affects the overall operational efficiency of the plant [6].

The evaluation of granulator performance to ensure the stability of the granulation process and compare design data with actual conditions. The evaluation was conducted through mass balance analysis and recycle seed ratio efficiency, which are key parameters in product quality control. The research data was obtained from operational records for six consecutive days during the production period that experienced significant anomalies. Mass balance analysis results showed a total feed of 236,726 kg/h and a total output of 230,575 kg/h, with a mass deficit of 6,151 kg/h identified as dust. In addition, the percentage of on-size product was recorded at 98.50% at the outlet, with a desired particle size range of 2 to 4.75 mm.

The problem of granulation in the urea production are the agglomerated quality affected fine particle handling process, storage, and application. Particulary, their size distribution, significantly affects the product's performance and marketability. Understanding the factors influencing granule size is essential for optimizing the granulation process.

This study aims to evaluate the performance of granulator on urea granule size product quality based on material balance and recycle seed ratio. The novelty is uniquely combine the examination of material balance and recycle seed ratio, two critical factors in granulation processes. Previous research may have addressed these factors separately, but this study provides a holistic view of how they interact and influence granule quality [7]–[9]. The results of this study confirm the importance of controlling operational variables in the granulation process to minimise material loss and ensure product quality in accordance with set specifications. Thus, this evaluation enhancing granule size uniformity and quality has direct implications for the agricultural sector. Improved urea granules can enhance fertilizer effectiveness, leading to better crop yields and more sustainable agricultural practices

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II. METHOD

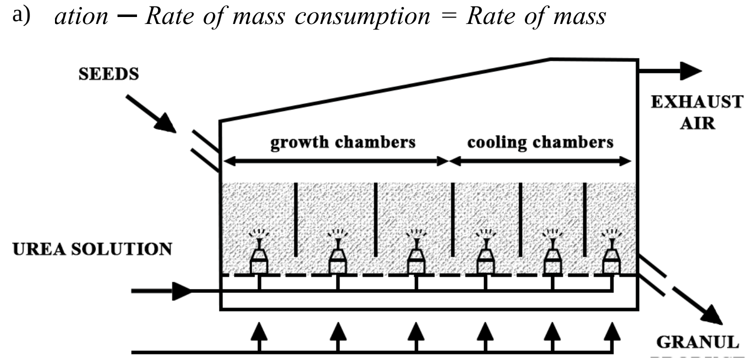
The evaluation focussed on the urea granulation process that takes place in the Granulator unit, with the main concerns being the quality of the final product, operational efficiency, and the effect of the recycle seed ratio on granulation yield. To achieve these objectives, a variety of equipment is used to ensure data accuracy and validity of analyses. The granulator acts as the main equipment in this process, where urea solution is sprayed onto the surface of seed particles under fluidised conditions to form granules of the appropriate size. In addition, a weigher is used to record the mass flow into and out of the granulator, including at the outlet stage of the granulator as well as the final product. The spray nozzle serves to spray the urea solution with precision, while the dust collection system captures urea particles carried during the granulation process to reduce material loss and improve process efficiency.

A mass balance was applied to calculate the balance of inflow and outflow, as well as monitor the potential for mass accumulation in the system. With a systematic approach and the use of appropriate equipment, this evaluation aims to provide an in-depth insight into the production efficiency and product quality in the urea granulation process, providing a basis for process optimisation and improved operational sustainability in the fertiliser industry.

A. Mass Balance

Mass balance is the detail number of materials entering, leaving, and accumulating in system. The main principle of mass balance is Lavoisier's law of mass conservation, which is the sum of the mass of compounds before and after the presence or absence of chemical reactions is the same. This can be expressed in the following equation [10], [11]:

Rate of mass input — Rate of mass output + Rate of mass ation — Rate of mass consumption = Rate of mass accumulation (1)



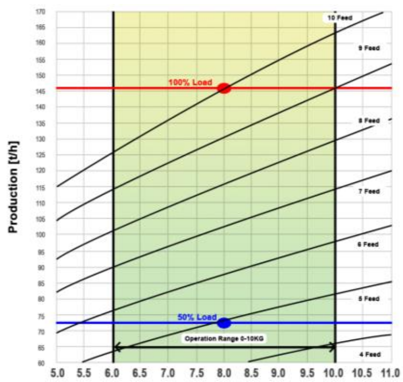


Figure 1. a) Representation of fluidized bed granulator scheme in urea production b) Imagery pressure and production (tonnes/day) on three way valve graph

If the accumulation is zero, for example for a steady state process (in = out), then the mass balance equation becomes:

Rate of mass input + Rate of mass generation = Rate of mass output + Rate of mass consumption (2)

Equilibrium occurs in the process without reaction, the values of generation and consumption are equal to zero, so the equation becomes:

Rate of mass input = Rate of mass output (3)

B. Recycle seed ratio (RSR)

Recycle seed ratio is the ratio between granulator inlet (recycle) and product (t/h). recycle seed ratio is used to determine how much product will be returned to produce the appropriate product onsize [12]. The formula used is as follow:

$$\text{recycle seed ratio (RSR)} = \frac{X1 - X2}{X2} \quad (4)$$

Actual outlet granulator using 2 weigher which is divided as follows:
X1 = granulator outlet weigher
X2 = product weigher

The undersize mass returning to the granulator also needs to be calculated as it is related to the recycle seed ratio. The formula used is as follows:

Mass Undersize = (Granulator Outlet Weigher A + Granulator Outlet Weigher B) – Product Weigher (5)

Recycle seed ratio is obtained from the undersize mass divided by the amount of urea granule product. With the following equation:

$$R = \frac{Massa\ undersize}{Product\ Weigher} \quad (6)$$

Recycle seed ratio (RSR feed base) can be calculated because urea melt enters using (m^3/h), so it can be converted to tonnes/h using the feed base according to the initial inlet pressure. With the following equation:

Feed Base (CPV) =

$$\frac{((\sqrt{PIV60}\ (Jumlah\ Header) \times 3500) : 10}{24} \quad (7)$$

$$R = \frac{Massa\ undersize}{Feed\ base} \quad (8)$$

Apart from using the formula above, an easy way can be done to find out the recycle seed ratio (feed base) by using the Figure 2, which can directly know the incoming feed base without the need to convert from m^3/h to tonnes/h [13].

The Figure 2 presents a comparison between the number of headers used and the operating pressure and production rate (tonnes/hour). Normal operation takes place over a pressure range of (6-10) kg/cm², with optimal conditions at 8 kg/cm². The blue line represents a 50% production load, while the red line indicates a full production load (100%). The y-axis represents the total feed base production, while the x-axis represents the urea pressure entering the granulator.

Labels such as 4 feed, 5 feed, 6 feed, and so on refer to the number of headers used, for example 4 Feed indicates the use of four headers in the granulation process. At an optimum pressure of 8 kg/cm² with a production load of 100%, a feed base recycle seed ratio of 146 tonnes/hour is obtained. This figure serves as a visual representation of formula (7) used to calculate CPV (feed base), providing a deeper understanding of the relationship between the number of headers, operating pressure, and production efficiency in urea granulation systems [8], [14], [15].

C. Unit Recycle

The granulator outlet weigher serves to transfer the coarse granules to the inlet Bucket Elevator, which then lifts them to the screening unit. At this stage, the coarse granules are classified into several categories, namely lump, oversize, product size, and under size. Meanwhile, the ammonia vapour generated from the liquid ammonia flash drum is returned to the ammonia plant unit for reuse. The recycle seed consists of crushed particles controlled within a ratio range of 0.5 to 1.0 [1], with varying feed rates to maintain system balance. If the ratio is below 0.5, the reseeded seed particles will be recaptured by the urea melt, causing excessive product size growth. Conversely, an increase in the amount of recycle seed that has not undergone reseeding can overload other process equipment, reducing system efficiency. Thus, the recycle seed ratio is a critical parameter that must be closely monitored and controlled in the recycle unit to ensure the stability of the granulation process and maintain the quality of the urea product produced [16].

TABLE 1.
DESIGN DATA RECYCLE SEED RATIO (RSR) BY FEED AND PRODUCT BASE

Days	RSR Feed Base (%)	RSR Product Base (%)	Onsize (%)
1 - 6	55.609	55.609	94.9

TABLE 2.
ACTUAL DATA RECYCLE SEED RATIO (RSR) BY FEED AN PRODUCT BASE

Days	RSR Feed Base (%)	RSR Product Base (%)	Onsize (%)
1	98.266	98.641	99.49
2	95.495	95.056	99.32
3	97.233	97.321	99.28
4	97.329	97.300	99.15
5	96.993	96.617	99.34
6	98.327	98.129	98.97

D. RSR (recycle seed ratio) feed

Feed RSR is the ratio between the undersize granule mass and the feed base value (CPV) entering the Granulator unit. The RSR feed parameter plays a crucial role in the granulation process, as it directly influences the particle size and quality of urea granules to match the desired specifications. Optimal control of RSR feed can reduce moisture during product formation, thereby helping to maintain other quality parameters, such as biuret formation, which affects the overall efficiency of the granulation process. In addition, RSR feed also contributes to the percentage of product onsize, namely products with a standardised size [12]. Therefore, monitoring and controlling the RR Feed is an important factor in improving process stability and final product quality in the urea granule production industry.

E. RSR (recycle seed ratio) product

RSR Product is the ratio between the amount of feed entering the granulator inlet and the amount of granulated urea product produced (tonnes/day). The recycle seed ratio parameter is used to determine the proportion of product that will be returned as seed, to ensure that the product onsize produced is in accordance with the set specifications [12]. This ratio plays a crucial role in the efficiency of the granulation process, as it directly affects the quality of the final product as well as the stability of the granulator operating conditions. Optimal control of RSR product can maintain granule size consistency, improve production efficiency, and prevent overloading of other process units. Thus, monitoring and controlling RR Product is a strategic step in improving the overall performance of urea granule production [17].

F. Product onsize

Onsize or product onsize is the fraction of urea granule products that meet specifications with a size of 3 mm. This parameter is a key measure in assessing the efficiency of the granulation process, as it shows how large a proportion of particles directly meet specifications without requiring additional processes, such as crushing oversize products using a crusher or recycle undersize products for re-processing [16]. The higher the onsize percentage, the more efficient the granulation process, as fewer urea granules have to undergo reprocessing cycles. Onsize products that have met the standard specifications will be packaged and

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marketed as the final product [18]. Therefore, controlling onsize yield is a key factor in optimising urea granule production to improve efficiency and reduce waste of energy resources.

III. Results and Discussion

A. *Design and actual technical data on mass balance urea granulator*

TABLE 3.
DESIGN MASS BALANCE UREA GRANULATOR

Component	Inlet				Outlet			
	xi	<61> (kg/h)	xi	<64> (kg/h)	xi	<62> (kg/h)	xi	<94> (kg/h)
UREA	94.75%	149,531.6075	98.50%	77,725.365	98.50%	223,525.065	98.50%	3,591.31
NH_3	0.05%	78.9085	0.00%	0	0.00%	0	0.00%	0
CO_2	0.00%	0	0.00%	0	0.00%	0	0.00%	0
H_2O	4.08%	6,438.9336	0.25%	197.2725	0.25%	567.3225	0.25%	9.115
BIURET	0.70%	1,104.719	0.80%	631.272	0.80%	1,815.432	0.80%	29.168
FORMALDEHYDE	0.43%	678.6131	0.45%	355.0905	0.45%	1,021.1805	0.45%	16.407
CH_3OH	0.00%	0	0.00%	0	0.00%	0	0.00%	0
CAUSTIC SODA	0.00%	0	0.00%	0	0.00%	0	0.00%	0
TOTAL	100.0%	157,817	100.00%	78,909	100.00%	226,929	100.0%	3,646
MASS BALANCE	236,726				230,575			

TABLE 4.
ACTUAL MASS BALANCE UREA GRANULATOR

Komponen	Inlet				Outlet			
	xi	<61> (kg/h)	xi	<64> (kg/h)	xi	<62> (kg/h)	xi	<94> (kg/h)
UREA	94.75%	149,531.6	98.26%	139,162.3	98.26%	282,365.96	98.26%	5,828.40
NH_3	0.05%	78.90	0.00%	0	0.00%	0	0.00%	0
CO_2	0.00%	0	0.00%	0	0.00%	0	0.00%	0
H_2O	4.08%	6,438.93	0.38%	535.80	0.38%	1,087.16	0.38%	22.44
BIURET	0.70%	1,104.71	0.91%	1,286.39	0.91%	2,610.15	0.91%	53.87
FORMALDEHYDE	0.43%	678,61	0.45%	637.29	0.45%	1,293.10	0.45%	26.69
CH_3OH	0.00%	0	0.00%	0	0.00%	0	0.00%	0
CAUSTIC SODA	0.00%	0	0.00%	0	0.00%	0	0.00%	0
TOTAL	100.0%	157,817	100.00%	141,621.80	100.00%	287,356.38	100.0%	5,931.41
MASS BALANCE	299,438.8056				293,287.8056			

B. *Design and actual granulator's mass balance*

Table 3 of the design mass balance includes the components in the urea production process, both at the inlet and outlet. In the inlet flow, there are two main lines, namely <61> (urea feed pump out) and <64> (recycle particle), with urea as the main component: 149,531.6 kg/h at <61> and 77,725.3 kg/h at <64>. NH_3 was recorded at 78.91 kg/h only in the <61> lane, while H_2O showed a total mass of 6,438.93 kg/h at <61> and 197.27 kg/h at <64>. Biuret recorded 1,104.719 kg/h in <61> and 631.272 kg/h in <64>, while formaldehyde (CH_2O) was 678.61 kg/h and 355.09 kg/h, respectively.

At the outflow, line <62> (Granulator Outlet) recorded urea 223,525.065 kg/h and line <94> (DHST from granulator) 3,591.31 kg/h, with H_2O decreasing to 567 kg/h and 9.11 kg/h, indicating evaporation during production. Biuret decreased to 1,815 kg/h and 29.16 kg/h, while formaldehyde yielded 1,021 kg/h and 16.40 kg/h.

The conclusion of the mass balance shows the efficiency of the production process in maintaining a high concentration of urea. The total inlet exceeded the total outlet by a deficit of 6,151 kg/h due to dust generated during the process, including granule fragments, biuret and moisture. The mass reduction of water and biuret indicates success in drying and purifying the product [19].

Table 4 of the mass balance shows the actual data on material flow in the urea production process in the granulator. The total inlet mass is 299,438.8056 kg/h, while the total outlet mass is 293,287.8056 kg/h. This difference indicates a mass loss in the process. Mass loss can be caused by several factors such as evaporation [20] and some are formed into dust with a mass of 6,151 kg/h. At the inlet, 139,162.3 kg/h of urea enters, and at the outlet, 58,284.1 kg/h of urea product is produced. This shows that although urea is the main product, not all raw materials are successfully converted into the final product.

C. Analysis of RSR againts design and actual product size

Table 1 and Table 2 presents six days of actual and design operational data on the recycle seed ratio in the urea granule production process. The evaluation results show that the recycle seed ratio for feed and product reached 55.609%, meaning that more than half of the material in the process was recycled. Production efficiency is also evident from the onsize product percentage which reached 94.9%, indicating that most of the products met the set size specifications. The calculation of the recycle seed ratio is based on the design mass balance of the urea process flow diagram (PFD). The similarity of feed and product recycle seed ratio values, as well as the high percentage of onsize products, reflects the effectiveness and stability of the production process [15]. In addition, this data can be used as a reference in comparing laboratory results

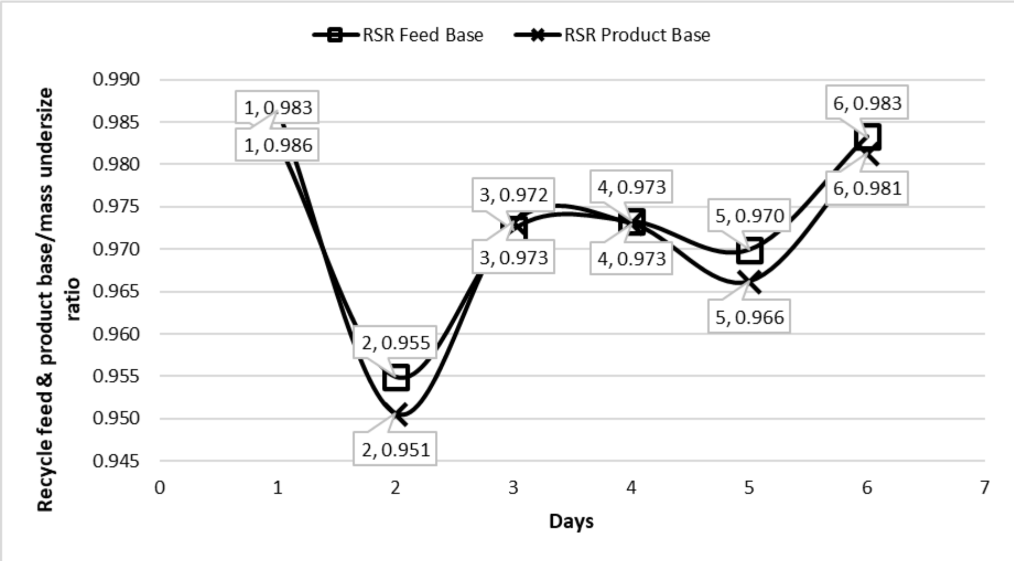

Figure 2. Comparison RSR feed and RSR product base rato

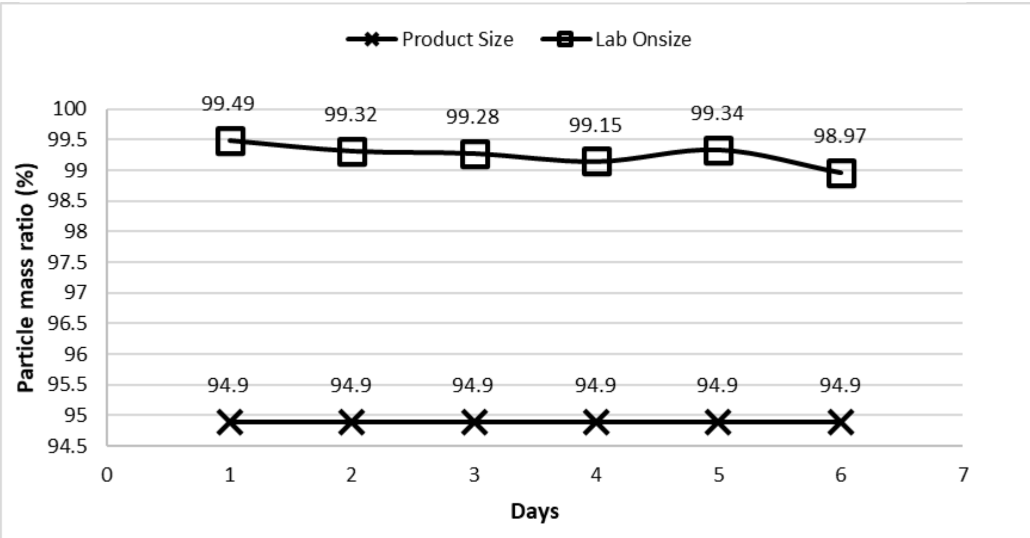

Figure 3. Product size vs laboratory on result graph

(actual data) to identify potential deviations.

Meanwhile, Table 2 shows the recycle seed ratio feed and product data for six days when significant process anomalies occurred. On the first day, the feed recycle seed ratio was recorded at 98.266%, while product reached 98.641%, indicating a difference between the two. Throughout the six days, there were fluctuations with the lowest value on the second day, which was 95.495% for feed and 95.056% for product. However, the percentage of onsize product remained stable, ranging from 98.97% to 99.49%, indicating that most of the product still met the size specifications. According to the design, the feed and product recycle seed ratio values should ideally be the same. However, the actual data shows a difference which is most likely due to the startup conditions, where not all products immediately reach the onsize. As a result, a higher percentage of undersize contributes to the ratio discrepancy observed in this evaluation.

D. Product comparison of RSR feed and product base

This graph shows a comparison between the recycle seed ratio of feed base and product base over six days of operation. Both parameters show a similar pattern, with a decrease on day two followed by a gradual increase until day six. Overall, the recycle seed ratio of the feed base is slightly higher than that of the product base, although the two should be equal under normal operating conditions.

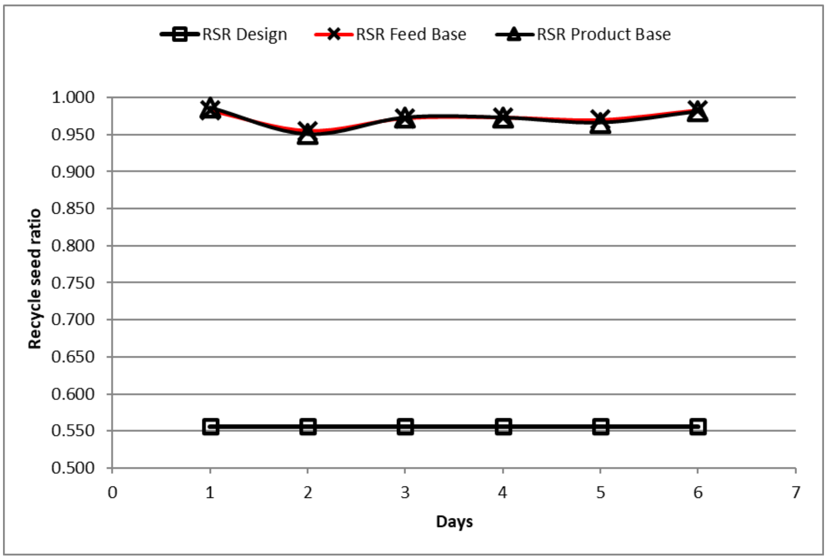

Figure 4. RSR design, RSR feed, and RSR product base proportion

These deviations may be caused by several factors, such as operating conditions, temperature, equipment breakdown, and poor granule formation [21]. Equipment breakdowns such as a malfunctioning crusher can reduce the recycle seed ratio [22], which in turn reduces the amount of product produced and makes the product ratio smaller.

On the first day, both recycle seed ratios started at a high level, close to 0.985%, reflecting high efficiency in the production process [8]. However, on the second day, there was a sharp decline, with the product ratio slightly below the feed ratio due to process interruptions. From the third to the sixth day, both ratios showed a steady upward trend, signalling a recovery in process efficiency after adjustments were made to the disturbance.

A recycle seed ratio value consistently above 0.945% during this period indicates that the plant is operating within the normal range. The pattern of increase after a sharp drop illustrates the ability of the system to adapt to operational fluctuations [12] and to return to high efficiency. Overall, this graph shows good stability and efficiency in the production process, despite temporary disruptions that may affect the seed recycle ratio (RSR).

E. Comparison between product size quality and onsize laboratory

The graph above illustrates the relationship between product size and onsize laboratory results (%) in the six-day urea production process. The design baseline value for product size is 94.90%, while the onsize laboratory result reaches 99.25%, indicating that the production process and quality control are functioning well and producing products that conform to the set specifications.

The product size line remained stable at 94.90% as the baseline, while the onsize laboratory results (%) showed small fluctuations but remained around 99%. This indicates that the majority of urea products produced are within the desired size range. These small fluctuations reflect variations in the production process, but are not significant enough to affect the overall product quality, indicating that quality control is effectively implemented [16], [23].

The consistency of product size and the high percentage of laboratory onsize results (%) indicate stability and efficiency in the production process. Fluctuations in the onsize yield reflect good control of process parameters, such as pressure, temperature, and material flow [13], [24], [25]. This graph reflects the success in maintaining high product size and quality throughout the observation period, confirming the effectiveness of the quality control system in the urea production process.

F. Appeal of RSR design, RSR feed base, and RSR *product base*

This graph illustrates an important aspect of urea plant operation. The design recycle ratio (red line) serves as the baseline with a stable value of about 0.5028, which indicates the optimal operating target [26]. The feed base and product base recycle ratio lines fluctuate above the design value, indicating high efficiency in raw material utilisation and product processing [22].

The feed base recycle seed ratio (RSR) has a higher value than the design, which signifies the plant's ability to recycle more raw materials, reflecting resource efficiency and waste reduction. On the other hand, the recycle ratio of the product base, which is also above the design value, indicates good and consistent product quality [4], [20].

The stability of both recycle seed ratios above the baseline confirms that the plant is operating under optimal conditions. Despite the lower design recycle ratio, the plant's ability to achieve higher ratios reflects good process management and effective quality control, which overall improves operational efficiency and production sustainability.

IV. Conclusion

Regarding the performance and efficiency of the production process in the granulator unit, the urea granulation process succeeded in producing 2-4 mm products with consistent specifications, reaching a percentage of 99%. This consistency was achieved despite several factors affecting the granulation process, such as fluctuating operating conditions. Although there are deviations between design and actual data, especially in the recycle seed ratio, the actual value tends to be higher than the design, reaching 98.266% on the first day, indicating better processing efficiency compared to the design of only 55.609%. The results of the mass balance analysis showed a difference between the inlet mass of 299,438.81 kg/h and the outlet mass of 293,287.81 kg/h, which was caused by water evaporation and dust formation during the process. Evaluation of the recycle seed ratio (RSR) indicated a high efficiency in raw material utilisation, with a stable feed to product ratio value of >95% over the six days of operation although it was noted that there were anomalies in the production process.

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