International Journal for Multidisciplinary Research (IJFMR)

E-ISSN: 2582-2160 ● Website: www.ijfmr.com ● Email: editor@ijfmr.com

Automation of Vertical Roller Mill for Bentonite Grinding

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Abstract:
Bentonite is a key raw material in the production of Iron Ore Pellet making [1], where it is used as a binder. It is typically available in the form of solid lumpy mass. To utilize Bentonite in iron ore pellet production, it must be ground to fine powder. At Rungta Mines Ltd. Dhenkanal Steel Plant (RML-DSP), this grinding process is carried out using a Vertical Roller Mill (VRM) also called as a Raymond Mill. To enhance grinding efficiency, ensure size consistency and elimination of manual intervention, we have developed a robust and simple automation process using a Distributed Control System (DCS) to enable autonomous mill operation.

Keywords: Bentonite Grinding, Vertical Roller Mill (VRM), Raymond Mill, Iron Ore Pelletization, Agglomeration, Automation, Distributed Control System (DCS).

1. Introduction

Iron Ore Pellets are a widely utilized primary raw material for producing sponge iron in direct reducing rotary kilns and pig iron in blast furnaces. Iron Ore Pelletization is an agglomeration process in which iron ore fines (typically below 10 mm in size.) are transformed into porous spherical pellets. There are three major technologies for iron ore pellet production: Shaft Furnace, Grate-Kiln and Straight Grate technology [2]. While the production method may vary, the raw materials remain largely the same, with only minor variations in quantity. At Rungta Mines Ltd. Dhenkanal Steel Plant (RML-DSP), the Straight Grate Technology (SGT) has been adopted for iron ore pellet production, with a total installed capacity of 3.75 million tonnes per annum.

The production of Iron Ore Pellets utilizes Iron Ore Fines as the primary source of iron, Limestone and Dolomite act as fluxing agents to adjust basicity and to enhance mechanical properties such as Cold Crushing Strength (CCS) and Tumbler Index (TI) of pellet, Coal or Coke provides the thermal energy required during induration and bentonite serves as a binder to impart green pellet strength (GCS) for handling and adequate dry strength prior to induration [3].

In iron ore pellet production, the raw materials must be finely ground to achieve the desired Pellet. Iron Ore Fines are required to be ground to a minimum of 80% passing through 45 micron screen. While the remaining raw materials such as Limestone, Dolomite, Coal, Coke and Bentonite must be ground to at least 80% passing through a 75 micron screen. To achieve this, the grinding circuit comprises a pair of wet ball mills dedicated to iron ore grinding, a dry ball mill used for grinding limestone, dolomite, coal & coke and a Vertical Roller Mill (VRM) commonly referred to as a Raymond Mill, specifically used for bentonite grinding.

1.1. Graphical Abstract

The Iron Ore Pelletization process consists of multiple stages as shown in Figure 1. It illustrates the flow of raw material in Pelletization by emphasizing the role of bentonite grinding of Vertical Roller Mill and its integration into the overall process.

This graphical representation provides a clear overview of how various raw materials including iron ore fines, limestone, dolomite, coke and bentonite are processed through different grinding mills before being mixed, balled and subjected to induration for final Iron Ore Pellet product.

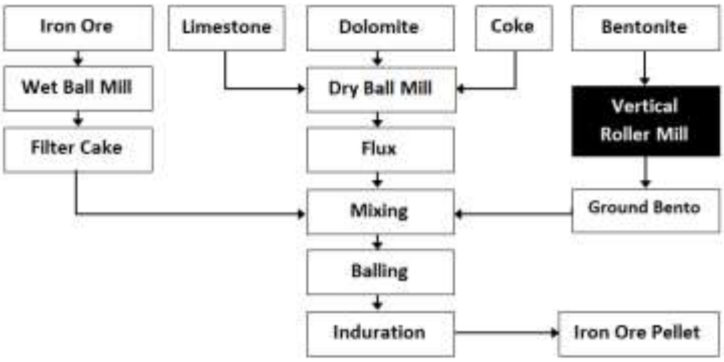


Figure 1: Iron Ore Pelletization Process

1.2. Role of Bentonite in Pelletization

Bentonite plays a critical role as a binder in the iron ore Pelletization process. During pellet formation, bentonite facilitates the agglomeration of fine iron ore particles by imparting sufficient green pellet strength (Green Compressive Strength – GCS), enabling the pellets to retain shape during handling, drying and induration [4]. Its high swelling capacity and water absorption help distribute moisture uniformly within the mix, promoting better pellet growth in the disc or drum pelletizer.

Moreover, bentonite contributes to dry strength development before induration, ensuring structural integrity during the preheating and firing stages. While its presence is limited to around 0.5%–1.2% of the pellet mix due to its non-ferrous nature, it is indispensable for maintaining pellet quality parameters such as Cold Crushing Strength (CCS), Drop Number, and Tumbler Index (TI). Proper grinding and dispersion of bentonite are essential to ensure homogeneous mixing and maximize binding efficiency.

1.3. Challenges in Bentonite Grinding at RML

Grinding Bentonite to the desired fineness presents several challenges:

- Operator Dependency: Manual operation of Raymond mill can lead to inconsistent results and reduced efficiency.
- Particle Size Variation: Maintaining consistent fineness is critical for uniform pellet bonding.
- Energy Consumption: The grinding process is energy-intensive and inefficient grinding can increase operational costs.

1.4. Objective of the Study

To address these challenges, this study focuses on optimizing the grinding process by automating the VR

M using a Distributed Control System (DCS). The objective is to achieve.

A. To obtain consistent particle size.
B. Higher grinding efficiency to reduce VRM mill run hrs.
C. Minimized operator dependency through autonomous mill operation.

By integrating automation, the study aims to enhance the stability, efficiency and sustainability of bentonite grinding, ultimately improving the overall iron ore Pelletization process.

2. Methodology

This study presents a structured approach to optimizing bentonite grinding using automation in a Vertical Roller Mill (VRM) at Rungta Mines Limited-Dhenkanal Steel Plant (RML-DSP). It covers the selection of raw materials, VRM Operation & equipment specifications, essential process parameters for achieving the required particle size distribution. The grinding process is enhanced through a Distributed Control System (DCS), which autonomously regulates key parameters such as feed rate, roller speed, Whizzer Separator speed & RC Fan to ensuring stable and efficient grinding operations. A comparative study was conducted to evaluate the performance improvements before and after automation, analysing key indicators such as mill running time, mill throughput and particle size consistency. The findings highlight that DCS-driven automation significantly improves grinding efficiency, reduces mill run hours and minimizes process variability. It’s leading to enhanced productivity and reduced operator dependency in Bentonite grinding of Raymond mill operation.

2.1. Raw materials

Bentonite is selected as the focus of this study due to its critical role in the iron ore Pelletization process. As a natural clay mineral predominantly composed of “Montmorillonite”, bentonite acts as a binder that provides the necessary mechanical strength to green pellets during formation and ensures their thermal stability during induration.

2.2. Vertical Roller Mill (VRM) Design

The Vertical Roller Mill, specifically a Raymond Vertical Air Swept Mill is installed at Ringta Mines Limited-Dhenkanal Steel plant. It plays a critical role in the bentonite grinding within iron ore pelletizing process. It is designed with a capacity of 10 tonnes per hour (dry basis), the mill efficiently grinds bentonite characterized by a bulk density of 0.6–0.9 t/m³ and a moisture content ranging from 6% to 14%. The feed material, with particle sizes up to 40 mm, is processed to a fine product with 80% passing through 75 microns screen. The mill system incorporates a variable frequency drive (VFD), while a recirculation fan (RCF) system with a capacity of 45,000 NCMH maintains airflow operating at an inlet pressure of 750 mmWc. To aid moisture reduction, a hot air generator (HAG) with a thermal capacity of 1.3 MKcal/hr supplies combustion gases at an outlet temperature of 250–350°C and a Whizzer Separator for precise product size control. Mill is powered and driven by a 190 kW motor and equipped with six high-chrome alloy rollers, the mill ensures optimal grinding performance and energy efficiency. This setup supports the stringent quality requirements of bentonite used in pelletizing, contributing to consistent pellet quality and improved plant productivity.

2.3. Vertical Roller Mill (VRM) Operation

Raymond Mill is a type of vertical roller grinding equipment widely used for pulverizing non-metallic minerals such as bentonite, limestone, gypsum, and others. It functions based on compression grinding and air classification, making it ideal for producing fine powder, typically up to 75 microns.

2.3.1. Bentonite Feeding

The process begins with bentonite feeding into the mill via a weigh feeder, ensuring a consistent and controlled feed rate. The material is then directed onto the grinding ring located at the base of the mill. Find the Figure 2 for schematic flow diagram of bentonite grinding.

2.3.2. Grinding Mechanism

A central rotating shaft drives multiple pendulum-type rollers, which swing outward due to centrifugal force. These rollers press against the inner surface of the grinding ring, crushing the material between the two surfaces. Repeated passes lead to effective size reduction to the desired fineness.

2.3.3. Air Flow and Classification

Re-circulation Fan forces air into the grinding chamber. This air stream lifts the finely ground particles and carries them upward to an integrated classifier called Whizzer Separator for particle size separation.

2.3.4. Separation in the Whizzer Separator

The Whizzer Separator, comprising rotating blades, classifies particles based on size and mass. Fine particles with low mass follow the air stream through the blades and are carried out of the mill. Coarse particles, being heavier, are deflected by the blades and fall back into the grinding zone for further size reduction.

The rotational speed (RPM) of the separator determines product fineness. Lower RPM (low speed) allows more particles to pass, resulting in a coarser product and higher throughput. Higher RPM (high speed) exerts stronger centrifugal force, retaining more particles for regrinding, yielding a finer product but with reduced throughput.

2.3.5. Product Collection via Cyclone Separator

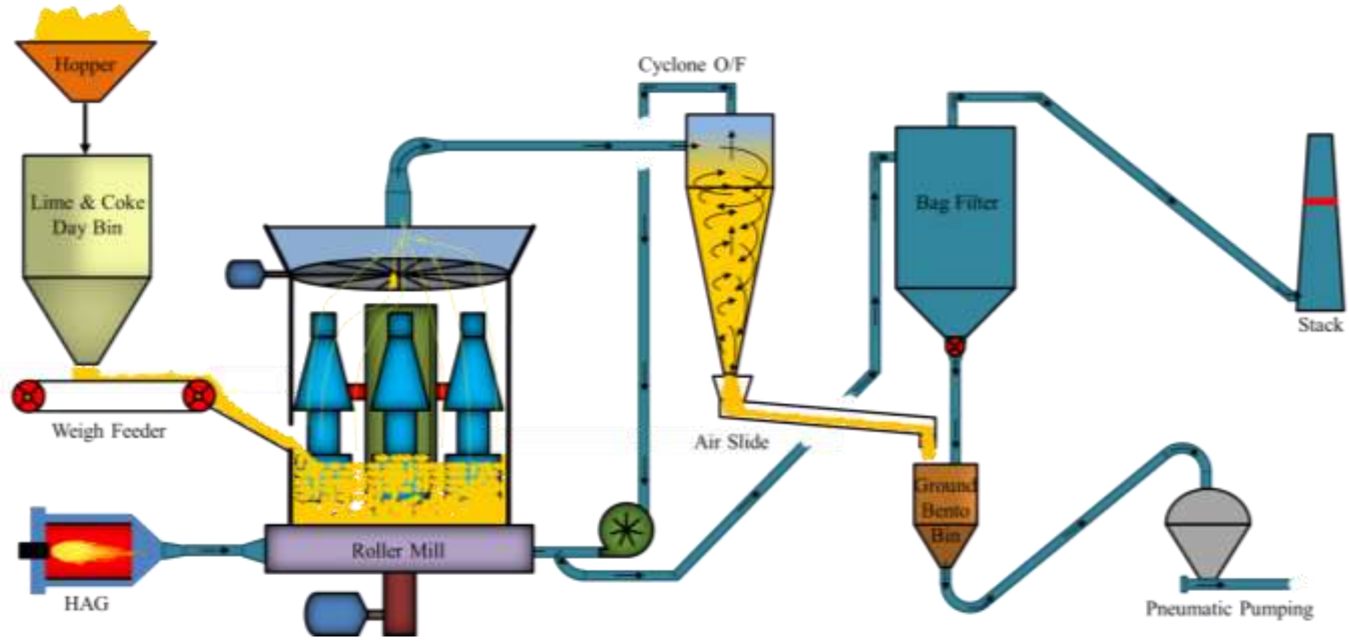
The air-fines mixture is directed into a cyclone separator at high speed. Inside the cyclone, the mixture spins in a vortex motion, generating centrifugal force that pushes heavier particles outward toward the walls. These particles lose momentum, settle along the walls, and drop into the air slide at the cyclone bottom, ultimately feeding into the product hopper.

2.3.6. Air Cleaning with Bag Filter

While the cyclone efficiently separates most particles, very fine dust (<5–10 microns) may remain airborne. To ensure environmental compliance, the remaining air-dust mixture is routed to a bag house filter system, where dust is captured by fabric filter bags. Clean air exits to the atmosphere or stack, while automatic pulse-jet cleaning removes the accumulated dust from the bags into a hopper for collection in the product bin.

2.3.7. Pneumatic Conveying

Figure 2: Schematic Flow Diagram of Bentonite grinding



The final ground bentonite product is transported via pneumatic conveying systems through pipelines to the additives building, where it is stored in a ground bentonite bin.

2.4. Challenges with Manual Operation

Since the commissioning of the plant approximately two years ago, the Vertical Roller Mill (VRM) has been operated manually from the Local Control Station (LCS) by a dedicated operator. This manual mode of operation presents significant challenges in achieving consistent product quality and operational efficiency.

The need to manage all auxiliary equipment manually complicates system stabilization, especially during unplanned scenarios such as weigh feeder jamming or equipment tripping. These disturbances often result in either underfeeding or overfeeding of the mill. Underfeeding causes increased noise levels due to roller hammering on the grinding ring, which can lead to severe mechanical damage. On the other hand, overfeeding may choke the mill, requiring time-consuming interventions to clear blockages and restart operations.

In addition, the product fineness varies considerably due to the absence of precise parameter control and inconsistencies in operator judgment. This variability negatively impacts product quality and overall process reliability. Manual operation also leads to suboptimal throughput, increased mill run hours and dedicated manpower, thereby increasing operating costs.

Frequent communication between field engineer and the Central Control Room (CCR) for monitoring and adjusting parameters further adds to the operational burden. This not only leads to delays but also increases the workload for both field and control room personnel.

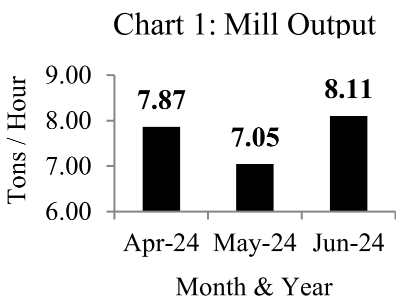
These challenges collectively highlight the need for automation—not only to improve product consistency and process stability but also to enhance safety, reduce operator workload, and allow skilled personnel to focus on value-added activities such as system diagnostics, preventive maintenance and process optimization.

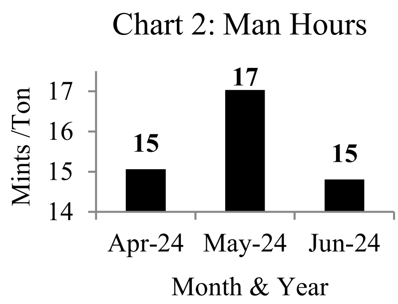
2.5. Operational Metrics of VRM in Manual

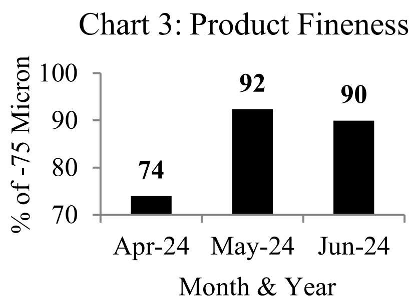
Prior to automation, the Vertical Roller Mill (VRM) was operated in manually, the data shows considerable variability in performance parameters. This data is collected for three months before automation and as follows:

Mill Output (TPH): The average output remained between 7.05 TPH and 8.11 TPH, indicating underutilization of the mill's full capacity as shown in Chart 1. **Man Hours (Mints/Ton) of Bentonite:** Due to frequent manual adjustments and inconsistent control, man-hours per ton of bentonite grinding were elevated, ranging from 15 to 17 minutes per ton as shown in Chart 2. This reflects increased dependency on operators for process correction, reducing overall labour efficiency.

Product Fineness (-75 micron 80%): Manual operation also impacted product quality, with fineness (% passing through 75 micron) fluctuating between 74% and 92% as shown in Chart 3. This inconsistency in fine material production it may affect downstream pellet quality. These metrics clearly highlight the operational shortcomings and limitations under manual control, thereby justifying the need for process automation and optimization.







2.6. Automation Implementation and Process Optimization

To overcome the limitations of manual operation, an automation system was implemented to optimize the Raymond Mill grinding process. The control logic was designed to dynamically regulate key parameters—such as mill RPM, feed rate, Whizzer separator speed and RC fan RPM based on real-time motor current feedback. This automation was executed using the Siemens Distributed Control System (DCS). The system ensures stable mill operation, reduces human error and minimizes downtime caused by overloading or underfeeding. Additionally, it improves product fineness consistency, enables predictive control adjustments and enhances coordination with auxiliary equipment. These improvements collectively contribute to increased throughput, reduced mill operating hours and enhanced overall process efficiency.

2.6.1. Mill RPM Control:

To ensure efficient grinding and prevent equipment damage, the Raymond Mill is operated with a dynamic RPM control logic based on mill current feedback. The mill starts at 150 RPM and gradually ramps up to a baseline speed of 800 RPM within 3 minutes. This 800 RPM is locked as the minimum operational speed with all RPM transitions are implemented with a 5-second delay. Further speed increases are controlled as follows.

When the current increases:

- Mill Current ≤ 220 A: RPM maintained at 800
- Mill Current > 220 A & ≤ 250 A: RPM increases to 850
- Mill Current > 250 A & ≤ 260 A: RPM increases to 900
- Mill Current > 260 A: RPM increases to a maximum of 950

Similarly, when the current drops:

- Mill Current < 250 A: RPM reduces to 900
- Mill Current < 235 A: RPM reduces to 850
- Mill Current < 215 A: RPM reduces to 800

2.6.2. Mill Feed & Whizzer separator Control:

To protect the mill from overload conditions, feed rate is also adjusted accordingly. When the current exceeds 280 A, the feed is reduced by 40% and if it surpasses 300 A, an additional 20% reduction is applied. Feed returns to normal once current drops below 250 A. The Whizzer Separator operates at 700 RPM by default but adjusts between 650–700 RPM based on current, optimizing product fineness.

2.6.3. RC fan Control:

Despite the successful implementation of mill automation, intermittent mill loading issues were still observed, particularly during mill run with full capacity (10 tonnes per hour). These issues led to frequent spikes in mill motor current & reduce of feed, indicating increased mechanical load and potential system instability. To address this challenge, the RC fan was integrated into the automation system to function in a dynamic feedback loop with the mill current.

The RC fan control logic was automated to respond to rising mill current by boosting airflow into the system. Increased airflow helps to fluidize the material bed inside the grinding chamber, preventing material build-up and reducing mill load. This not only aids in quickly dissipating excessive material but also helps stabilize constant feed and maintain consistent product fineness. The automated response of the RC fan effectively eliminates overloading conditions, improves grinding efficiency and ensures safer, uninterrupted mill operation and the logic is fallows.

Starting Logic

- The RC fan starts at 100 RPM, with the discharge damper in an open condition (>95%).
- After the fan reaches 100 RPM, it waits for 1 minute.
- Then, it ramps up speed at a rate of 3 RPM/second until it reaches 1350 RPM.
- 1350 RPM is the minimum operating speed of the fan during mill operation.

Running Logic

- While the Raymond mill is running, the RC fan speed is adjusted based on the mill current:
- If mill current is ≥ 250 A: RC fan increases by 50 RPM (to 1400 RPM) within 10 seconds, after a 5-second delay.
- If mill current remains ≥ 280 A: Another increase of 50 RPM (to 1450 RPM) is applied within 10 seconds, after a further 5-second delay.
- If mill current drops to ≤ 270 A: RC fan speed is reduced to 1400 RPM after a 5-second delay.
- If mill current falls below 250 A: RC fan speed is reduced to 1350 RPM.

2.6.4. Process Bag Filter Temperature Control Logic

In earlier operation, the mill continued running even when the Process Bag Filter inlet temperature was low. This led to an increase in differential pressure (DP) across the bag filter, restricting airflow and directly impacting the grinding efficiency and mill performance. To overcome this issue, control logic was implemented that dynamically adjusts the weigh feeder output based on bag filter temperature, along with a safety trip for the Hot Air Generator (HAG).

Temperature-Based Feeding Control Logic:

- If bag filter inlet temperature < 65 °C, the weigh feeder output is reduced to 50% of the weigh feeder set point to prevent condensation and filter bags clogging.

- Feeding continues at reduced rate until temperature rises to ≥70 °C, after which 100% feed is restored.
- If the temperature drops below 60 °C, all weigh feeders are stopped automatically to protect the filter bags.
- To maintain the above temperature ≥70 °C HAG temperature is raised from 350 °C to 400 °C. If HAG temperature exceeds 420 °C, it will trigger a trip the HAG burner to safeguard filter bags.

3. Results

The performance evaluation of the Vertical Roller Mill (VRM) highlights a marked improvement in operational efficiency, manpower productivity and product quality following automation.

3.1. Mill Output and Capacity Utilization:

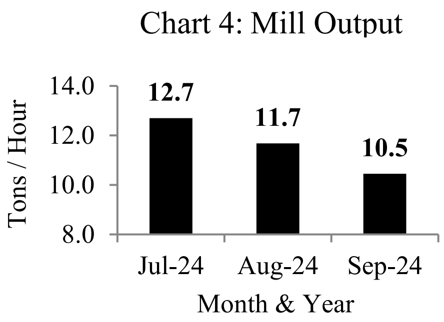
After automation, mill output increased significantly to 10.5 – 12.7 TPH as shown in Chart 4 and effectively exceeding the design capacity. This reflects a utilization of 105% to 127%, demonstrating the benefits of real-time control, optimized feed rates and consistent roller operation. It also suggests the mill had latent capacity that was untapped under manual operation.

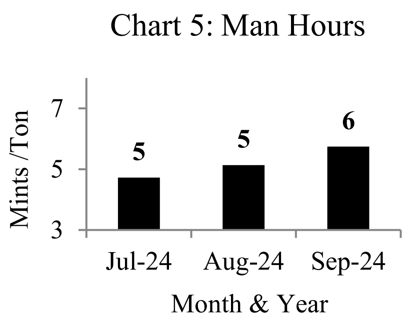
3.2. Man-Hours per Ton of Bentonite

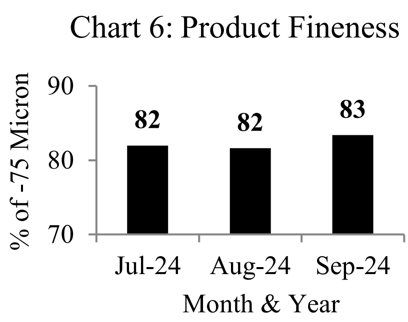
Labour efficiency also improved dramatically. In manual mode, producing one ton of bentonite required 15 to 17 minutes of operator involvement, driven by the need for frequent manual interventions. Automation brought this down to just 5 to 6 minutes per ton as per shown in Chart 5 and reducing operator dependency by 65–70%. This reduction implies substantial labour cost savings and allows operators to focus on higher-level tasks.

3.3. Product Fineness and Quality Stability

Fineness stabilized within a narrow band of 82% to 83% as shown in Chart 6 and ensuring more reliable and consistent product quality. This stability is crucial for maintaining the quality standards of the final product and minimizing rework or rejection.







4. Summary

These outcomes underscore the effectiveness and necessity of process automation in enhancing operational efficiency, reducing costs and improving product quality in industrial grinding operations as shown as final summary in the Table 1.

Table 1: Final Summary

Metric	Manual	Automated	Capacity Benchmark	Remarks
Mill Output (TPH)	7.05 – 8.11	10.5 – 12.7	10.0 TPH	Overachieved post-

				automation
Capacity Utilization (%)	70.5% – 81.1%	105% – 127%	100%	Underutilized vs. overachieved
Man-Hours per Ton	15 – 17 min	5 – 6 min	-	65–70% improvement
Fineness (-75µ 80%)	74% – 92% (inconsistent)	82% – 83% (stable)	≥80% ideal	Improved control & consistency

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