MA'ADEN

MAGNESITE PROJECT

Saudi Arabia

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Ma’aden Magnesite Project

In 2006 PegasusTSI was awarded engineering, procurement, construction management, training and commissioning services for the Saudi Arabian Mining Company’s (Ma’aden) Magnesite Project. This paper discusses the processes utilized for the conversion of magnesium carbonate to saleable magnesium oxide products. Project management methods utilized for the coordination of process technology providers and detailed engineering of the facilities are also discussed.

Project Overview

Ma’aden is developing existing reserves of raw magnesite ore that are located at Zarghat, Saudi Arabia. The magnesite reserves will be open pit mined, crushed, graded, sized and stored at the mine site. The sized and graded magnesite ore will then be transported to the processing facility, located at Al-Madinah, where the magnesite ore will be fed to two separate processing lines. The Multiple Hearth Furnace line will be utilized to convert magnesite into calcined caustic magnesia (CCM) and the Vertical Shaft Kiln line will be utilized to convert the magnesite into sintered magnesia product. The products are bagged and stored at Al Madinah for shipment to customers.

Figure 1. Magnesite Facility Locations Zarghat and Al-Madinah

Zarghat Mine Facility

Ma'aden is planning to develop magnesite mineral reserves that are located at Zarghat, Saudi Arabia which is located 700 km north east of Jeddah. Open pit blasting operations will be utilized for mining and recovery of the raw magnesite ore. The Zarghat deposit consists of four separate bowl shaped deposits of magnesite. Each of these deposits will be mined independently. Raw magnesite containing 85% to 99.5% MgO will be recovered. The deposit will be mined in such a manner as to allow lower quality material to be blended with the very high quality material in order to meet final product specifications at the processing facility located at Al Madinah. The mine site includes a 100 mtph primary "jaw" crusher to reduce the raw ore to minus 50 mm size. The magnesite ore from the primary crusher is stockpiled by grade and is then blended, on a campaign basis, to produce the required grade of magnesite feed for the end products that are to be produced at Al-Madinah. Magnesite ore is fed to a primary screen that transfers oversize material to a 25 mtph secondary “cone” crusher that produces 100% minus 50 mm size material. The product from the secondary crusher is screened to produce various size fractions (25-50 mm, 10-25 mm, 3-10 mm, 0–3 mm) that are stored in separate stockpiles at the mine. The sized and graded Magnesite is transferred by pay-loader to long distanced haul trucks that transport the material to the processing facility that is located at Al Madinah.

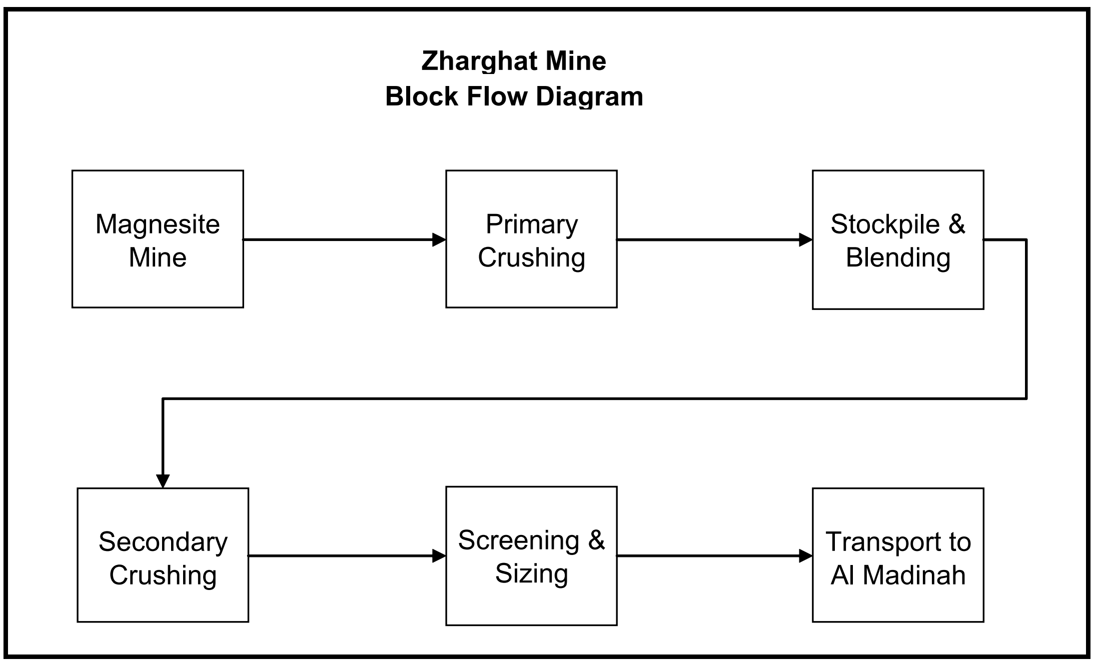

Figure 2. Zarghat Mine Block Flow Diagram

<u>Al Madinah Process Facility</u>

The magnesite processing facility will be located at the Al-Munwarah Industrial City which is located on the outskirts of the city of Al-Madinah, 370 km north of Jeddah. Magnesite ore is received from the Zarghat mine in haul trucks that transfer the magnesite ore into two separate open containment areas. The process facility includes two separate process lines, a Multiple Hearth Furnace and Vertical Shaft Kiln for the production of MgO products.

Multiple Hearth Furnace (MHF)

A Herreshoff Multiple Hearth Furnace is utilized for the production of calcined magnesia. Magnesite ore 10-50 mm in size is fed to a cone crusher and sizing circuit that reduces the material to 3-10 mm size for feeding the Multiple Hearth Furnace (MHF). The calcination of magnesite (magnesium carbonate) is carried out in a Multiple Hearth Furnace (MHF). The MHF is operated at temperatures ranging from 760 to 900 deg C to decompose the magnesite into MgO and CO_2 according to the following reaction:

$$MgCO_3(s) + Heat \text{------>} MgO(s) + CO_2(g)$$

The reaction is endothermic and requires heat to be added to the process for the reaction to be completed. The heat required to increase the temperature of the magnesite from 25 deg C to 760 deg C is 1131 kJ/kg and the heat required to decompose the magnesite is 1284 kJ/kg. Total heat required for the decomposition process is 2415 kJ/kg [1].

The MHF is a vertical furnace that is approximately 6.8 meters in diameter and 16 meters high, with 12 circular hearths, central shaft, rakes and rabble arms. The hearths are constructed of high temperature refractory bricks and the shell is lined with refractory bricks. Raw magnesite, 3 to 25 mm in size, is fed into the top of the MHF. The material is raked through each hearth in a spiral path by the central shaft and rabble arms and teeth. The rotational speed of the main shaft and rabble arms can be adjusted in the range of 0.5 to 3 revolutions per minute. The shaft speed is controlled by a variable speed drive motor that allows the retention time in the MHF to be varied. The material passes through drop holes in each hearth to the next hearth below over and across each hearth until the final product is discharge from the bottom hearth. The ductile iron central shaft is insulated and the rabble arms are constructed of heat resistance alloy material. The central shaft and rabble arms are cooled by ambient air that flows up through the central shaft and annular space inside each rabble arm. Shaft cooling air is supplied by a shaft cooling fan. The hot air exiting the shaft is recovered and used as combustion air in the MHF burners.

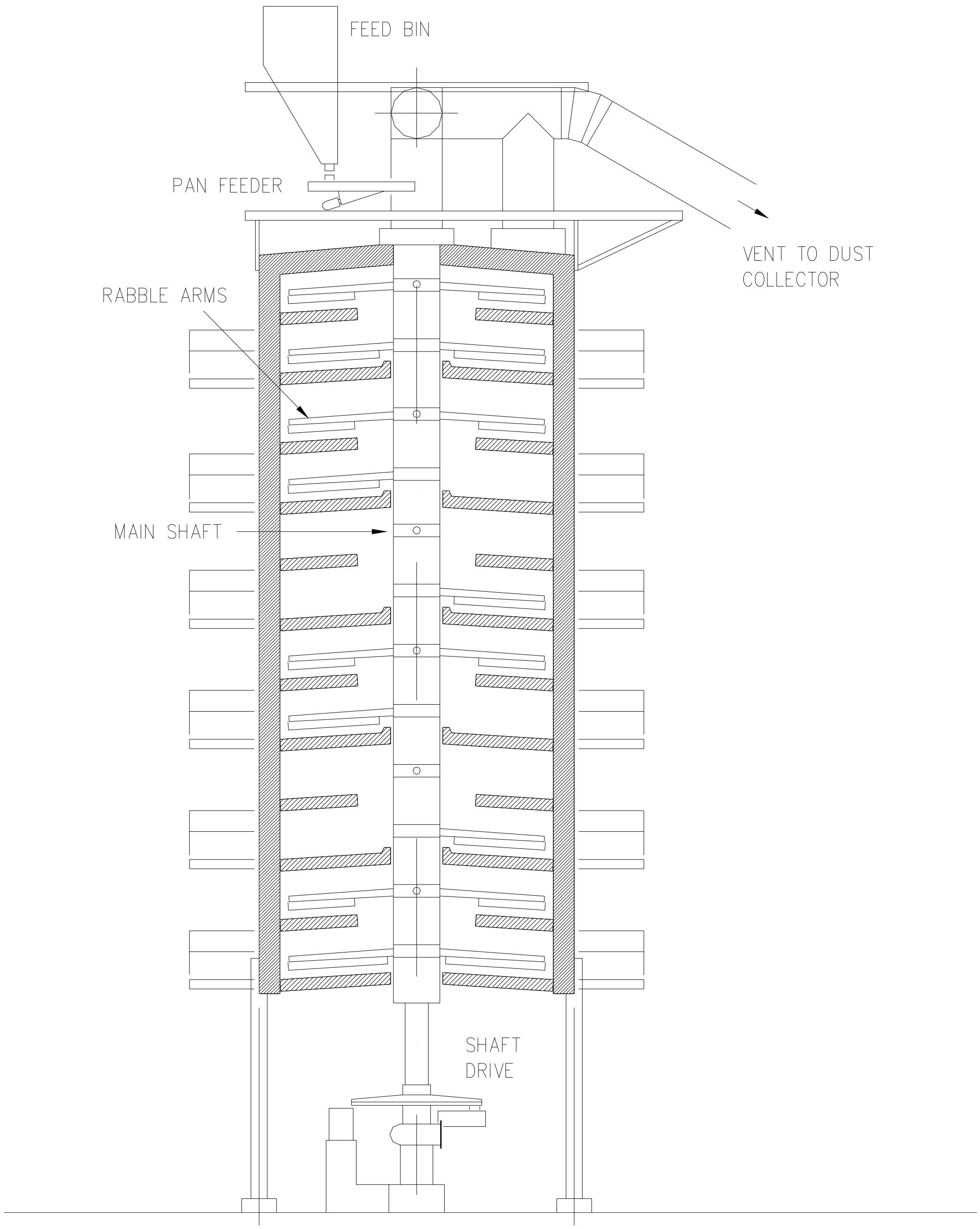

Figure 3. Multiple Hearth Furnace

Gases inside the MHF are heated by the burners that are installed in hearths 2 to 12. The gases flow counter-current to the flow of material to heat the magnesite material to reaction temperature. The lower hearth cools the MgO product with ambient air that is bled into the MHF. The 34 burners are operated on diesel fuel and are controlled to maintain temperatures necessary for the desired magnesium oxide product quality. The temperature of each hearth is controlled individually in order to achieve the optimum temperature profile. The temperatures and residence time in the MHF can be closely controlled and varied within wide limits to meet specific customer quality requirements.

Effluent gases from the MHF are mixed with dilution air, from the Dilution Air Fan, to cool the gases to approximately 200 deg C. The cooled gases are drawn through the MHF Dust Collector by an induced draft fan and are discharged to the MHF stack. A baghouse is utilized to remove particulates from the gas stream prior to discharge to atmosphere. Dust in the exhaust gas is recycled back into the MHF for recovery.

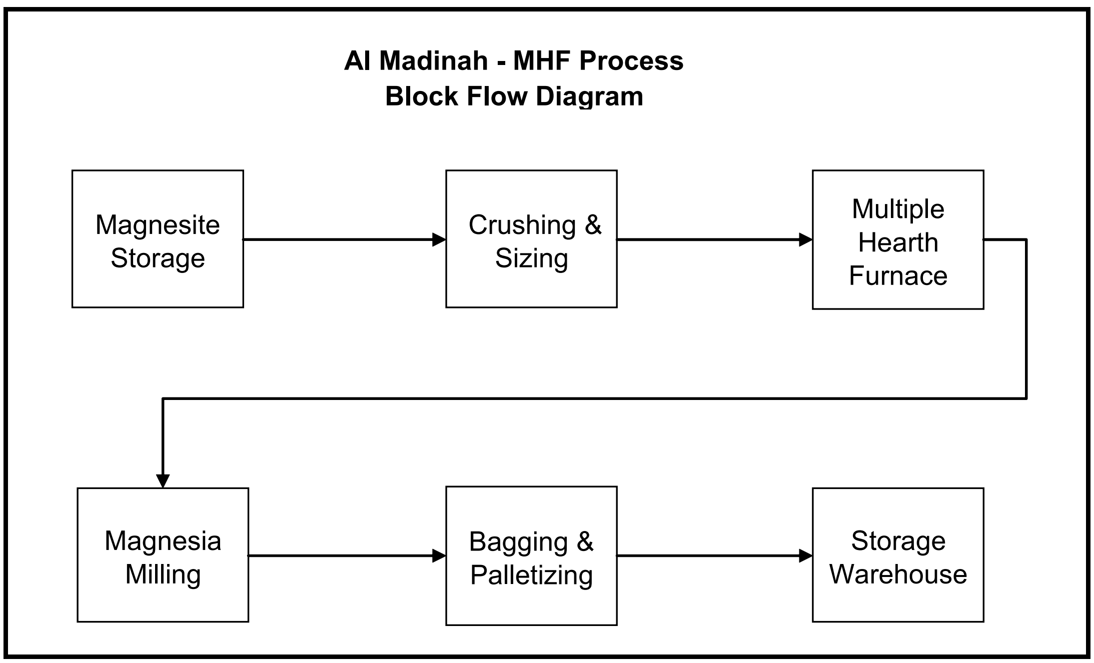

Figure 4. MHF Process Block Flow Diagram

Calcined magnesium oxide product from the MHF is cooled prior to grinding in an ANIVI closed circuit roller mill. Ground magnesium oxide (MgO) product is stored in a bin from which it is loaded into super sacks or bags for storage and sale to customers. Calcined magnesium oxide is utilized for water treatment, as a raw material in the food industry, animal feed industry, agricultural applications, industrial floorings and for specialty chemicals applications.

Vertical Shaft Kiln

A Vertical Shaft Kiln is utilized for the production of sintered or dead-burned magnesium oxide. Magnesite ore 10 to 25 mm or 25 to 50 mm size is fed to a screen that removes any minus 10 mm size material from the feed. Under size material is recycled to the MHF process. The 10 to 25 mm or 25 to 50 mm size product material from the screen is fed to the Vertical Shaft Kiln (VSK). The kiln is operated on one continuous feed for long periods of time in order to maintain very consistent feed and product quality. The Vertical Shaft Kiln (VSK) is a high temperature vertical kiln that is 3200 mm outside diameter with 700 mm thick refractory lining and 1800 mm inside diameter. The cylindrical shell is 11 meters in length and is constructed of special high temperature steel. The VSK shell is lined with high grade alumina castable in the bottom section and high grade magnesium oxide bricks on the shell. The VSK design allows for a wide range of operating temperatures and temperature profiles that are required for the production of high density, high grade magnesium oxide (MgO) sinter.

Raw magnesite ore is fed into the top of the VSK in order to maintain the VSK full of material at all times. The magnesite feed flows down through the VSK at a constant rate of speed. A screw type blower, with variable speed drive, discharges a controlled amount of cool (combustion) air into the bottom of the VSK which cools the sintered magnesite product to approximately 200 deg C before it is discharged from the kiln. The cool air is preheated to above 800 deg C and flows counter-currently up through the bed of magnesite. Diesel fuel is injected at a controlled rate into the hot bed of magnesite material through two (2) rows of eighteen (18) burners (36 burners total). Diesel fuel is supplied to the burners at a controlled flow rate by a two (2) multi-head piston type positive displacement pumps. Each pump is equipped with 18 separate piston type pump heads on a single shaft that supply fuel to 18 burners. Each fuel pump is driven by a variable speed motor that provides precise control of the amount of fuel that is fed to the burners. The diesel fuel is injected directly into the hot bed of magnesite material where spontaneous combustion occurs and extremely high temperatures are produced. The VSK is normally operated at temperatures ranging from 1900 to 2200 deg C. The extreme heating of the gases causes the gases to expand which results in very high gas velocities within the bed of magnesite and produces very effective and uniform heat transfer to occur in the bed. When the burning temperature is achieved, the sintering process begins.

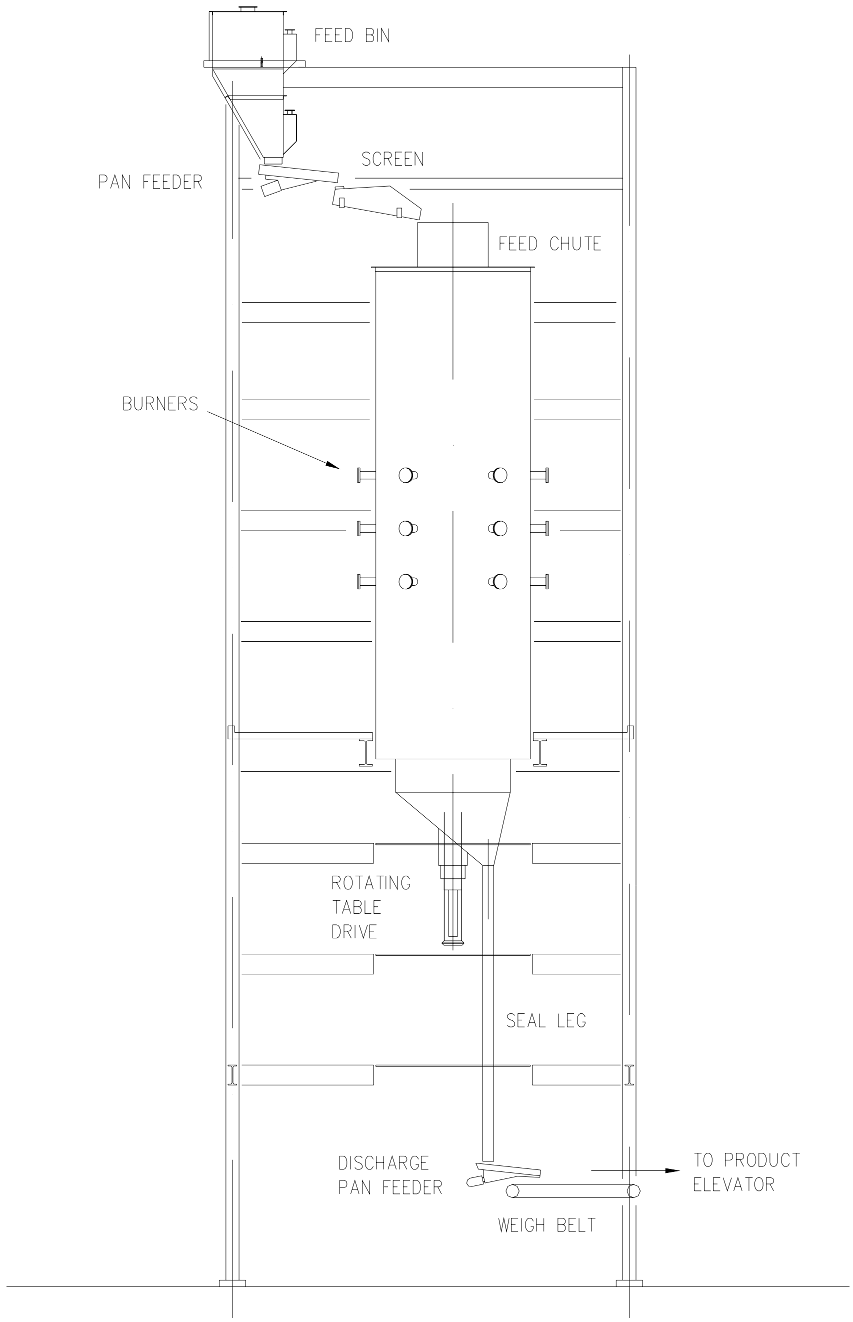

Figure 5. Vertical Shaft Kiln

The burning temperature in the kiln is controlled to prevent over-heating by the introduction of cold air through the burners with the diesel fuel. Proper balancing of the fuel and air ratio allows exact control of the bed temperature and temperature profile inside the kiln. Sintered magnesia has a very high melting point (2800 deg C) and high density. In the Sintering process, fine magnesium oxide particles agglomerate and the porosity of the particle is reduced while the bulk density of the mass increases [1].

The burners consist of lances constructed of special steel through which air and diesel fuel are introduced. Each of the burners is water jacketed and is supplied with a constant flow of cooling water. Cooling water is supplied to the burners by a closed loop cooling water system with air cooler and head tank that maintains constant pressure for cooling of the burners. A spare diesel drive emergency cooling water pump is provided to insure that cooling water is always available to the burners.

Sintered magnesia product is discharge from the VSK by a rotating table that is located at the bottom of the VSK. The discharge table rotates at very low speed. The speed of the table is controlled by a variable speed drive that directly controls the amount of product discharged from the VSK. The VSK discharge seal leg is located on the bottom of the VSK. The seal leg is approximately six (6) meters long and maintains the air seal inside the VSK. A nuclear level instrument is installed on the seal leg to monitor the level of the product in the seal leg and to insure that the seal leg is always full of material. The discharge rate from the VSK is controlled by setting the speed of the rotating table and set-point of the VSK discharge weight belt in order to maintain the seal leg full of product material.

Hot exhaust gases from the VSK exit the bed at a temperature of approximately 400 deg C. The gases are mixed with ambient air that is drawn across the top of the bed to quench the gases down to a temperature of approximately 200 deg C. The gases pass through a drop-out box where any entrained coarse particles are removed. The gases are then drawn into the VSK Dust Collector where entrained dust is removed and the gases are discharged by the VSK Dust Collector Fan to the VSK stack.

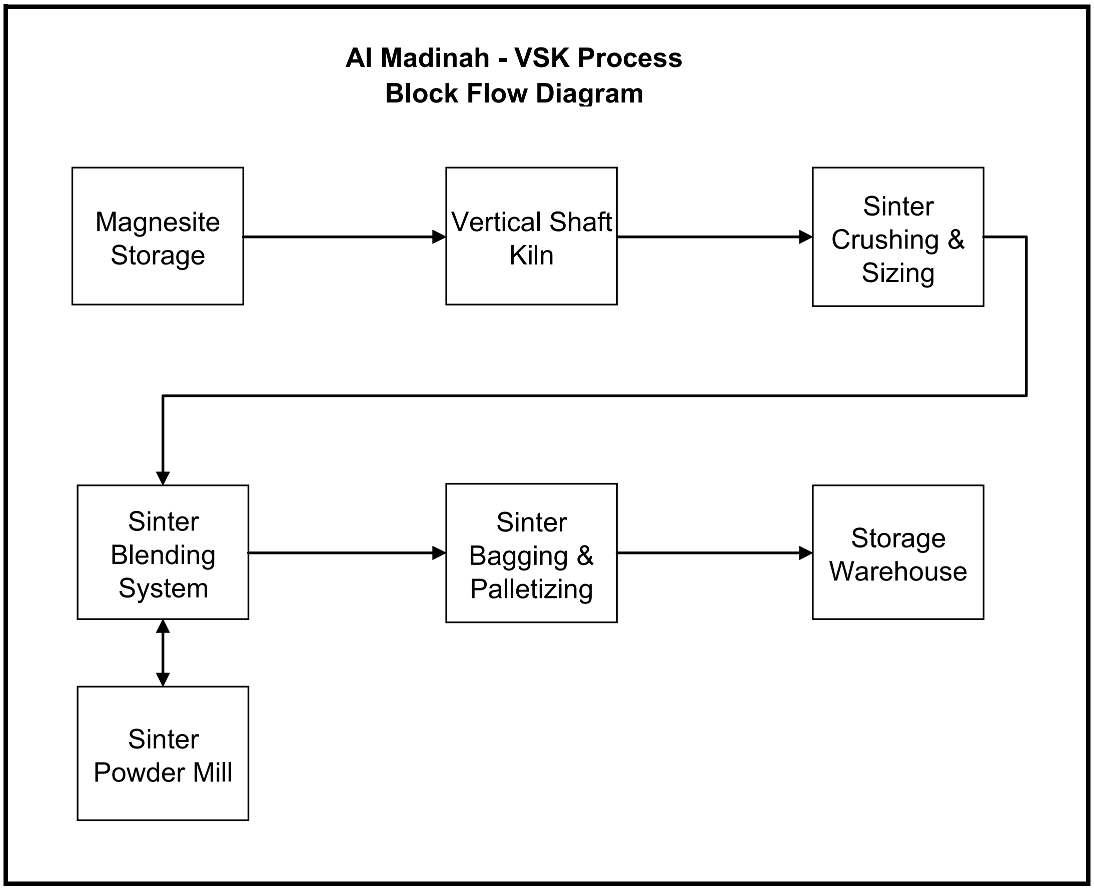

Figure 6. VSK Process Block Flow Diagram

Sintered magnesium oxide product is transferred by elevator into a storage bin where the material is fed to an impact crusher. The variable speed impact crusher reduces the magnesite product to 0 to 8 mm size. The crushed product is transferred to a sizing circuit where various size fractions are separated and stored in bins. The coarse sinter fraction is transferred to the Powder Mill. The Powder Mill is a vibrating rod mill that produces minus 50 micron size material that is stored in separate bins. Sized sinter product and special additives are metered from the storage bins into a Lodige weighing and mixing system where custom blended magnesium oxide products are produced. The blended sinter product is loaded into super sacks for storage and sales to customers. Sintered grade magnesium oxide product is used in the production of high temperature refractory products and is used in the steel industry for gunning, fettling, ramming and tundish applications.

Technology Provider Coordination and Management

PegasusTSI has found that many years of reduced demand for engineering services in the chemicals industries has caused many technology providers to eliminate their detailed engineering capabilities in order reduce overhead costs and remain viable technology companies. The Ma'aden Magnesite Project includes several technology packages that are being supplied by the following technology providers:

- Multiple Hearth Furnace Package – Supplied by CMI NESA, Belgium
- Vertical Shaft Kiln - Supplied by CMI NESA, Belgium
- Sinter Blending System Package – Supplied by Lodige, Germany
- Magnesia Mill – Supplied by Anivi, Spain.

The Ma'aden Magnesite Project was initially tendered to several technology providers, by Ma'aden, with the concept that the technology providers would each be awarded a section of the plant and that the technology providers would provide all of the detailed engineering and design necessary to complete the project. After the tenders were issued, it was discovered that the technology providers did not have the detailed engineering expertise to execute the project in this fashion. Ma'aden awarded PegasusTSI the detailed engineering for the project which includes responsibility for technology transfer and coordination with the technology providers. The basis for the award to PegasusTSI also requires that the detailed engineering be completed inside the Kingdom of Saudi Arabia. PegasusTSI selected an in-kingdom partner for execution of the detailed engineering and the front end engineering design was completed in the Tampa, Florida office of PegasusTSI.

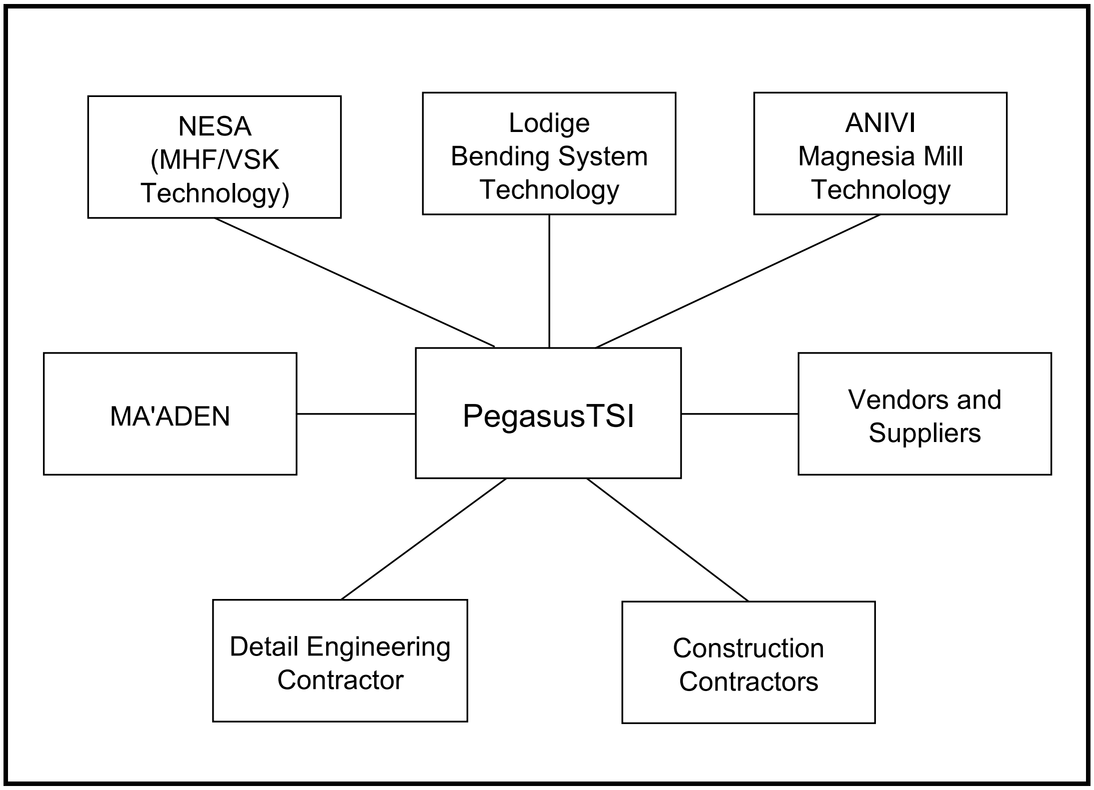

Figure 7. Project Coordination Diagram

During the early stages of the project it was recognized that language and cultural barriers could not be allowed to interfere with the transfer of process technologies for detailed engineering and design of the project. The technology provider for the Multiple Hearth Furnace and Vertical Shaft Kiln supplied the primary components of the equipment but would not agree to supply the vessel shells, ductwork, structural supports, certain instrumentation and control systems and other items critical for construction and operation of the systems. Responsibility matrices were designed by PegasusTSI to clearly define the scope of supply and level of engineering to be provided by the technology provider. The technology provider's scope of supply for equipment was itemized and the various levels of completion for deliverables were subdivided into the following categories:

CE Conceptual Engineering

Conceptual Engineering to define the process, major equipment and utilities, Deliverables typically include:

- Process Flow Diagrams
- Preliminary Piping and Instrumentation Diagrams
- Equipment Lists
- Motor Lists
- Utility Consumptions

BE Basic Engineering

Basic Engineering includes front end engineering and design necessary to produce a +/-10% cost estimate. Deliverables include:

- Process Flow Diagrams
- Piping and Instrumentation Diagrams
- Equipment Lists
- Motor Lists
- Utility Consumptions
- Utility Flow Diagrams
- Equipment Specifications
- Preliminary Equipment Arrangement Drawings
- Piping Specifications
- Process Line Tables
- Instrument Data Sheets

DE Detailed Engineering

Detailed Engineering includes engineering design and engineering documents necessary for construction including the following:

- Final Process Flow Diagrams
- Final Piping and Instrumentation Diagrams
- Equipment Lists
- Motor Lists
- Utility Consumptions
- Utility Flow Diagrams
- Equipment Specifications
- Equipment Elevations
- Arrangement Drawings
- Civil/Structural Design Drawings
- Site Preparation Plans
- Piping Isometric Drawings
- Piping Specifications
- Process Line Tables
- Instrument Specifications.

SU Equipment Supply

Equipment supply includes specification and procurement of equipment and delivery to the port of shipment. Typically the technology provider will be required to include all auxiliary equipment necessary to operate the equipment that is supplied. Scope of supply may include spare parts, operating and maintenance manuals and instructions.

QA Quality Assurance

Quality Assurance includes specific technology provider inspections necessary for the supplier to insure that the equipment that is fabricated to meet the technology provider's requirements. This is important to insure that none of the supplier's guarantees are voided due to equipment quality issues. Major equipment that is designed by the technology provider may be fabricated by a subcontractor to the engineering company and it is necessary to obtain the technology provider's sign-off and approval on major fabricated items during manufacturing to insure that the equipment is built to correct specifications and tolerances.

GT Technology Provider Performance Guarantees

The technology provider may have specific process performance guarantees. These guarantees must be taken into account through-out the project to insure that the final design meets the technology provider's requirements and does not jeopardize the technology provider's warranties or guarantees.

Multiple Hearth Furnace Equipment List								
NESA Scope of Supply Matrix								Comments
PegasusTSI Equipment Name	Equip. Number	CE	BE	DE	SU	QA/QC	GT	
MHF Weigh Belt Feeder	GH-0104	X	X					
MHF Feed Elevator	GH-0105	X	X					
Feed Distribution Bin	DT-0104	X	X					
MHF Feed Conveyor	GH-0112 A/B	X	X					
Multi Hearth Furnace (MHF)	HB-0101							
Steel shell, top, bottom, frame, & columns		X	X	X		X	X	DE define QC plan for fabrication/installation, but not included services for cover the inspection of QC
Refractory materials		X	X	X	X	X	X	Refractory fabrication inspection included. Install by third party. To provide installation Supervision.
Insulating materials (internal)		X	X	X	X	X	X	Refractory fabrication inspection included. Install by third party. To provide installation Supervision.
External insulation								Not required
Center shaft, rabble arms, teeth, access doors		X	X	X	X	X	X	Fabrication-Inspection Included. To provide installation supervision.
Burner system	HE-0101	X	X	X	X	X	X	Supply include: burners, burners control instruments, cabinet, control logic, safety interlock, hoses, pilot system
Fuel piping		X	X					BE: line list, piping specs, P&IDs
Emergency vent		X	X					
MHF Shaft and Rabble Arms	HB-0102	X	X	X	X	X	X	VFD Not included
MHF Shaft Cooling Fan	PC-0101	X	X	X	X	X	X	Piping, filter, expansion joint not included
MHF Combustion Air Fan	PC-0102 A/B	X	X	X	X	X	X	Piping, filter, expansion joint not included
Product Cooler		X	X	X	X	X	X	Water Cooling
MHF Fuel Pump	PP-0106 A/S	X	X	X	X	X	X	
MHF Product Cooler Screw	GH-0106	X	X	X	X	X	X	Water Cooling
MHF Magnesia Elevator	GH-0109	X	X					
MHF Dust Collector	GX-0101	X	X					
MHF Vent Stack	GK-0101	X	X					
MHF Dust Recycle Conveyor	GH-0108	X	X					
MHF Dust Recycle Screw	GH-0115 A/B	X	X					
MHF Dust Collector Fan	PC-0105	X	X					
MHF Product Cooling Water Loop		X	X	X	X	X	X	
MHF Product Cooling Water Pump	PP-0602 A/S	X	X	X	X	X	X	
MHF Product Cooling Water Cooler	EE-0602	X	X	X	X	X	X	
MHF Product Cooling Water Cooler Fan	PC-0602	X	X	X	X	X	X	
Cooling Water Piping		X	X					
MHF Product Cooling Water Tank	DT-0606	X	X					
Drop Box (pre Bag House)		X	X	X	X	X	X	
Double Pendulum Gate (from Drop Box)		X	X	X	X	X	X	
MHF Fuel Day Tank	DT-0105							Excluded
MHF Atomizing Air Fan	PC-0107	X	X	X	X	X	X	
MHF Dilution Air Fan	PC-0103	X	X					

Figure 8. Scope of Supply Matrix

The technology provider's scope of supply including unique equipment items and major process components were listed on the responsibility matrix and the scope of supply for each item was agreed with the technology provider in contract pre-award meetings. The responsibility matrix was then finalized and agreed to by the technology provider and PegasusTSI. The responsibility matrix was included in Ma'aden's final contract with the technology provider. This methodology for managing the technology providers has been proven to be very effective in defining the scope of work and in execution of the project. A high level of detail in defining the scope of supply matrix is necessary to insure that all aspects of the supply are clearly defined early in the initial technology supply bid evaluation stages of the project.

The Ma'aden Magnesite project is currently scheduled for completion and start-up during the first half of 2009. Lessons learned from this project include:

- Need for liaison and good working relationship with technology providers is essential.
- An experienced project management team is required to manage geographically diverse suppliers and complex technology packages.
- Engineering contractor must maintain flexibility in order to fill in the "gaps" between the technology providers and equipment suppliers.
- The overall execution approach must be flexible in order to deal with the current "hot" market for engineering services, equipment supply and materials.
- The establishment of a core discipline engineering team is necessary to manager technology providers and detailed engineering subcontractors and to insure that a sound technical basis of the project is maintained.
- In order to meet project objectives, a local execution team is needed in-kingdom to support the detailed engineering effort and to coordinate with the home office. This core team should include:
    - Detailed Engineering Liaison
    - Procurement Liaison
    - Construction Management
    - Commissioning Management

List of References and Acknowledgements

1. The Chemistry and Technology of Magnesia, Mark A. Shand, John Wiley and Sons, Inc., 2006.

2. Process Technology for the Ma'aden Magnesite Project is supplied by: CMI NESA, Axis Parc, B-1435 Mont-Saint-Guibert, Belgium. Process design and descriptions were provided by CMI NESA.