



Process Reactor Technologies

from

The Torftech Group



Company Profile



Torfttech Group



Process Reactor Technology

Torfttech Process Reactor Technologies are developed to provide novel, cost effective means for processing many different materials. The technologies facilitate rapid and accurate control of processes requiring gas-solid contact, often at higher temperatures than those experienced in conventional equipment. In many instances, this opens the door to the launch of products and processes unique in their marketplace.

Our engineers have expertise in the processing of particulates in gas streams, combustion systems, feed preparation, product post treatment and process control.

We have developed several world leading new technologies including:

- TORBED Compact Bed reactors ('CBR')
- TORBED Expanded Bed reactors ('EBR')
- TORBED Transport Bed reactors ('TBR')
- High temperature fuel injection systems
- Fine powder process reactors



Torfttech provides the following services:

- Process modeling
- Lab testing
- Pilot plant development
- Full scale implementation
- Development project management

Torfttech engineers have also been responsible for the development of several remarkable new processes in the food, chemical, petroleum, mineral and metallurgical industries. Commercial plants are operating around the world, generating profits for our customers and licensees alike.

The development of new commercial applications

In order to minimise the risks of the development of a new application, a project typically goes through several stages with clearly defined phases such as those listed below.



Pre-feasibility Study

In this initial phase of the project the design constraints are established and the relevant Torftech technology is chosen. This leads to an order of magnitude estimate for the cost of the plant.



Feasibility Study

This study normally includes preliminary pilot studies. The results enable Torftech to provide a $\pm 30\%$ estimate for a full scale plant and, together with the client, an assessment of the economics of the project. This study normally takes one to two months to complete depending on the complexity of the process.



Engineering Design Study and Pilot Trials

If the feasibility study indicates viability, a series of pilot trials will be carried out. These trials should not only give confidence that the chosen Torftech technology can satisfy the process needs, but also provide the necessary process data, ancillary plant design criteria and product information to allow prediction of scale up to commercial operation. In some cases a dedicated pilot plant may then be used for extensive trials development work.

Sufficient engineering work is carried out during this study to establish a design basis and develop a cost estimate for the proposed plant to a level of accuracy of 10-15%. This is normally sufficiently accurate for further assessment of the economics of the project.



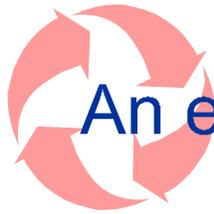
Demonstration

A commercial scale plant is designed and built to optimise the full-scale process. The economics of the project can be verified and, if required, further scale up data can be obtained.



Commercialisation

If the process is to be marketed to third parties and all the previous steps have been completed, a commercial partner (a suitable process plant contractor or manufacturer) may be sought to take the developed process to their market place under licence.



An executive summary

The TORBED* process reactor technologies are novel but well proven generic gas/solid contacting techniques used for processing materials and are protected by a portfolio of Patents and Trade Marks throughout the industrialised economies of the world. They were invented and developed as techniques to revolutionise the processing of minerals, foods, chemicals and wastes.

The TORBED reactors provide unique benefits in precise, rapid, smaller scale and lower cost solutions to industrial materials processing problems with operating temperatures ranging from cryogenic to greater than 1,600°C (2,900°F). The reactors will handle almost any shape of feed solids, including micron-sized powders, sludges and slurries. The low pressure drop across these new reactors facilitates easy process gas recirculation allowing reducing, oxidising and neutral atmospheres to be maintained at high temperatures.

Installation of the first commercial prototypes took place in 1986. Now TORBED reactors are in commercial use with some 100 or more plants in Europe, North America, South Africa, New Zealand, Australia, China, India and Japan for applications as diverse as fat free “frying” of snacks, toxic waste destruction and materials recycling.

The New Zealand Aluminium Smelter at Tiwai, South Island New Zealand, installed and successfully commissioned the largest TORBED reactor built to date at six metres (20ft) diameter early in 1994. This prototype was successfully tested for dry scrubbing exhaust gases from the smelting operations. The application was put into operation in 1996 with twelve 6 metre diameter TORBED reactors installed at Tiwai scrubbing 1,000 m³/s of exhaust gases and a further six 6 metre TORBED reactors were installed at Bell Bay in Tasmania in 1997. These smelters are part owned by Comalco Aluminium Ltd of

Australia who are also using TORBED reactors for thermal destruction of their cyanide and carbon laden waste at a rate of 10,000 tonnes per year in their smelting plant on Boyne Island, Australia.

TORBED reactors are commercially in use and continually being developed for:

- waste combustion
- catalyst processing
- high temperature calcination
- cocoa roasting
- vegetable bloating
- sulphide ore roasting
- soil, rock and sediment remediation
- ash treatment
- chemical reactions
- gasification/combustion of agricultural residues
- combustion rice hulls

and many other novel processes.

Pilot plant facilities are available for test, development and demonstration purposes in Canada and Europe. Both these pilot plants are fully staffed with analytical facilities available. These pilot plants utilise 400 mm diameter TORBED reactors complete with feed and product discharge arrangements.

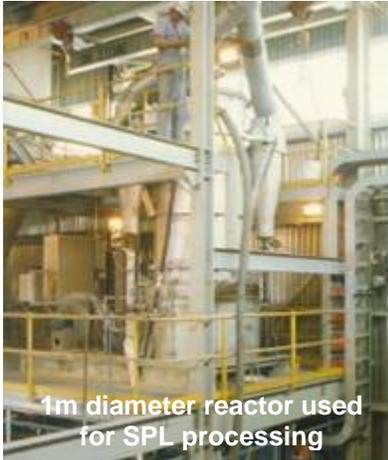
It is our policy to grant licences for exploitation of the TORBED reactors to organisations that can demonstrate a proven ability to address a particular market or application. Descriptions of some of the non-confidential uses of the process are listed in the following brief application notes.

*TORBED is a registered trade mark of Mortimer Technology Holdings Ltd

Industrial Applications

Combustion

The ability of TORBED reactors to handle wide variations in feed shape, size and quality is being applied to the controlled combustion of a variety of materials including carbon, shredded wood waste, organics and hydrocarbons.



One such application that relies on the absolute precision of the TORBED reactor is the **processing of Spent Pot Lining (SPL)** from the aluminium smelting industry. The refractory lined "pots" in which aluminium is smelted are removed from service when they have reached the end of their useful life and the spent refractory lining and carbon cathode are broken up and removed from the pot as Spent Pot Lining (SPL) so that a new lining and carbon cathode can be installed. The material that is removed is often classified as a toxic waste.

SPL contains a mixture of refractory, carbon and other contaminants including fluxes and cyanide. Comalco Aluminium Ltd of Australia commenced a development programme in 1987 to process SPL to produce a waste stream that is non hazardous. In order to thermally dissociate the cyanide in the SPL, processing of the material was attempted in various calcination devices including a rotary kiln, fluidised bed and transport reactor without success. A TORBED reactor proved to be successful. In 1990, a plant capable of processing 3,000 tonnes per year of SPL was commissioned. The process has proved to be as effective as predicted and by the end of 1994, the plant capacity was increased to 10,000 tonnes per year. This is a well-proven industrial application of the TORBED technology.

The TORBED technology was identified as being one capable of satisfying the need for the **controlled combustion of shredded wood waste**. Pilot trials were successfully completed and two 5MWt combustors were installed in 1999 in the Netherlands. These reactors must also handle tramp feed materials including door handles, hinges, nails and other metal and incombustible materials.



Removal of volatiles from solids



In 1993, a pilot plant capable of processing 150 kg/h of oil-contaminated solids was fully tested at BP's Sunbury laboratories. A consortium of oil and gas exploration companies then funded the further development of the TORBED reactor as a **transportable de-oiling plant** for eventual off shore use. This plant demonstrated the capability of stripping hydrocarbons from solids in a controllable manner.

When **recycling machine shop ("swarf") and other metal wastes such as mill scale**, it is a problem when these contain cutting oil and a coolant since the wastes cannot be added directly to a remelting process without serious disruption of the molten metal from the steam and explosive vapours that are generated.

Industrial Applications

Rotary kilns have been used in the past to evaporate the oil and water from these wastes providing a clean feed stream to the remelting process.

Because the feed stream has a widely varying quantity of cutting oil and water, the process needs very close control to prevent combustion of the oil in the drying process. A TORBED reactor has been demonstrated to provide up to 8 times more throughput of clean dry metal per unit of energy input than rotary kiln techniques. The quality of the metal was found to be consistent and of higher purity with minimal oxidation.

The TORBED process has been in full-scale production since 1989 processing up to 3 tonnes per hour of swarf containing anything up to 20% by weight cutting oil and water.

In the summer of 2000, a 1.8m diameter reactor was commissioned for the **devolatilisation of up to 20 t/h of old asphalt coated road stone.**

The plant was opened formally in September 2000. The plant is designed to volatilise old asphalt (laden with PAHs) so that the road stone can be recoated and reused. The volatiles produced in the process are thermally oxidised directly in the upper part of the TORBED reactor.



1.8m diameter reactor used to devolatilise old road stone

Mineral Processing

The ability of the TORBED reactors to carry out precise calcination and heat/mass transfer processes has allowed the development of unique process plants. The first mineral processing application was the **calcination of vermiculite.**

Vermiculite is a naturally occurring mineral. When crushed, graded and fed into a hot furnace (1,200 °C or 2,200° F), the vermiculite expands or exfoliates to produce a lightweight particle that is then used as an insulating and fire retardant fill. The process requires a very rapid heat transfer to the particles to promote as large an increase in particle size as possible to give low densities. Historically, vertical shaft and rotary kilns have been used to exfoliate vermiculite.



High temperature mineral processor

The TORBED reactor has shown itself to have unique capabilities in this application in producing higher quality, lighter and more consistent product with lower energy consumption. High heat and mass transfer and precision of control with the TORBED reactors have provided these advantages. Most important, the TORBED process provides more saleable product per unit of raw material fed i.e., a higher yield.

The TORBED process is in successful operation in 11 major production plants in Europe and Japan. Throughputs vary according to raw material grading but typically range from 1-5 tonnes per hour.

The ability of TORBED reactors to carry out flash processing of fine powders with particle retention times of often less than 50 milliseconds has led to the development of novel products and processes. This ability has been developed at pilot scale (up to 300 kg/h) and was put into commercial operation during 1998.

A 1m diameter high temperature “fuel injected” TORBED reactor was commissioned in 1998 to **calcine industrial minerals at temperatures up to 1,600°C.** The use of direct injection techniques whereby

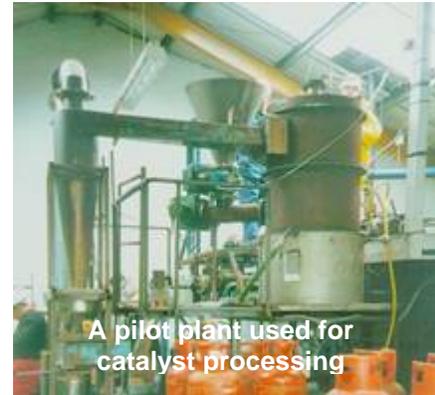
Industrial Applications

natural gas is mixed and combusted directly in the process chamber base allows intense high temperature calcination reactions to be undertaken.

Catalyst processing

Extrudates/pellets that support catalytic material need a high free surface area. The higher the surface area, generally the more effective is the catalyst. Most catalyst support materials are calcined at high temperature to "fire" or "set" the support structure. This calcination is a critical phase in the production process.

The TORBED reactor has been demonstrated to produce exceptionally high surface area and uniquely structured particles when used to carry out the calcination process. Several pilot trials have now been successfully concluded and commercial plant has been in continuous operation for more than 4 years.



Gas scrubbing



The extract ductwork that draws fumes away from the smelting pots in an aluminium smelting plant contains levels of contaminants that need to be removed from the exhaust before discharge to atmosphere. The TORBED process is used as a reactor to contact alumina with the exhaust gas stream to adsorb the pollutants prior to discharge. A TORBED reactor can be employed in a single or two-stage assembly providing unique adsorption properties.

The low pressure drop across TORBED reactors is important because the volumes of gases to be processed are high at 200,000 m^3/h (117,500 acfm) per TORBED

reactor and the particle size range that is used in the reactor is small and substantially un-graded.

After construction of a 5000mm prototype in 1993, a 6000mm (20 ft) diameter two-stage reactor was installed and commissioned in early 1994. The results were sufficiently favourable that New Zealand Aluminium Smelters Ltd decided to proceed with an expenditure of NZ\$94m (£30m) on a new scrubbing plant based on thirteen 6000mm (20 ft) diameter TORBED reactors. These were installed in 1995/6 and the plant is achieving the best world standards. A further 6 such units were commissioned at Comalco's Bell Bay smelter in Tasmania in 1997.



Industrial Applications

Food processing

In the snack food industry, most products available are either fried or "cooker extruded" before being dusted with oil and flavours. A trend toward lower fat and healthier eating snacks has allowed the development of new low fat products, particularly based on expanded "half pellet" products.



The TORBED process has shown itself to have unique capabilities in this application in producing higher quality, lighter and more consistent product with lower energy consumption. Indeed, some shapes of product can only be air expanded in a TORBED reactor. High heat and mass transfer and precision of control with the TORBED reactors have provided these advantages. The installation is quiet and compact.

The TORBED process is in successful operation in several major production plants in Europe, Australasia, the Americas and the Middle East. Throughputs vary but typically range from 50-500 kg per hour.

Traditionally spices have been pasteurised by steam or radiation. The former technique has limitations in terms of product quality and ultimate levels of pasteurisation. It has been found by extensive trials on a range of spices that much lower residual contamination can be achieved using the TORBED reactor with hot air as the process medium.

The TORBED process has shown itself to have unique capabilities in these applications in producing higher quality, more consistent product at low energy consumption with low residual contamination levels. The process can rapidly be changed for different products and characteristics. The installation is quiet and compact. Pilot trials have been successfully carried out and full-scale production plant is in operation processing 300 - 400 kg/h of spices. Many other precision roasting, drying and bloating processes are in commercial use.

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Technology Description

TORBED COMPACT BED REACTOR ('CBR')

The TORBED Compact Bed Reactor ('CBR') transfers heat and mass between gases and solids more quickly and efficiently than any comparable process. Heat and mass transfer rate is dependent on the resistance to flow. This is determined by several factors, the most important of which is the effect of a microscopically thin boundary layer of gas that surrounds each particle. This boundary layer has an insulating effect, hence the more it is reduced in thickness, the less the resistance and the more quickly heat and mass transfer can be achieved. This microscopic boundary layer can be reduced in thickness by subjecting the particles to turbulent impact by the process gas at high velocity.



Why a CBR achieves faster heat and mass transfer

In the CBR, the layer of moving particles to be processed is held in suspension by jets of the process gas. These jets are created by passing the process gas stream through the slots between stationary angled "blades" (similar to closely spaced stationary turbine blades) so that the high velocity energy generated as the process gas passes through these slots is dissipated on the base of a shallow bed of particles. Where the base of this bed is impacted by the high velocity jets, a highly turbulent area is created imparting both vertical lift and horizontal motion to the bed. (See Fig. 1)

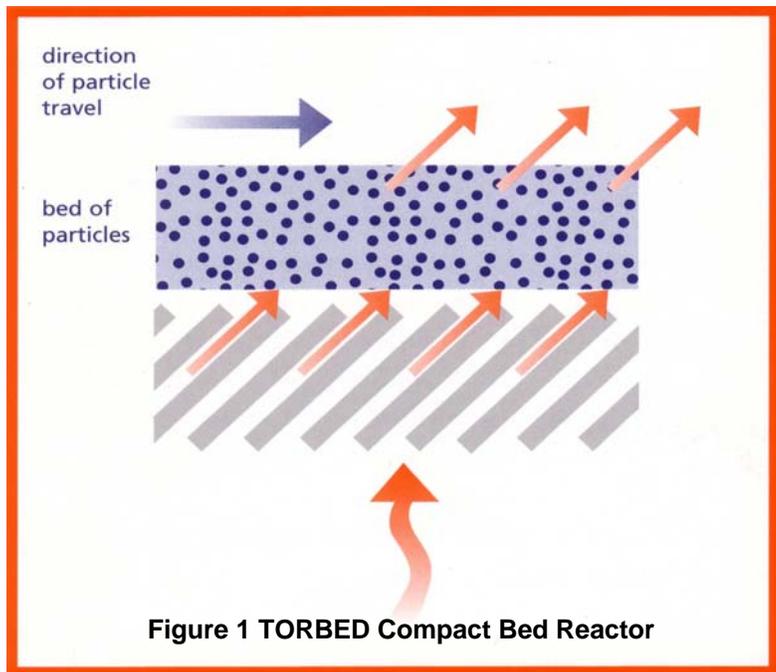


Figure 1 TORBED Compact Bed Reactor

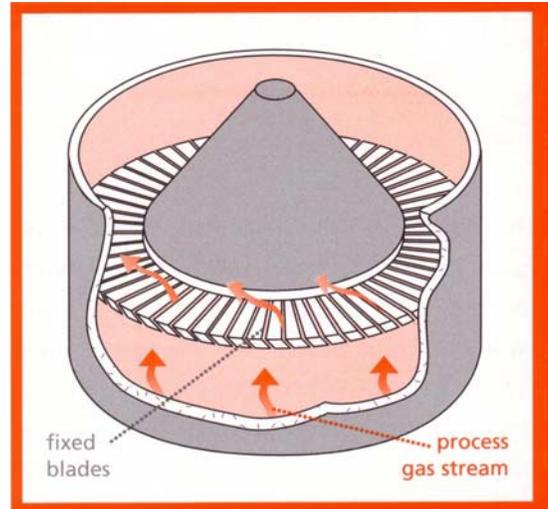
A given bed mass can be supported either by a large mass flow of process gas at low velocity or by a smaller mass flow of process gas at higher velocity. In a Compact TORBED reactor, the mass flows can thus be chosen to optimise the process. The annular shape of the CBR creates a compact gently rotating bed of material which describes a **TORoidal BED** circulation pattern above the blades. Indeed, this motion led to the creation of the TORBED Process Reactor Trade Mark.

Although the process gas stream leaving the blades in a Compact TORBED reactor may exit at speeds many times that which would entrain all particles, the high impact velocity is dissipated against the base of the shallow bed while superficial gas velocity can remain low enough not to carry away smaller particles.



Major advantages of the CBR

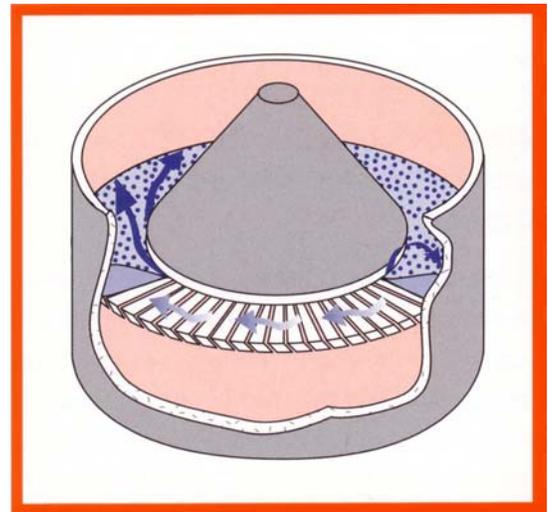
- ☉ The substantial de-coupling of hot gas mass flow and 'fluidising' velocity
- ☉ A high velocity drop or gradient through the bed means that substantially ungraded material can be processed
- ☉ High impact velocities provide exceptional heat and mass transfer
- ☉ The bed shape presents a large surface area to the blades in proportion to the bed volume, particularly beneficial where the blades are at high temperatures
- ☉ A shallow bed (typically a few centimetres) provides very small solids hold up and rapid response to process control
- ☉ A high specific throughput is achieved
- ☉ The static pressure loss through the process is low, often an order of magnitude less than conventional fluidised bed techniques. Process gas recirculation at high temperatures is thus more simple bringing energy savings



Process gas flow through fixed blades gives toroidal particle motion. By producing an annular processing region with toroidal mixing, material is continuously passed through the base of the bed where the high heat and mass transfer occurs. This ensures uniformity of processing

The TORBED CBR - already proven in many industries

TORBED Compact Bed Reactors are being used with great success in widely different industries, including minerals, metals, chemicals and foods. Most installations today are full size, not prototypes, and have given tens of thousands of hours of totally satisfactory operation. For all these reasons, the Compact TORBED reactor is now well established as an efficient, viable and more cost effective alternative to many conventional fluidised bed and rotary kiln processes.



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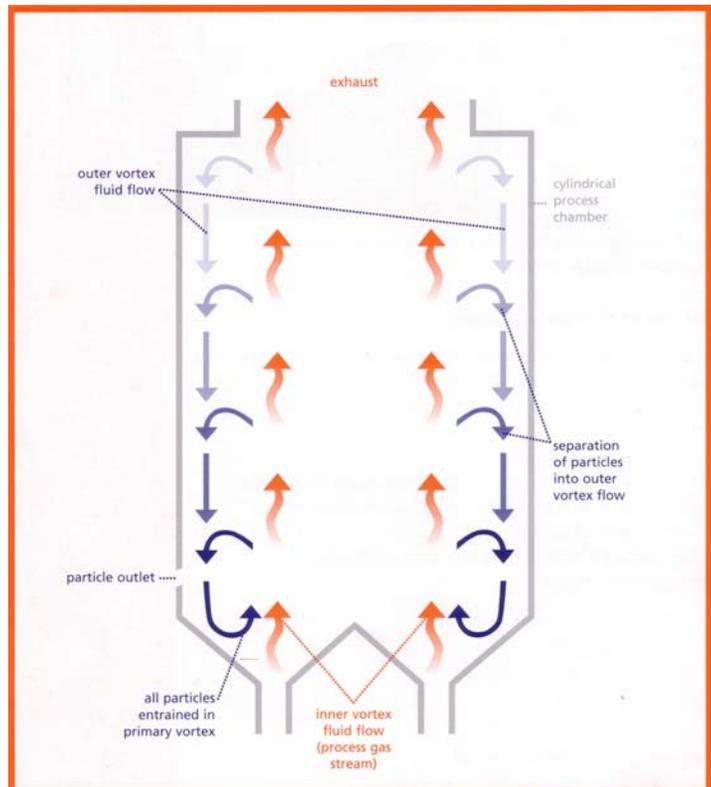
Technology Description

TORBED EXPANDED BED REACTOR ('EBR')



What is a TORBED Expanded Bed Reactor ('EBR')

The TORBED Expanded Bed Reactor ('EBR') has been specifically developed to retain a diffuse bed of solid particles in a toroidal circulation pattern within a high velocity process gas stream. The cyclonic motion creates centrifugal forces that separate the particles outwards. The particles then recirculate back to the base of the reactor to be re-entrained in the process gas stream.



- 

An EBR provides faster, more cost effective and efficient gas/solid contacting over a Circulating Fluidised Bed (CFB) and provides the following advantages:
- 

An equivalent particle retention time to a CFB is easily obtained in a smaller EBR since the horizontal component of the motion provides a longer contact path
- 

The cyclonic effect within the EBR allows for the separation and direct recirculation of particles in the expanded toroidal bed without the need for cyclones for separation and subsequent re-injection
- 

The EBR can readily be "fuel injected" (see separate Technology Description for Fuel Injection) to generate process gas temperatures in excess of 1,600°C.
- 

High gas flow rates with low pressure drop are possible in this new type of reactor. The higher the fluid flows, the better the retention of the smallest particles within the reactor.



Ideal for use in dry gas scrubbing

In gas scrubbing, the more turbulent the contact between reagent particle and gas to be scrubbed, the more effective the process. The EBR is ideal for this application for several reasons:

- lower gas pressure drop than competing systems better fine particle retention
- faster reaction kinetics due to improved mixing and turbulence attrition of the surface of reagent particles providing more complete reagent utilisation
- selective capture of differing particle sizes (which may have different characteristics).



A bank of 5m diameter TORBED EBR dry gas scrubbers in New Zealand



Ideal for use in combustion

When applied to combustion applications, the violent circulation of the particles within an EBR continually presents combustible surface area. Ash particles are retained within the EBR until they have been reduced to a small enough size such that they are carried out in the exhaust gas stream from the reactor. This unique capability allows temperature sensitive processes to be accurately controlled for commercial applications that in some cases were not possible before. The EBR is ideally suited to this application for the following reasons:

- ability to retain wide particle size ranges
- precise control of particle process conditions
- high specific throughput per unit volume



One of two 5MWth wood combustors

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Technology Description

FINE POWDER PROCESSING



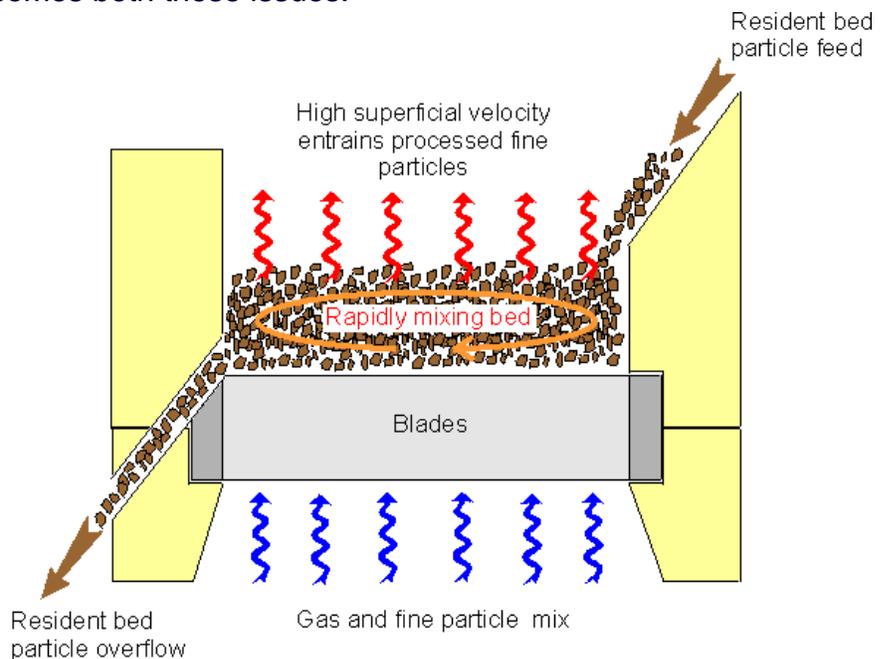
Background

Efficient gas/solid contacting where fine particles are involved can be a technically challenging assignment. Although reduced size usually makes the material more reactive, keeping it in the reactive environment for a sufficient amount of time can be difficult to achieve. Conventional unit operations are often completely unsuitable for this task. By employing a re-circulation strategy, circulating fluid beds overcome the retention time issue but at the expense of simplicity and cost. As such, the viability of these units is restricted to high value added and/or very large throughput applications. An enhancement to the basic TORBED reactor concept overcomes both these issues.



The fine powder injection process

In this mode of operation, the reaction zone of the TORBED unit is occupied by suitable inert material which act to form a "resident" bed. The fine powders are injected into the reactor just above the distributor where they then become entrained in the bed above. The resident bed not only ensures good mixing between the gas and the powder, it also creates a torturous path for the particles thus extending their residence time. In addition, the resident material improves the quality of heat transfer by providing thermal inertia and greater surface area for heat transfer.



Extra gas-solid contact time can be provided in the freeboard above the bed. Particles leaving the bed follow a spiral path out of the reactor, forming bands on the upper wall. When the mass of these bands exceed the carrying capacity of the air, they collapse, returning material to the bed thus creating an internal solids recycle loop.

The net effect is enhanced transfer properties and extended residence time without the need for a large and complicated reactor.

*TORBED® is a registered Trade Mark of Mortimer Technology Holdings Ltd



Major benefits

In comparison with conventional techniques, the benefits associated with the TORBED Powder Injection system are:

-  Extended particle residence time in the gas stream
-  Independently adjustable solids and gas retention times
-  Enhanced interparticulate and interphase heat and mass transfer
-  Isothermal reaction environment
-  Accurate temperature control with near adiabatic conditions possible
-  Smaller, simpler reactor
-  Low pressure drop
-  Potential to de-bottleneck existing plant by treating fine unreacted material that by-passes the main reactor

Because processing under such conditions has not been previously possible, the results can be unexpected and defy "conventional" wisdom. For example, the specific surface area of many solids increase dramatically upon processing. This is due to the formation of fissures, and the effect can lead to increased activity of the solid in downstream operations.



Applications

This technology tends to be most applicable to materials with a diameter less than 100 microns. Typical feed stocks include:

-  Process filter cakes (wet or dried)
-  Industrial minerals
-  Mineral concentrates

Because of its small size, the TORBED reactor has also been retrofitted to existing plant to address the issue of unreacted fines by-passing the main processor.

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Technology Description

FUEL INJECTION



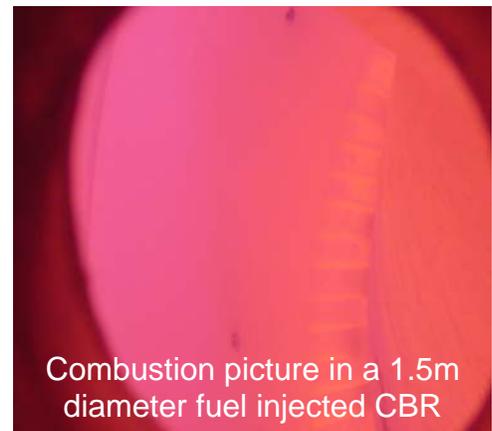
Background

In many gas-solid reaction systems, there are genuine benefits in being able to process at elevated temperatures. Unfortunately the optimum processing temperature often exceeds those permissible by the available materials of construction. The resulting compromise in processing conditions can lead to sub-optimal performance. A simple reactor system capable of overcoming materials based temperature limitations was therefore required.



The direct fuel injection process

Solids processed in the Torbed reactor form a compact bed just above the gas which is ideal for direct fuel injection. Using a proprietary technique, fuel is metered directly into the bed where it undergoes spontaneous combustion. The resulting flame envelopes the entire bed producing a high temperature, isothermal processing environment. Control is both straightforward and accurate. Localised temperatures approaching the actual flame temperature ($>1,500^{\circ}\text{C}/2,730^{\circ}\text{F}$) of the fuel being injected are possible. Because the elevated temperatures only exist within the compact bed zone suspended in the reactor chamber, the need for exotic construction materials is reduced.



Combustion picture in a 1.5m diameter fuel injected CBR



Major benefits

The primary advantage of this technique is that it enables solids to be processed at elevated temperatures on a commercial scale. Given this is now a viable processing option, a number of application dependant benefits previously unattainable become possible including:

- Higher single pass conversion
- Rapid heating
- Capability to create controlled oxygen processing environments
- Ability to create a reducing reaction environment
- Option to employ short time-high temperature (flash) processing strategies to increase throughput and/or enhance product quality
- Lower specific energy consumption

Because processing under such conditions has not been previously possible, the results can be unexpected and defy "conventional" wisdom. For example, the specific surface area of many solids increase dramatically upon processing. This is due to the formation of fissures, and the effect can lead to increased activity of the solid in downstream operations.

Application

Developed for a proprietary application, gas injection technology has since been successfully applied to a number of other duties including:

-  limestone calcination
-  reduction of metal ores
-  high temperature mineral calcination
-  flash processing of powders
-  sintering of clay prills



A 1.5m diameter fuel injected powder processor

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TORBED* Process Reactor Technology Application Description



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CATALYST & ZEOLITE PROCESSING

The ability of the TORBED reactors to carry out precise calcination and heat/mass transfer processes has allowed the development of unique process plants. The ability to control strong exothermic reactions allowed the regeneration and recovery of catalysts and zeolites to be carried out faster and with greater precision. The precise temperature control achieved in endothermic calcination of catalyst substrates produces higher surface area support structures and more reactive catalysts.

There are several application areas where TORBED reactors are already utilised including:

- Catalyst manufacture
- Catalyst regeneration
- Catalyst recovery
- Zeolite regeneration

Catalyst Manufacture

The ability to dry and precision calcine the catalyst substrate presents exciting opportunities, particularly in the generation of higher surface area support structures. TORBED reactors have been in commercial use since 2001. In the production of mineral based substrates, an increase in particle surface area of 10 times has been routinely achieved. Torftech has also provided their technology to aid users for the development of new catalysts.

Catalyst & Zeolite - Regeneration & Recovery

The removal or stripping of Volatile Organic Compounds ('VOCs') from catalyst and the control of the combustion of surface carbon and sulphur is best achieved in a TORBED reactor. The precise temperature control, and gentle physical handling afforded by the TORBED concept allows greater precision in processing. This close process control minimizes damage to the catalyst due to uncontrolled combustion.

TORBED reactors have been in commercial use for catalyst regeneration since 1997. The surface area, shape and reactivity of the catalyst are retained but with higher throughputs than was possible previously.



Catalyst Processor During Assembly

*TORBED® is a registered trademark of Mortimer Technology Holdings Ltd

Catalyst recovery, is applied to catalysts no longer regenerable due to physical or chemical degradation. These are processed in multi-stage TORBED Reactors to remove carbon and volatiles prior to hydrometallurgical or pyrometallurgical metals recovery processes. A TORBED reactor has been in use since 2000 preparing spent catalyst for a leach recovery process. As the prices for metals used in catalyst manufacturing continue to rise, recovery will become an increasingly attractive commercial opportunity.

The removal of VOCs from mineral matter, particularly where there is a large exotherm potential, is well controlled and precise utilizing a TORBED Reactor. This precision enables faster and less energy intensive commercial operation to be achieved.

A TORBED CBR has also been used for removal of water from zeolites used in drying of slurries.

TORBED Reactors are co-current heat transfer devices that have similar characteristics to fluidised beds. However, their very low pressure drop compared with fluidised beds allows multistage operation creating near plug flow processes. TORBED Reactors are smaller, cheaper and are usually factory assembled and tested.



A Catalyst Processor is hoisted into position

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November 1997

DRY GAS SCRUBBING



Why aluminium smelters have to clean up their act

Aluminium smelting companies all over the world are facing increasingly stringent regulations governing the emission of acid vapours. Basic dry scrubbing methods have been used since the 1960s in an effort to clean up the exhaust gases from these smelters but these techniques are often too inefficient to economically meet the requirements of current air emission legislation.

The use of venturi reactors, fluidised beds and reactant recycling systems have been explored, but these methods usually lead to increased processing time and/or significant pressure drops across the system which waste considerable amounts of energy. In some instances, up to 20 times more reactant is needed to scrub the exhaust gases. These technologies also call for large ancillary processing plants with additional capital investment.



Comalco tests out TORBED reactors

In 1990, Comalco Aluminium Ltd were exploring methods of removing hydrogen fluoride from the exhaust gases of their aluminium smelter in New Zealand by using the incoming feed material for the aluminium pots as the scrubbing medium. Their main aims were:

-  to save energy by reducing the pressure drop across the reactor
-  to eliminate alumina wastage
-  to achieve world standards for the emission of fluoride and particulates.

The company had been introduced to the TORBED Expanded Bed Reactor ('EBR') concept two years previously, and were impressed by its ability to achieve far greater slip velocity between solids and gases than is possible with other technologies. A pilot TORBED EBR based plant was therefore designed and set up in New Zealand. This study proved beyond doubt that the TORBED EBR was capable of scrubbing the gases to the required degree, simply by passing the alumina **once** through the exhaust gases.



Refining the design

A TORBED reactor 5 metres in diameter was then built so that any problems regarding bed stability and aerodynamic behaviour of the feed material could be identified and solved. After this stage had been completed, a full-scale prototype TORBED reactor was built. Its design was based on two chambers, each 6 metres in diameter, which were

configured so that they could operate either as a single stage reactor or as a two-stage counter-current operation.

Three times more efficient than expected

Before the prototype had been installed, Comalco envisaged that at least 30 TORBED reactors would be needed to clean up the exhaust gases. The refinements incorporated in the developmental stages, however, meant that the reactors were more than three times as efficient as had been anticipated. As a result, only 13 dry scrubbing units, each with a single stage TORBED reactor, were needed as part of the \$NZ94 million (US\$60m) gas emission project. Subsequently, Comalco have also equipped their Bell Bay Smelter with a further 6 TORBED reactor units



Reactor processing power

- each TORBED reactor treats a gas flow-rate of 380,000 m³/h in a single pass system for both the gas stream and the alumina particles
- emission levels for both gaseous hydrogen fluoride and particulates are approximately 1 mg/Nm³, which is comparable to the best performance figures for any dry gas scrubbing systems, anywhere in the world
- despite the outstanding processing efficiency, no extra power was required as the TORBED reactor creates only a low pressure drop across the system. As a result, the dry scrubbing units could continue to use the six existing 1 MW exhaust fans, whereas the use of alternative systems would have meant upgrading existing fans.

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TORBED* Process Reactor Technology Application Description



August 2002

MINERAL, CATALYST & CHEMICAL PROCESSING

The ability of the TORBED reactors to carry out precise calcination and heat/mass transfer processes has allowed the development of unique process plants. The first mineral processing application was the **exfoliation of vermiculite**.

Vermiculite is a naturally occurring mineral. When crushed, graded and fed into a hot furnace (1,200°C or 2,200°F), the vermiculite expands or exfoliates to produce a lightweight particle that is then used as an insulating and fire retardant fill. The process requires a very rapid heat transfer to the particles to promote as large an increase in particle size as possible to give low densities. Historically, vertical shaft and rotary kilns have been used to exfoliate vermiculite.

The TORBED reactor has shown itself to have unique capabilities in this application in producing higher quality, lighter and more consistent product with lower energy consumption. High heat and mass transfer and precision of control with the TORBED reactors have provided these advantages. Most important, the TORBED process provides more saleable product per unit of raw material fed i.e., a higher yield.

The TORBED process is in successful operation in 11 major production plants in Europe and Japan. Throughputs vary according to raw material grading but typically range from 1-5 tonnes per hour. The UK Department of the Environment Energy Efficiency Office, Best Practice Programme, published their Case Study 216 describing the use of the TORBED Reactor for this application with several significant benefits identified.

A 1m diameter high temperature “fuel injected” TORBED reactor was commissioned in 1998 to **calcine industrial minerals at temperatures up to 1,600°C**. The use of direct injection techniques whereby natural gas is mixed and combusted directly in the process chamber base allows intense high temperature calcination reactions to be undertaken.

The ability of TORBED reactors to carry out flash processing of fine powders with particle retention times of often less than 50 milliseconds has led to the development of novel products and processes. This ability was developed at pilot scale (up to 300 kg/h) and a 1.5m diameter TORBED Reactor was successfully commissioned in 1999 for the flash processing of sub 5 micron ore. This reactor uses the same direct gas injection technique described above.



High Temperature Mineral Calciner

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Flash Processor for Fine Ore

Multiple dense phase conveying injectors are used to distribute the raw material feed around and into the TORBED Reactor process chamber. The finished product is carried out of the TORBED Reactor in the exhaust gas stream and collected in a bag house after gas and solid cooling.

The ability to heat the fine particulate feed from ambient to more than 1,000°C in milliseconds provides a process environment where high surface area products are routinely produced. It is not uncommon for a tenfold increase in particle surface area to be achieved.

The roasting of sulphide ores with the TORBED Reactor has also produced high surface area, more leachable materials.

Catalysts and Zeolites are commercially processed in TORBED Reactors to remove carbon and volatiles prior to metals recovery or impregnate/form the substrates required. The precision of the process environment usually creates unique, higher surface area materials that can revolutionize total processes.

The removal of VOCs from mineral matter, particularly where there is a large exotherm potential, is well controlled and precise utilizing a TORBED Reactor. This precision enables faster and less energy intensive commercial operation to be achieved.

TORBED Reactors are co-current heat transfer devices that have similar characteristics to fluidised beds. However, their very low pressure drop compared with fluidised beds allows multistage operation creating near plug flow processes. TORBED Reactors are smaller, cheaper and are usually factory assembled and tested.



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TORBED* Process Reactor Technology Application Description

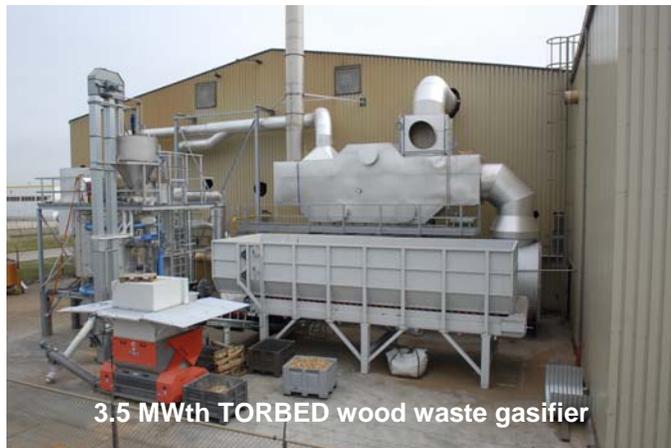


April 2006

ENERGY PRODUCTION FROM BIOMASS WASTES

Throughout the world, there are massive quantities of lignocellulosic wastes generated as a result of manufacturing processes which turn trees and other vegetative growth into lumber, paper and food products. These wastes that are generated centrally during the manufacturing process, are more conveniently used as an energy resource than are the wastes from harvesting that are scattered, normally left in field or forest.

Since the alternative to utilization of these wastes is disposal to land where they will slowly degrade and ultimately generate carbon dioxide and other greenhouse gases, there is the potential for real savings in greenhouse gas emissions if these wastes are used to generate energy to replace energy generated from fossil fuels.



Many of these potential energy resources are either small in particle size and light and 'fluffy' (e.g. sawdust, rice husk, wheat chaff) or physically heterogeneous in size range (e.g. mixed wood waste containing sawdust, bark and off cuts). These physical characteristics often make them difficult to handle effectively in conventional combustion equipment.

Some wastes contain potentially valuable inorganic ash. For example, with the ash produced from rice husk, it is critical to maintain a very controlled combustion or gasification temperature to avoid causing undesirable changes to the morphology of the ash.

TORBED reactor technologies are ideally suited to combust or gasify coarse and mixed size wood waste streams after a minimum degree of size reduction, e.g. coarse shredding. TORBED reactors can handle the elongated product of primary wood shredding simultaneously with sawdust. The temperature within a

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TORBED reactor can be controlled precisely so that where there is sensitivity to temperature for a potentially valuable inorganic ash by-product, adverse effects are avoided.

TORBED reactors are operating commercially in Europe combusting mixed urban wood waste to generate a hot gas stream that is used to dry manure for use as a fertilizer product.

A TORBED reactor is being installed in India to combust up to 2 tonnes/hr of rice husk to generate steam in an adjacent heat recovery boiler. The ash by-product which constitutes some 18% of the husk will be recovered for sale as a component to be used in the production of low-porosity, high-strength concrete.

Extensive pilot test work has been undertaken on the use of the TORBED reactors for the gasification of agricultural residues and poultry house litter.

When applied to combustion and gasification, the unique properties of the TORBED reactors include:

- 🌀 Ability to receive a wide range of particle sizes e.g., shredded, chopped, milled, ground and mixed feeds
- 🌀 Close temperature control for production of more valuable ashes
- 🌀 Compact plant with a high throughput per unit volume thus occupying a small foot print
- 🌀 Factory assembled to minimize site installation infrastructure and costs
- 🌀 Low NO_x due to rapid and turbulent mixing in the process chamber
- 🌀 Low pressure drop to minimize electrical consumption

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TORBED* Process Reactor Technology Application Description



August 2002

ENERGY & AMORPHOUS SILICA PRODUCTION FROM RICE HUSK

Global production of rice, the majority of which is grown in Asia, is approximately 550 million tonnes/year. The milling of rice generates a waste material, which is the husk surrounding the rice grain. This is generated at a rate of about 20% of the weight of the product rice, or about 110 million tonnes/year globally. The husk in turn contains between 15 and 20% of mineral matter the majority of which is amorphous silica. There is a growing demand for finely divided amorphous silica in the production of high strength, low permeability concrete, for use in bridges, marine environments, and nuclear power plants. This market is currently filled by silica fume. Limited supply and high demand has pushed the price of silica fume to as much as US\$1,000/tonne. Rice husk has the potential to generate 16.5 to 22 million tonnes of ash containing over 90% amorphous silica, which could be used as a substitute for silica fume. Assigning a more realistic price of US\$300/tonne would make the potential value of this ash product world wide US\$5-6.5 billion/year.

The husk has an energy content of about 13.5GJ/tonne, so that the energy potential world wide would be about 1.5 billion GJ/year, which at US\$5/GJ would have an annual value of US\$7.5 billion. This amount of energy is equivalent to over 1 billion barrels of oil per year.

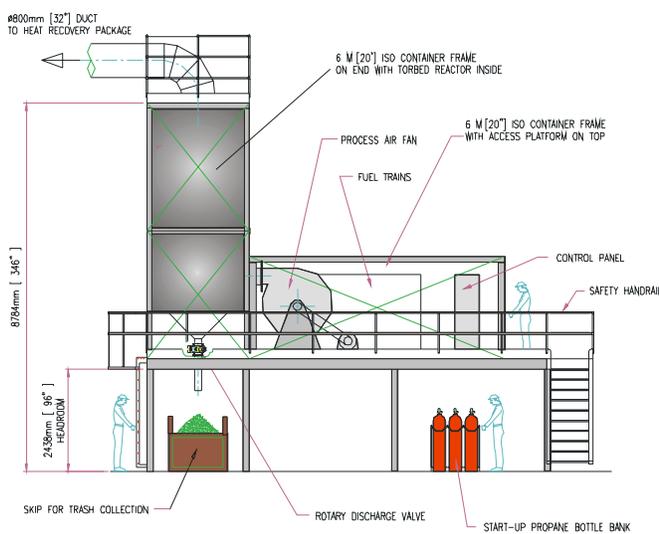
Rice husk is currently being used for energy production through direct combustion or gasification in many areas of the world. Unfortunately, in almost all of these installations, the ash produced is not suitable for use as a silica fume substitute. Generally there are two shortcomings in the ash by-product from current rice husk to energy technology: first, they contain unacceptably high concentrations of residual carbon; and second a portion of the amorphous silica has been transformed into crystalline silica, cristobalite. The second of these two problems is the more serious, cristobalite does not have the same pozzolanic (cementitious) properties, as the amorphous form, and in the particle size range at which it would be used in concrete, it is recognized as a potential human carcinogen. The transformation to the crystalline state takes place if the ash is exposed to high temperatures and becomes even more likely if it is exposed to these high temperatures for extended time periods. Most of the current energy generation technology does not control temperatures well and most allow the ash to remain at high temperatures for a relatively long residence time.

TORBED rice husk combustion and gasification technology utilizes a unique reactor configuration that completes the combustion or gasification of husk in a short

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residence time at precisely controlled temperatures. Pilot scale tests have shown that, using the TORBED reactor technology, an ash can be produced at a moderate temperature, which has zero, or at most minor trace quantities of, cristobalite and a residual carbon content of 1-3%. The first commercial TORBED rice husk combustor will be going into production in India in early 2003.

Because of the moderate temperatures used in the TORBED reactor there is a slight reduction in the usable energy that can be recovered from a TORBED combustor. In some instances this may be compensated for by achieving a much more complete combustion of the available fuel.



A Typical 1tonne/hr Rice Husk Combustor

The TORBED reactor can be designed into a new facility to combust rice husk for energy production, or this combustor can be retrofitted into an existing facility to replace a current combustor that is producing an unusable ash waste. The capital investment in a replacement combustor will generate an attractive return on investment ('ROI') based on the benefits of turning a waste disposal cost into a by-product credit. Similarly, installation of new plant for energy generation will produce an attractive ROI based on both energy and ash values.

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TORBED* Process Reactor Technology Application Description



November 2002

PILOT PLANT FACILITIES

While Torftech is not an R&D company, it undertakes development and piloting of new processes in order to understand the application of its technologies to new applications. The most extensive TORBED pilot facility is located at **Process Research ORTECH in Mississauga, Ontario, Canada** and provides a world class capability for the development of novel products and processes at a range of temperatures up to over 1,500°C.



The facilities include:

- 🌀 Two new reactors – the complete line up now includes a TORBED Compact Bed Reactor ('CBR'), a TORBED Expanded Bed Reactor ('EBR') and a Transport Bed Reactor ('TBR').
- 🌀 The original CBR is still used for a wide variety of applications including catalyst, fine chemical, mineral and metallurgical applications
- 🌀 The new EBR has been developed to handle ashes, combust biomass, roast and calcine materials, scrub gases and classify
- 🌀 The new TBR is providing flash processing of ultra-fine (down to submicron) materials at high temperature and in controlled and modified atmospheres
- 🌀 Gas injection on the CBR to facilitate processing of materials at up to 1,600°C
- 🌀 Venturi blower recycle to allow direct recycle of the process gas stream at elevated temperatures (enhancing the capability of the reactors to operate in modified atmospheres for gasification, reduction, hydrogenation and devolatilisation)
- 🌀 Computerized data logging of relevant parameters
- 🌀 Addition of new feeders and other relevant ancillary equipment



There are two refractory lined natural gas fired hot gas generators onto which the TORBED reactors are placed. Each is equipped with inlet points where steam, nitrogen, oxygen or any other gases to be introduced to modify the atmosphere within the reactor. An oxygen analyser is available and can be connected to either reactor to measure oxygen concentration in either the hot gas generator or a reactor. More detailed online gas monitoring equipment is available from Canadian Environmental ORTECH for monitoring services. The pilot facility includes a Hosokawa circular vibrating table feeder, a low and high capacity screw feeder, a large screw feeder and several vibrating pan feeders.

The exhaust gas handling system includes a cyclone where the bulk of product samples are collected. A quench tower/scrubber combination can be incorporated into the exhaust train for projects where large amounts of acid gases such as SO₂ are generated. A small baghouse can be incorporated into the exhaust gas line on a slip stream for sampling only (the full flow creates too high a pressure drop. A general purpose baghouse ensures that exhaust gases are cleaned prior to exit from the building.



On site equipment includes various crushers, mills, screens and drying ovens for feed preparation. Laboratory facilities are available to allow simple analytical tests to be undertaken such as screen size analysis, moisture content, loss on ignition (LOI) and particle density and bulk density. Other analyses are contracted out to Bodycote ORTECH that is located in adjoining facilities or samples can be returned to clients for their own in-house analysis.



Current processes under development include novel combustion, mineral calcination, catalyst, waste and chemical reaction processes.

The addition of a **400mm electric food processor** has also expanded the capability of the pilot facilities to allow the precise thermal processing of food products including fat free snacks, breakfast cereals, spices and beans.

In **Europe**, the facilities include a **transportable** low and high temperature 400mm diameter ceramic CBR complete with a post combustion chamber, heat exchanger and venturi scrubber. There are numerous ports for monitoring process parameters and the process data can be automatically logged. This plant can be transported to sites throughout Europe for long term trials.

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