NOVEL THERMAL TREATMENT CAPABILITY OF THE TORBED® PROCESS REACTOR TECHNOLOGIES

C. E. Dodson
Torftech Limited, 2395 Speakman Drive, Mississauga,
Ontario L5K 1B3, Canada

R. G. W. Laughlin
ORTECH Corporation, 2395 Speakman Drive,
Mississauga, Ontario L5K 1B3, Canada

ABSTRACT

The first TORBED process reactor was invented and patented in 1981. (TORBED® is a registered trademark of Torftech Ltd.). The technology has since been extensively developed to provide novel process techniques in gas/solid contacting. Over 80 plants have now been installed for applications as diverse as gas scrubbing, fat free snack production, clinical waste pasteurization, mineral processing, combustion and other industrial uses.

During more recent years this novel process reactor technology has been developed for the thermal treatment of highly hydrocarbon contaminated solids, wood wastes, coal and spent pot lining. One major advantage of these reactors is their generic ability to flash process fine particles, often down to a few microns in diameter that allows high specific throughputs and precision in thermal treatment of hitherto difficult to process materials.

The fundamental principles of these novel reactor technologies are explained. The problems encountered and valuable experience gained when applying the reactors to a range of materials processing needs, including several hazardous substances, is discussed as well as the results obtained.

TORBED PROCESS REACTOR TECHNOLOGIES

The principle characteristics, advantages and limitations of these reactors are set out below.

Compact TORBED Reactor

The Compact TORBED reactor retains a compact shallow packed bed of particles suspended above an annular ring of stationary blades or vanes (somewhat similar to a static set of turbine blades) through which a process gas stream is passed at high velocity (see Figure 1).

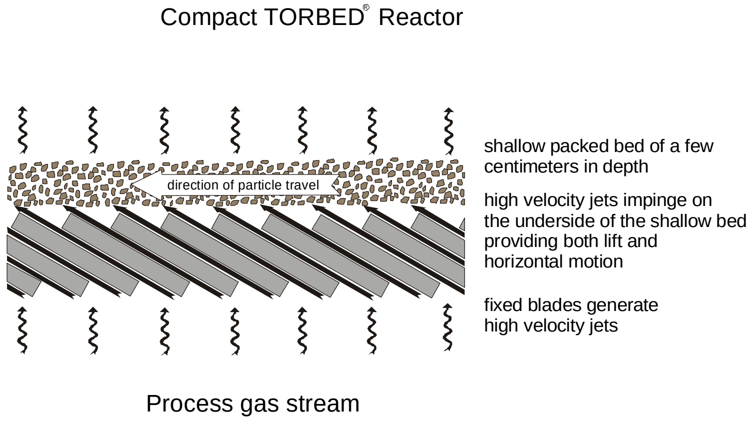

Figure 1 *Compact* TORBED Reactor Principles

The high velocity gas jets (generated in the restriction between the blades) exchange energy on impact with the particles on the underside or base layer of the bed providing both vertical lift and horizontal motion. This high velocity impingement enhances the heat and mass transfer to that base layer. The blades and bed are arranged in such a way that the bed mixes rapidly in a controlled fashion thus continually presenting material into the base layer and thus to the process gas stream (see Figure 2).

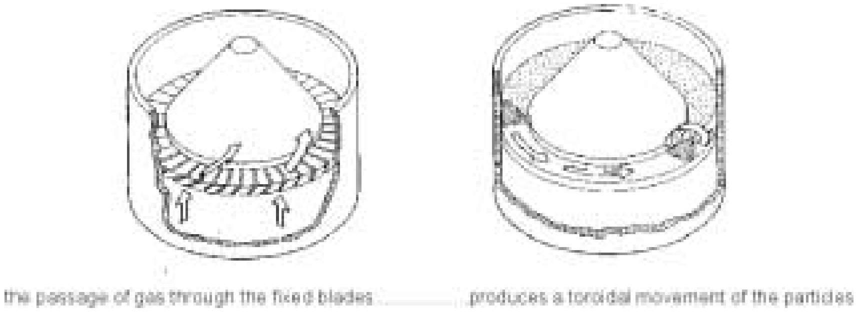

Figure 2 Compact TORBED reactor principles

Unlike fluidized beds where a particle’s diameter, density and geometry dictate the minimum process gas velocity, the process gas mass flow through a Compact TORBED reactor can be set to suit the process - a smaller process gas mass flow can be used but at a higher velocity at exit from the blades to keep the bed in proper motion.

Compact TORBED reactors have similar superficial freeboard velocity restrictions (somewhat increased due to the cyclonic effect of the gas flows in the freeboard) as bubbling fluidized beds, to minimize elutriation. However, they achieve higher specific throughputs (due to enhanced heat and mass transfer rates) without the inherent high pressure drop, long retention time and large solids inventory issues associated with fluidized beds. Unlike bubbling fluidized beds, Compact TORBED reactors are not limited to near spherical closely sized particles. Indeed these reactors accept widely graded feedstocks with irregularly shaped feedstocks including shredded, flaked and complex shaped extruded materials. Packed beds of widely graded feed stocks can be suspended by a process gas mass flow lower than that required for fluidization of the largest particles.

The small solids hold-up in the Compact reactors is both an advantage and a disadvantage. For processes that can be undertaken in milliseconds, seconds or at most a few minutes, these reactors can provide real time process control, allowing the process limits to be explored. The advantages that these reactors bring are:

- Heat/mass transfer rates higher per unit volume allowing smaller reactor size with rapid start-up and program change.
- Particles are processed faster and with more precision giving consistent product or process.
- Low process gas stream pressure losses facilitate process gas recirculation and operation with neutral, reducing or other special atmospheres at high temperatures.
- Ability to process widely graded and irregularly shaped feed stocks.
- Real time control that allows simplicity in operation and precise and simple automation.

Where a process retention time (for example where phase changes are involved) is by necessity more than a few minutes, the small bed mass of the TORBED reactors are unlikely to be economically viable and conventional fluidized bed reactors or rotary kilns will be more applicable.

It is worth noting, however, that perceived residence time requirements derived from other gas-solid contactors are often many times those needed in a TORBED reactor because of its enhanced heat and mass transfer characteristics.

The Compact reactors surprisingly produce minimal particle degradation due to reduced inter-particulate motion (all particles are traveling in the same general direction and are not in collision) and short retention times.

Some applications require an inert resident bed of particles to be held in the reactor into which materials to be processed can be introduced. Liquids, slurries and sludges can be pumped directly into such a bed for evaporation, combustion or similar processes (where the bed remains predominantly dry since if the bed becomes fully saturated with liquid, it will cease to operate and will slump). Catalysts have also been used to enhance combustion and dissociation reactions within the reactors.

Expanded TORBED Reactor

The Expanded TORBED Reactor was developed to retain an expanded diffuse bed of particles. The particles follow a toroidal circulation pattern. Initially they are entrained in a high velocity central vortex (the process gas stream) whose cyclonic motion creates forces that cause the particles to separate radially outward. The particles are then transferred in an outer downward direction back to the base of the reactor to be re-entrained in the process gas stream again (see Figure 3).

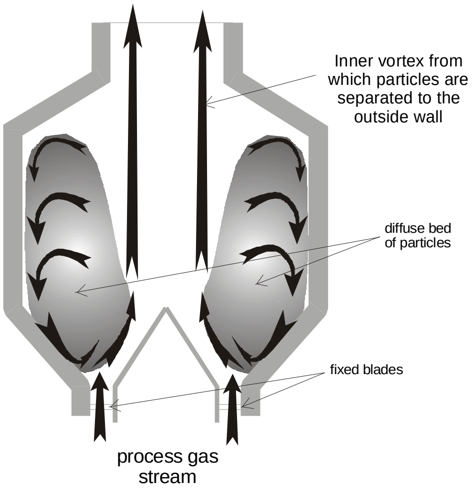

Figure 3 The Principles of the *Expanded* TORBED Reactor

An Expanded TORBED reactor provides as fast and efficient gas/solid contacting as existing Circulating Fluidized Beds (CFB) and provides the advantages outlined in the comparison shown in Table I.

Table I

Comparison of the Characteristics of Expanded TORBED Reactors with Circulating Fluid Beds

Aspect	Circulating Fluid Bed	Expanded TORBED Reactor
Size	Tall vertical vessel to give required retention time of particle in gas in a single pass.	Shorter reactor vessel since gas flow helical in pattern giving equivalent contact time.
Recirculation	Normally external to the reactor by cyclone with solids returned to the base of bed for recirculation.	Solids are separated by centrifugal force directly within the reactor and recirculated internally with no requirement for a cyclone.
Pressure drop	Reactors have a relatively high pressure drop.	The pressure drop can be as low as 100mm (4in) water gauge.
Solids	It is not possible to selectively discharge differing particle size ranges.	Differing particle size ranges can be selectively removed from the reactor.
Fuel injection	To present particles in a predictable path through a zone of closely controlled combusting gases is difficult.	Particles can be continually circulated through a combustion path in the inner vortex at up to stoichiometric temperatures.

These reactors can, if required, be configured for high gas and particle velocities that inevitably cause relatively high attrition rates, as also happens within a CFB. Such attrition can be an advantage in applications where the renewal of a particle surface is beneficial as in dry gas scrubbing or combustion.

GENERAL CHARACTERISTICS

Both the Compact and Expanded TORBED reactors exhibit co-current or modified cross-flow heat transfer characteristics (i.e., the processed material leaves the reactor at the same temperature as the off gases). A general comparison between a range of reactors and the TORBED reactors is shown in Figure 4 below.

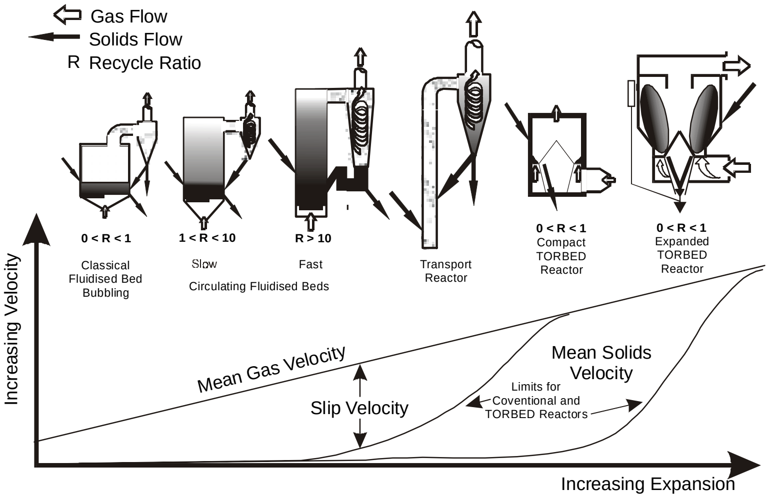

Figure 4 Illustrative comparison between a range of reactor types

PARTICLE RESIDENCE TIME DISTRIBUTION

Particle residence time distribution curves usually approximate to fully stirred reactors. The exception is when there is a physical characteristic of the processed material that can be used to differentiate it and allow separation when processing is complete (e.g., change in density, vaporization or particle size reduction).

FUEL INJECTION

Both the above reactor types can have gaseous fuel injected at blade level which generates a combustion reaction directly within the bed of material in the reactor. Near stoichiometric combustion temperatures can thus be generated in the vicinity of the suspended solids.

FINE POWDER PROCESSING

It has been found that fine powders (typically less than 50μm diameter) can be injected into the reactor between the blades and the bed such that the powder is transported through a resident packed bed of inert particles (typically 1-2 mm diameter) held in the reactor. By this means the fine powder can be “flash processed” with retention times within 10-50 milliseconds. Such a processing technique allows temperature lifts of the fine powder of 1000°C or more within this short residence time.

Frequently the retention time is so short that high surface area materials are produced with particle morphology that has not been achieved before. This is either due to exfoliation, formation of fine fissures (caused by rapid expansion of gases), or increased porosity. This characteristic of the TORBED process has distinct advantages in situations such as the flash roasting of sulphide ores where the increased surface area allows for much more effective leaching of the oxidized metal species.

EXAMPLES OF APPLICATIONS OF TORBED TECHNOLOGY TO THE REMEDIATION OF CONTAMINATED SEDIMENTS AND SOILS*.*

The TORBED Reactor can be effectively utilized for the remediation of soils contaminated with hazardous organic compounds, such as poly aromatic hydrocarbons (PAHs). Many of the positive features of the TORBED technology discussed earlier make it a very attractive option in this application, these include:

- The ability to handle a wide range of particle sizes, including the ability to handle extremely fine particles less than 50 μm.
- The very precise control of process conditions.
- The compact size of the reactor, which allows it to be transportable.
- The closed nature of the reactor allowing total control over emissions.

Example 1 Harbour Sediment

In late 1997 a demonstration of the TORBED reactor technology was undertaken on harbour sediments from Lake Superior adjacent to a wood preserving plant. This work was undertaken in the TORBED pilot plant at ORTECH, and was sponsored by GL & V Process Equipment Group Ltd., Torftech Ltd. and ORTECH Corporation[1].

Two different samples of waste sediment were obtained from the site, both had very similar physical characteristics, typical of sediments they were about 40% solids content, and the solids had an average particle diameter of 15-16μm. One sample contained 32400ppm total hydrocarbon and 5500ppm of PAH, the second material contained 8800ppm total hydrocarbon and 1268ppm of PAH.

The samples were dried at 40ºC (which resulted in minimal changes to the PAH concentration in the material) prior to testing in the pilot scale TORBED reactor located at ORTECH, a schematic of which is shown in Figure 5.

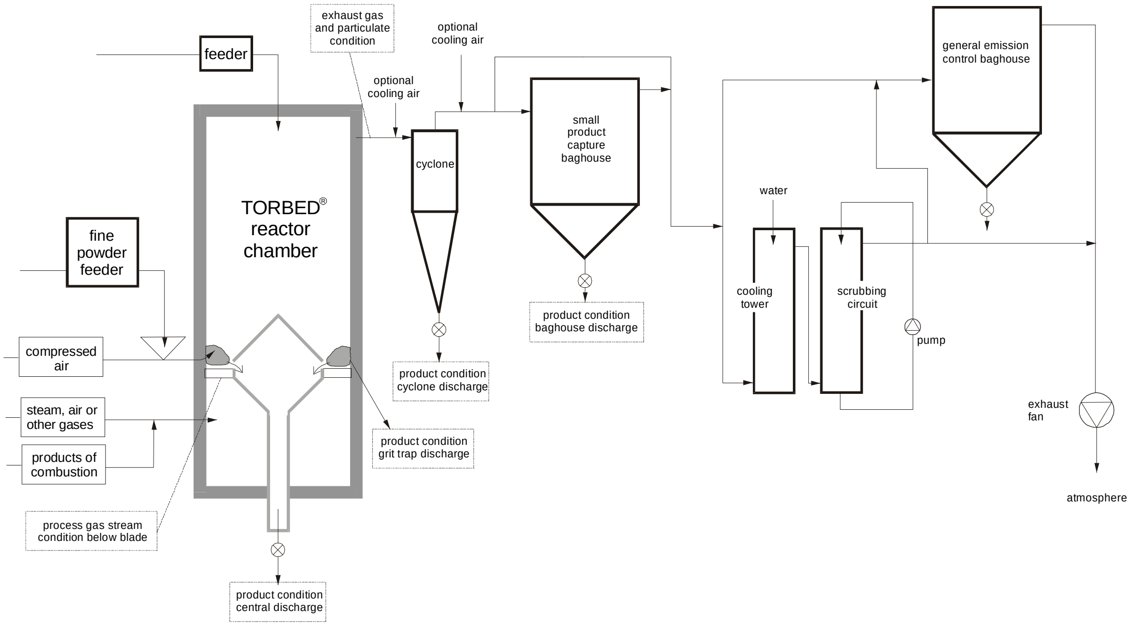

Figure 5 Illustration of the 400mm TORBED reactor pilot plant at ORTECH

The dried harbour sediments were introduced directly into a resident bed of fused alumina. The powder was fed using a compressed air operated pneumatic feed system. After treatment the powders exited the reactor with the exhaust gas stream, and were captured in the cyclone and scrubber used to treat this exhaust gas.

The results were extremely good. All tests run at 900 to 1050°C resulted in undetectable amounts of residual PAH associated with the treated solids.

Two extended test runs were undertaken in which the offgases were monitored and ORTECH's stack sampling team took samples for particulate and trace organic analysis immediately downstream of the cyclone. Table II shows a summary of the gas monitoring results on the two runs. The total hydrocarbon levels are reported as ppm methane equivalent.

TABLE II

Summary of Gas Analysis Data
Monitoring and Audit Tests
TORBED Reactor Test on Harbour Sediments
November 05/97

Test	O2 %	CO_2 %	CO ppm	THC ppm	NO ppm	NO_X ppm	SO_2 ppm
1. Low PAH feed							
Average	17.68	1.87	3	2	17	18	9
Minimum	17.52	1.41	1	1	7	8	3
Maximum	18.41	1.99	7	12	19	20	21
2. High PAH feed							
Average	18.01	1.72	6	2	17	17	7
Minimum	16.54	1.54	2	1	8	7	3
Maximum	18.08	2.11	21	6	19	19	10

Table III reports the particulate emissions measured after the cyclone. These show an apparent emission rate of 20% of the feed. Obviously, for a commercial application of this technology, a scrubber, hot baghouse or ESP would be used downstream of the cyclone. Our interest in monitoring was directed toward a good understanding of PAH destruction, rather than compliance monitoring. Hence, monitoring at this point, in conjunction of analysis of the product captured in the cyclone, gave us a good estimation of total PAH destruction.

TABLE III

Summary of Particulate Emission Data

Test	Solid Feed Rate g/sec	Particulate Emission Rate g/sec	% of Particulate Captured in Cyclone	Emission Concentrates mg/Rm^3
1. Low PAH Material	1.1	0.28	80	1221
2. High PAH Material	1.4	0.28	80	1276

Table IV summarizes emission data for PAH. Since no PAH was detected on the product from the cyclone, the emission of PAH at this point compared to the feed rate of PAH shows that a destruction efficiency of about 99.99% was accomplished. Monitoring for chlorophenols was also undertaken, with none detected either in the feed or effluent.

TABLE IV

Summary of PAH Emission Data

Test	PAH Feed Rate mg/sec	PAH Emission Rate mg/sec	% Destruction	Emission Concentrates mg/Rm^3
1. Low PAH Material	1715	0.328	99.981	1.44
2. High PAH Material	7700	0.626	99.992	3.09

In a test designed to determine how sensitive these high destruction levels were to the temperature of operation in the reactor, the temperature was lowered to 800 and then 750°C. The measured gaseous total hydrocarbon level increased to 24 and 36ppm respectively. The residual PAH associated with the treated solid was still undetectable in the product from the run at 800°C and only increased to 8.2ppm at 750°C (this test having been run with the starting material containing 5500ppm of PAH). The increase in gaseous hydrocarbon levels at lower temperature without significant increases in residual PAH is probably due to a reduction in the gas phase oxidation rates of volatilized organic species.

From the results of these tests we concluded that the TORBED reactor technology was excellent for the treatment and remediation of very fine harbour sediments, and that its performance would not be adversely effected by quite large decreases in operating temperatures down to 750°C.

While the pilot runs on this material were quite short and therefore would not predict operational reliability of a commercial plant, commercial TORBED reactors operating at similar conditions enjoy very high on stream availability typically 95%+.

Example 2 Processing Manufactured Gas Plant (MGP) Wastes

A second program to test the applicability of this technology to processing wastes from old MGP disposal sites is just in the very preliminary stages. This material contains, PAHs, oils, wood chips, cyanides and other soil materials. Unlike the harbour sediments this waste contains a very mixed range of sizes from very fine silt to large chunks of wood. The sample we tested contained about 100ppm total PAH, 580ppm of cyanide, and 140,000ppm of solvent extractable hydrocarbons. In the one preliminary test we ran at 1000°C, the average treated residues contained undetectable PAH concentrations, <50ppm solvent extractable hydrocarbons, and 10ppm of cyanide. We are quite sure with optimization of the process we will achieve even higher levels of destruction of the cyanide contained in the waste.

This MGP waste material is generally regarded as being quite difficult to process, but even at this early stage of testing we believe that the TORBED technology has shown itself equal to the challenges this material presents. The pilot work undertaken on the controlled combustion of wood waste by N. Bolt et al[2] has shown that the processing of wood waste is readily achieved in a TORBED reactor which gives confidence in the eventual commercial success of this application.

CONCLUSIONS

The novel characteristics of the TORBED reactors make them ideal to handle difficult to process materials such as the harbour sediments and MGP wastes described above. Their ability to handle both very small particle sized material, and materials with a broad range of particle size and shape are key in these two applications.

One of the other major advantages of TORBED reactors applied to remediation projects is the compactness of the plant which allows for it to be made transportable. Hence a unit can be brought on site, process the materials, and then replace the remediated soils, without ever moving them offsite. At the end of the campaign, the TORBED unit can be moved to another application.

TORBED reactors have been in continuous commercial operation in the following applications that are relevant to the development work described above.

- In the mineral industry for such applications as the calcination of vermiculite since 1985[3].
- In the recycling industry for the de-oiling of machine shop metal wastes since 1988[4].
- In the aluminium industry for the treatment of spent pot lining (SPL) containing cyanide and PAHs since 1990[5].

These existing applications give us the confidence that the new processes described above for soils, sediments (and specifically MGP wastes) will become commercially viable processes.

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