MANAGEMENT OF PAPER MILL SLUDGES

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DESCRIPTION OF THE TORBED®* REACTOR TECHNOLOGY

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The Torftech Group has developed a novel gas solids contacting reactor technology, which have been applied commercially to many different commercial applications since its first introduction in 1982.

The unique air flow patterns developed within the TORBED* Reactor achieves very fast mass and heat transfer rates in processes involving interactions between gases and solids. There are two major reactor types which are described briefly below:

Compact Reactor

The Compact 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 below).

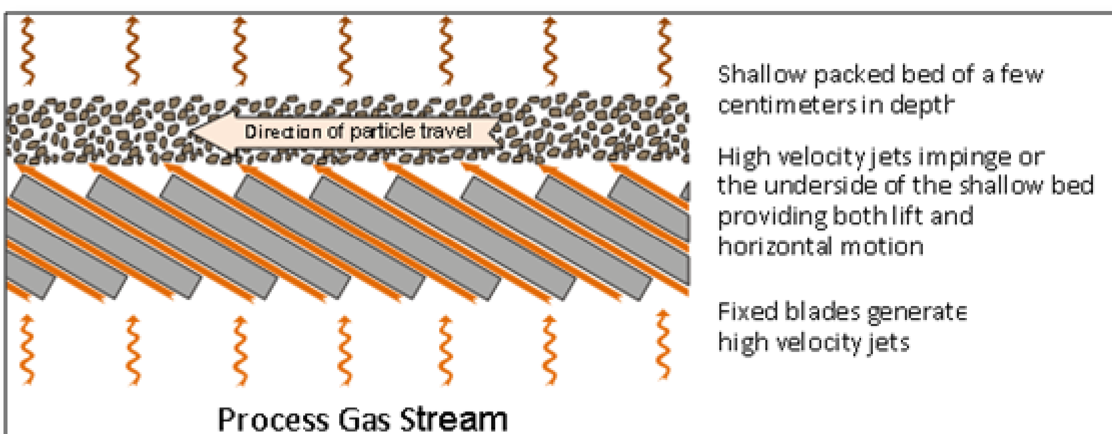
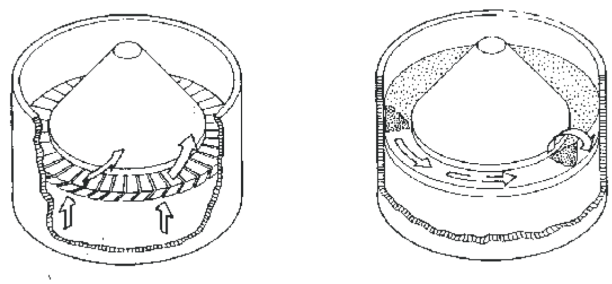


Figure 1: Compact Bed Reactor principles

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 below).



the passage of gas through the fixed blades.................produces a toroidal movement of the particles

Figure 2: Torroidal movement in Compact Bed Reactor

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 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 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, toroidal fluidized bed reactors are not limited to near spherical closely sized particles. Indeed these reactors accept widely graded feed stocks with irregularly shaped feed stocks 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 these 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 the toroidal fluidized bed 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 travelling 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 sledges 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 Reactor

The Expanded 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 below).

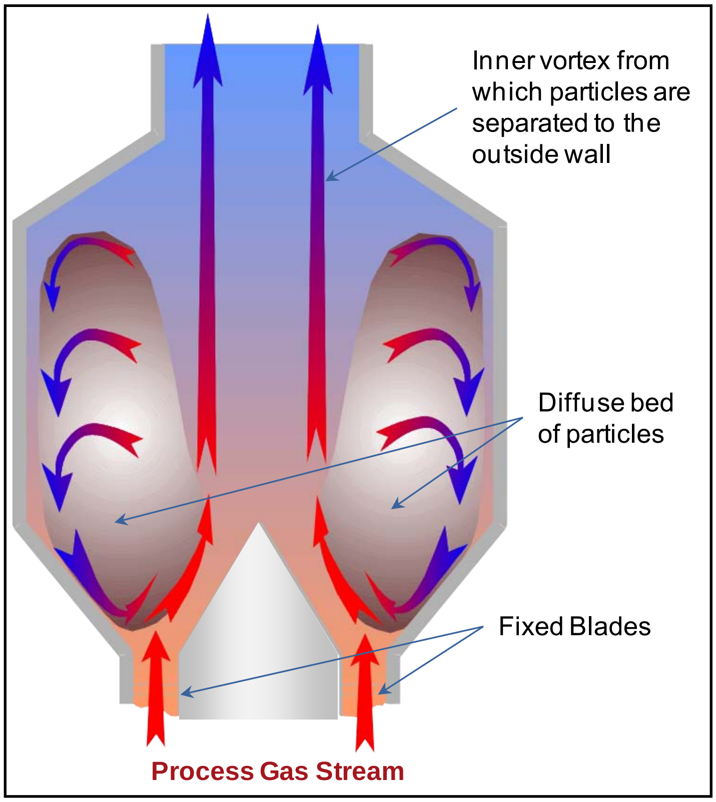


Figure 3: Principles of the Expanded Bed Reactor

An Expanded reactor provides fast and efficient gas/solid contacting and longer residence time for fine particles than is achieved in the compact bed reactor. Fine particles are "cycloned" out of the spinning inner vortex and re-circulated within the reactor.

Both the Compact and Expanded 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).

PULP AND PAPER MILL SLUDGE

Paper mills generate sludge streams from their wastewater treatment plant operations which contain wood or paper fibre with varying amounts of inorganic material and moisture. Mechanical dewatering of these sludges cannot lower the moisture content significantly below 50%, and typical values can be in the range from 50-75%. The costs for disposal of these sludges are increasing, and adding a significant operating cost burden for the mills.

Some primary pulp mills which have power boilers fired with wood waste incorporate the sludge with the wood feed to avoid the cost of external disposal. The incorporation of the wet sludge in the boiler feed reduces the efficiency of the boiler.

Secondary paper-mills utilizing recycled fibre generally do not have solid fuel fired boilers on site, so utilizing existing solid fuel combustors is not an option for sludge disposal at these sites.

APPLICATION OF THE TECHNOLOGY TO PAPER MILL SLUDGE MANAGEMENT

Sludge from pulp and paper mills is challenging to handle and process. The toroidal fluidized bed gas solids contacting reactors are well suited to processing such materials in an effective manner, in a number of different scenarios:

- Drying the sludge prior to combustion in an existing wood waste power boiler
- Drying the sludge to reduce the cost of disposal or to make it a more attractive "fuel" for use elsewhere
- Drying the sludge prior to combusting in a dedicated sludge combustion reactor.
- Combusting the wet sludge directly using natural gas to support the combustion process.

DRYING WET SLUDGE TO INCREASE THE EFFICIENCY OF POWER BOILERS

A commercial Compact Bed Reactor has been drying sludge from a specialty papers mill in Holland, since 2004. The unit is designed to dry sludge from about 67% moisture to a dry product with an average residual moisture content of 5% at a rate of 2 tonnes/hr (product). This is achieved using low grade waste heat from elsewhere in the mill which provides a warm drying gas at a temperature of between 105 to 110°C. A photograph of this facility is shown in Figure 4. At one stage the dried product was being marketed as an adsorbent cat litter. Currently the dried sludge is utilized as a fuel in a local cement kiln

Figure 4: Compact Bed Reactor used as a paper sludge drier at a Sappi Mill in Holland

INCREASING BOILER EFFICIENCY

Torftech believes that this same approach can be used to improve the efficiency of power boilers at primary pulp mills fired on wood waste and mill sludge, by utilizing the exhaust gas from the power boilers as the energy resource for drying.

Mills choose to burn sludge as a means of avoiding disposal costs rather than considering sludge as a premium energy resource. With typical moisture levels of 75% it is definitely not an attractive fuel. The waste wood and bark that would be the major fuel in these boilers can also have moisture levels that can be as high as 50%. All of this water that is introduced with the fuel is evaporated using energy (generated by the combustible fraction of the feed) that is not recoverable. This decreases the overall efficiency of the conversion of the calorific value in the dry wood portion of the feed to usable energy.

If a portion of this moisture can be removed by utilizing the energy contained in the exhaust gas stream which would normally be wasted, the overall energy recovery will be improved. For mills that are not able to provide for all of their energy requirements from their waste streams and have to augment this with purchased fossil fuels, improvements in energy conversion efficiency will result in savings in purchased fuel costs.

It is suggested[1] that the specific steam generation rate per tonne of dry wood combusted in the boiler increases as the moisture content decreases:

Table 1: Steam production vs. Feed moisture content

Moisture Content	40%	50%	60%
Specific Steam Production (Tonnes/tonne dry wood feed)	5.4	5.0	4.5

The efficacy and financial attractiveness of drying sludge and wood waste prior to combustion will vary from mill to mill depending upon the generation rates of sludge, the availability of waste wood and bark, their inherent moisture contents and also on the volumetric flow and temperature of the boiler exhaust gas stream.

A Business Case Example

As a hypothetical example, consider a mill generating and disposing 3,300 kg/hr of sludge at 75% moisture and burning 64,000 kg/hr of wood/bark at 50% moisture as depicted in Figure 5. This boiler is raising 160 tonnes/hr of steam (32 dry tonnes/hr of wood generating 5 tonnes steam/tonne) from the wood waste and a further 40 tonnes/hr of steam by burning 88 GJ/hr of natural gas. The exhaust from the boiler system is estimated to be about 500,000 kg/hr at a temperature of 180°C.

All of the sludge and about 30,000 kg/hr of the wood could be dried to 15% moisture at 100°C using this exhaust stream. When recombined with the un-dried wood, as shown in Figure 6, the moisture content of the mixed boiler feed would be about 37.5%. The addition of the dried sludge adds the equivalent of another 800 dry kg/hr of wood, so the steam generation from the 32.8 dry tonnes/hr of wood at an interpolated specific steam rate for 37.5% moisture of 5.5 tonnes/tonne would be about 180 tonnes/hr of steam. This would reduce the amount of steam to be generated from natural gas by 20 tonnes/hr - a saving of 44 GJ/hr of purchased gas.

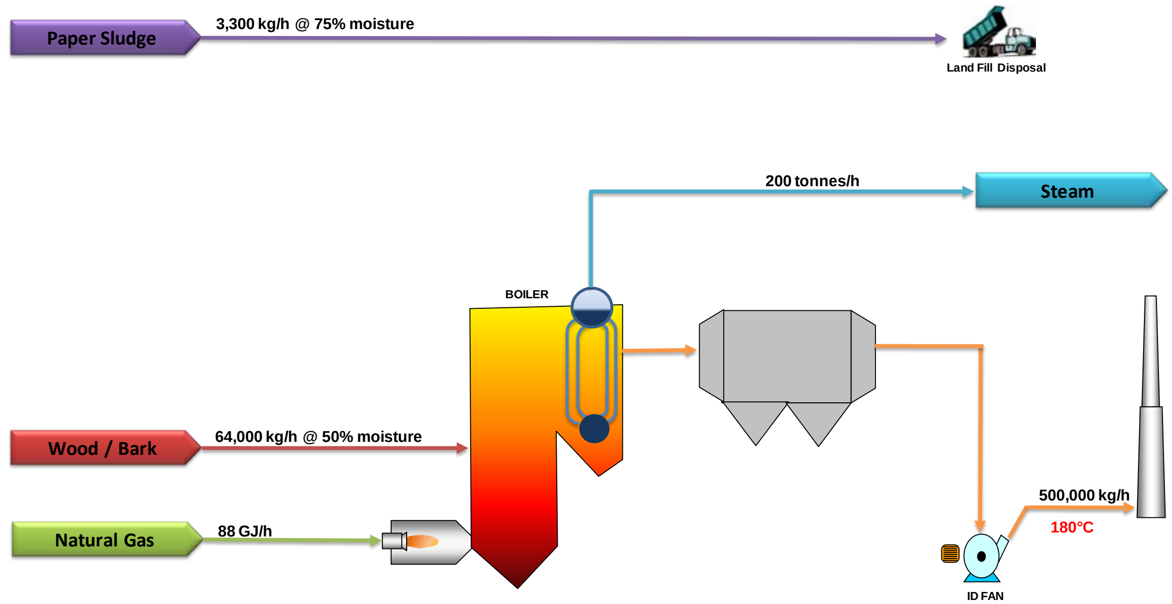


Figure 5: Scenario where sludge is disposed at landfill site

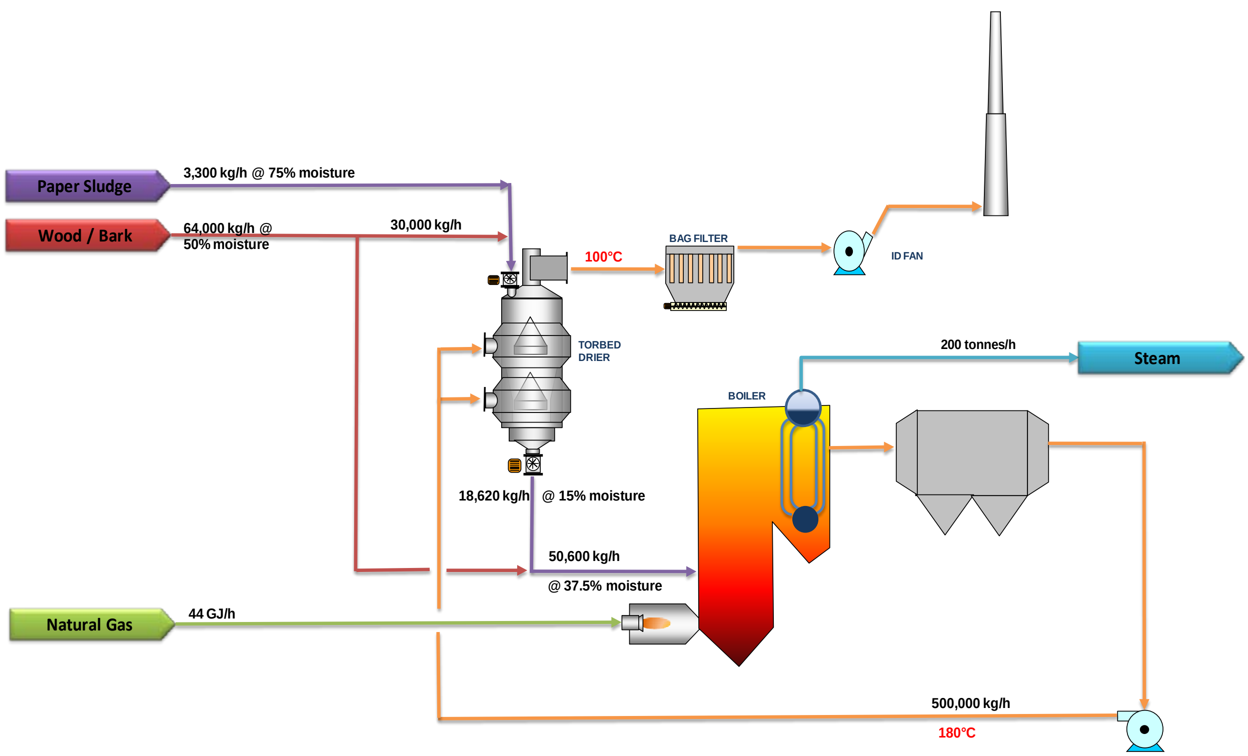


Figure 6: Scenario where sludge is dried and co-fired in boiler

Using a natural gas cost of $8/GJ, then in an 8,400 hour year, the annual savings would be about $2.7 million. In addition if the mill is paying $25/tonne for sludge disposal, this avoided cost would provide an additional annual benefit of $700,000 resulting in a total of $3.4 million/year. An additional ID fan would be required, drawing ~700kW for an additional power cost, at $0.10/kWh, of $600,000/year leaving a net benefit of $2.8 million to apply against capital.

The expected payback period for the drier and ancillary equipment will depend on the mill and mill layout, but is anticipated to be less than 3 years.

Expanded Bed Sludge Combustor Example

Mills that utilize waste paper as their fibre source do not have solid fuel boilers in which to incorporate sludge from re-pulping and deinking of the waste paper feed. These mills are experiencing significant increases in the cost for disposal of these sludges, which are a potential source of energy to raise steam for mill operations. The Expanded Bed Reactor can also be used to combust these sludges, with or without pre-drying. When compared to a bubbling bed fluid bed combustor with the same sludge burning rate, the toroidal fluidized bed combustor is a much smaller reactor and does not utilize a sand bed.

A commercial plant has been installed in Canada, where paper mill ‘sludge’ without a pre-drying step is converted to heat energy and a valuable mineral by-product stream is recovered. The sludge, with a moisture content of about 52% is combusted and calcined at high temperature in the combustor using a process air stream that is preheated with natural gas, to supplement the low calorific value of the wet sludge. The combined energy generated from the combustion of the fibre portion of the sludge and the natural gas is recovered as steam a conventional Heat Recovery Steam Generator. The mineral filler contained in the sludge is calcined in the combustor and recovered in a bag filter. A photo of this plant is shown below.

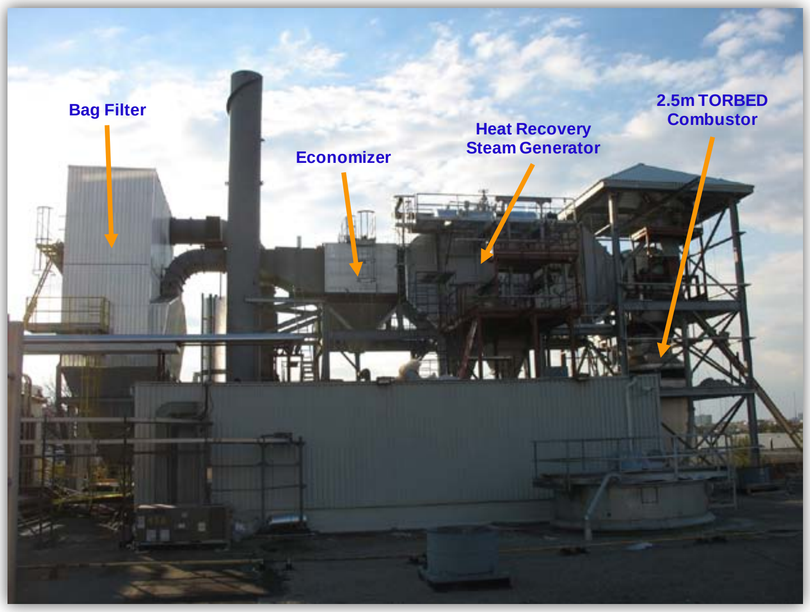


Figure 7: Expanded Bed Reactor used as a paper sludge combustor for steam generation

This concept was conceived in response to the growing environmental and economic pressures on a well respected Ontario based paper recycling company to find an alternative to disposal for their process sludge. The company supported initial trials of the process at Torftech Canada's pilot scale facility in Mississauga and after encouraging results from the pilot trials, obtained funding support for a commercial demonstration of the concept from Sustainable Development Technology Canada (SDTC).

The plant is now operational and processing over 6 tonnes/hr of sludge producing up to 18,000 kg/h (40,000 lb/h) of steam and 1 tonne per hour of calcined mineral filler with potential for use as a partial substitute for cement in concrete or as a feed material to a cement kiln.

The steam demand at this mill allows the steam generated from this sludge combustion system to be base loaded, while additional steam is generated in pre-existing conventional natural gas boilers.

While the natural gas burned in the process generates useful energy in the form of steam for the mills operations the overall boiler efficiency achieved in the sludge management facility is slightly lower than the efficiency obtained in conventional gas fired burners. Consideration is now being given to add a sludge pre-drier at this facility to minimize the amount of gas used. The addition of a pre-drier would have the added benefit of increasing the plant's capacity for sludge management and allow it to bring in additional sludge as feed from a second mill located in the same town. A conceptual flow sheet shows the combined drying and combustion option in Figure 8.

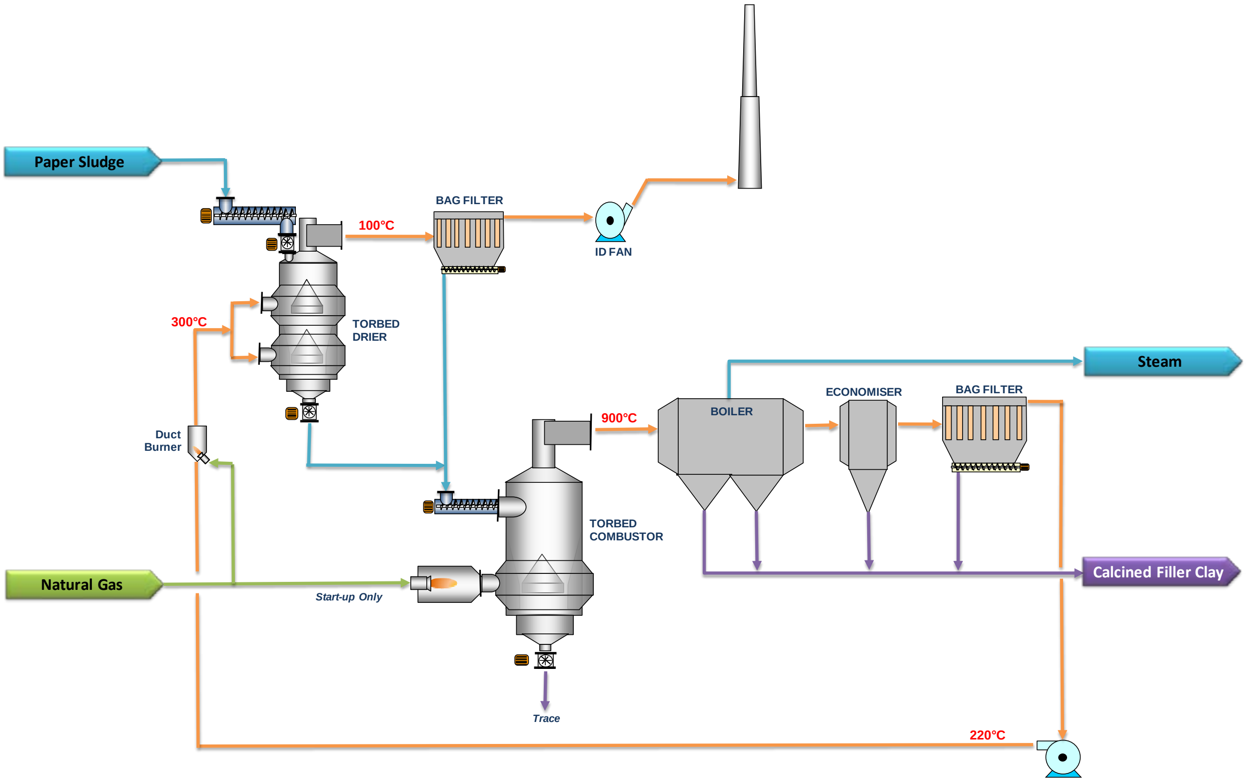


Figure 8: Deinking sludge drying and combustion process for steam generation

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1. *Energy Cost Reduction in the Pulp and Paper industry.* Canada : s.n.