Resistant heated rotary furnaces for heat treatment of rare earth minerals and quartz sand

by Peter Wübben

The rotary tube furnace combines, in most cases, today’s expectations of a modern continuous heat treatment furnace - high throughput, energy efficiency, easy automation and a reliable reproducibility. Nowadays a number of applications can be realized by the use of high performance materials for the rotary tube. The various operational possibilities of rotary tube furnaces were recently extended by applications for the production of rare earth minerals and high purity quartz sand.

The increasing demand for raw materials for the production of glass, quartz and ceramics for electronic or medical purposes leads to higher requirements with regard to purity, homogeneity and surface properties of the initial powders. Caused by more stricter environment constraints resp. high disposal costs it becomes more interesting to recycle waste materials (i.e. from steel works) internally which requires an intermediate processing. By a thermal treatment organic and inorganic impurities can be decomposed or directly vaporized. For all applications is valid: optimum homogeneous properties will be reached only if every particle of a powder or granulate has received the same treatment. This applies to a temperature-time-curve as well as to the surrounding atmosphere i.e. the oxygen content during calcination.

The simplest method for thermal treatment is the filling of the initial powder into ceramic or metallic boxes resp. crucible and the processing in a batch furnace. However this procedure has a major disadvantages: The weight resp. thermal mass of the containers usually is higher than the product. Due to this a high energy consumption and long cycling time resulting from heating up and cooling down is pre-programmed.

At bulk materials the diffusion of reaction gas is strongly hindered - sometimes amplified by sinter crusts - which limits the filling height to a few centimeters and results in long holding times. The additional effort for loading and unloading reduces the productivity considerably. Furthermore it cannot be excluded that powder properties will vary from the bottom to the surface of the fill. Theoretically this problem can be minimized by cyclic vacuum pumping. But this will increase the effort and consequently the investment and operating costs of a furnace plant. In the case of sensitive products there will be the danger of evaporation or decomposition. Problems also can arise from the contamination of the product by the material of the transport container.

In spite of the above mentioned difficulties a major part of the powder will react at the same time and following disposal systems (i.e. gas scrubber or thermal post combustion) have to be designed for high and very small flow rates. The solution for all these problems is a furnace with a continuous transport system without containers where all particles will be equally mixed to have an exposition against temperature and atmosphere which in average is homogenous: a rotary furnace.

Rotary furnaces can directly or indirectly heated. In the case of direct heating usually the rotating tube will be heated directly internally by a flame from a burner. The temperature impact on the rotating tube can be minimized at an adequate thermal insulation which is advantageous. The thermal insulation can be designed for an outer low temperature. This gives many choices for the material selection of the rotary tube and the abilities for the mechanical bearing, drive etc. are nearly not limited. This enables the manufacturing of extremely large furnace dimensions as used in the concrete industry. A disadvantage of direct heating is the mixing of the flue
Gases from the combustion with process gases released by the heat treatment. In the worst case the flue gas reacts with the product. In the simplest case this leads to bigger diameters of exhaust/process gas ducts.

Contrary to the direct heating the indirect heating is effected by heating the rotating tube from the outside. The heat transfer to the product occurs by the heated wall of the rotating tube. The heating is made electrically or by burners. In opposite to electric heating, gas/oil fired rotary furnaces require a more complex infrastructure and higher investment cost. For use in laboratories or operation as pilot plant with small throughput the gas/oil heating has a lower limit which results from the necessary low heating power. Electrical heated rotary furnaces can be controlled even at low heating power very accurately regarding the temperature and require at permanent operation a few spare parts only.

For tests, technical centers and small production furnaces - the throughput (approx. 1 to 300 dm³/hour) will be given by the holding time and specific filling degree of the tube - electrical heated rotary furnaces are the best choice. The use of ceramic, plasma sprayed rotary tubes is limited to a diameter of Dmax= 600 mm and to a length Lheated = 5 mtrs. At metallic tubes this dimensions can be higher at temperatures less than 600 °C. **Fig. 1** shows an electric heated rotary furnace for laboratories with a ceramic tube as used at the heat treatment of high purity quartz sand.

**MOTION OF PRODUCTS WITH A WATER-LIKE FLOW BEHAVIOUR IN ROTARY KILNS**

The motion of the product in the kiln tube is the decisive factor in the transfer of heat from the heated wall of the kiln tube to the product. Seven different flow patterns are differentiated in the motion of bulk products with water-like flow behaviour (**Fig. 2**).

1. Pure slip: The friction between tube wall and bulk material is so low that the good stands in the tube with a time constant angle without any movement and mixture.
2. Oscillation: Caused by the somewhat higher number of turns there is a continuous change between static friction and slide friction on the tube wall. A mixing does not happen. For this reason the first two modes have no practical meaning.
3. Periodic fall: At the change-over from phase 2 to 3 a mixing of the bulk material can be observed at the surface and boundary faces. The surface of the good is designated by two surfaces with an obtuse angle between.
4. Unroll: This angle increases by increasing number of turns. Finally one single layer is created with a material transport at the surface which is continued at the underside.
5. Over-slope: The top edge of the bulk material heightens with increasing number of turns and is rounded continuously by the down slide. The mixing becomes more intensive.
6. Wave rollover: Across the total cross sectional area a big rollover is taking place which is able to grind down the bulk material. This kind of transport happens quit often if fixtures mounted in the tube.
7. Centrifugation: Only at sufficient static friction between tube wall and bulk material the typical centrifugation process can be observed at which the total good sticks.

<table>
<thead>
<tr>
<th>Mode</th>
<th>Slip</th>
<th>Cascade</th>
<th>Cataract</th>
</tr>
</thead>
<tbody>
<tr>
<td>Phase Cycle</td>
<td>1</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>Process Application</td>
<td>Slip none</td>
<td>Mixing</td>
<td>Grind down</td>
</tr>
<tr>
<td></td>
<td>Rotary furnaces and reactors, dry- and cooling drums, ball mills</td>
<td>Drum mixer</td>
<td></td>
</tr>
</tbody>
</table>
on the tube wall. This unwanted condition can be con-
verted into condition 6 by using a scraper. This scraper
ceramic or metal tube) can serve at the same time as a
protection tube for thermocouples.

**FRAME AND MECHANICAL CONSTRUCTION**

**Charging**
The dosage and feed of a rotary tube is realized by vibra-
tion conveyors, screw conveyors or belt conveyors. Agi-
tators require beside a frequency control in most cases
additional flexible mechanical fixtures for the adjustment
of accurate flow rates. At screw conveyors increased abra-
sion can lead to problems. For continuous charging at
protection gas atmosphere double flap sluices are used.

**Transport and drive**
The rotary drive usually happens via a frequency con-
trolled alternating current motor. The residence time of
the product in the tube can steplessly adjusted by the
number of turns and the slope of the rotary tube. The
number of turns mostly is in the range 1 to 10 min-1.

The furnace itself is built on a tilting frame. The tit-
ing angle at small furnaces can be adjusted manually
with a crank handle in a range 0 to 10° (Fig. 3). At bigger
furnaces in most cases a hydraulic lifting system is used
which allows a slope of 0 to 5°. A furnace housing made
of stainless steel is advisable because of furnace use in an
often chemical polluted environment. The rotating tube
should have heads at both ends at operation with normal
air too. Particularly at high temperature - even at a small
tilting angle - strong natural draught can occur. This air
flow is noticeable at a strong radial temperature gradient
in the tube. At a temperature control with a thermo-
couple inside the tube an overheating of the tube wall can
occur, which will lead to caking of the bulk material
at the tube wall. At a temperature control with a thermo-
couple between furnace insulation and outer tube wall
the normal working temperature in the tube will not be
reached. Dependent on tube geometry, furnace slope
and temperature the radial temperature gradient can be
more than 100 °C at missing end heads.

It is important, that the rotary tube easily can be
changed without damaging the furnace insulation heat-
ing elements. At smaller rotary tubes it is helpful to insert
a long light weighted plastic tube into the rotary tube
and use it as a carrier. At bigger rotary tubes the furnace
housing must be separable resp. must have a lid to insert
the rotary tube from top.

**Cooling zone**
At small plants an active cooling at the discharge end
mostly is required for the protection of the tube bearing,
because the product transports only small quantities of
heat to the outside. A cooling with air blowers usually
is sufficient. Higher cooling rates can be achieved with
water cooling and circulating air. At high product dis-
charge rates the rotary tube can be extended and exter-

nally behind the furnace housing directly cooled with
water sprinkling from nozzles on the tube. The cooling
zone length depends on product flow rate, particle size
and required product exit temperature.

**Product discharge**
At the discharge end of the rotary tube resp. cooling zone
the product can be collected in a vessel (at small systems
water cooled) or transported continuously to following
plants.

At Microwave- and Microwave-hybrid rotary furnaces
(Fig. 4) quartz glass or ceramic tubes will be used. If a
metal tube has to be used the Microwave feed has to
done from the front sides of the tube. At Microwave-
1,050 °C the formation of Cristobalite (polymorph of silica) takes place and leads at cooling down below 600 °C to the destruction of the rotary tube. A prediction regarding the allowed number of cycles or life time of a quartz tube is difficult to make because of a strong dependency on many factors i.e. atmosphere, air humidity, wall thickness etc. Quartz glass as preferred material of the semiconductor industry is available in high purity quality. A contamination is excluded if the quartz itself is not degraded. Furthermore the thermal shock behaviour of quartz is extremely good.

**Ceramic rotary tubes**

Ceramic tubes have a high abrasion resistance. Tube materials are mostly uncritical. High application temperatures up to 1,700 °C are possible with ceramic tubes. The maximal tube dimensions are very limited with slurry casted clay. Plasma sprayed tube allow dimensions up to 600 mm diameter. Compared to metal tube the price of plasma sprayed tubes is very high which often leads to multiple furnaces with smaller diameter tubes.

The most commonly used material is Al2O3. Dependent on temperature the Al2O3 content is between 60 to 99.7 wt.-%. For special application, i.e. heat treatment of high purity quartz sand, rotary tubes made of high purity Al2O3 will be used. Even for these materials many different qualities are available due to different impurities which result from different production methods.

In special cases the use of SiC tubes is useful. The high thermal conductivity enables a good heat transfer at high product flow rates and allows high heating-up rates. For alumina-oxide tube the maximal heating-up rate at dense sintered qualities is 120 to 360 K/hr up 1,200 °C; above this temperature 180 to 360 K/hr. Porous qualities allow up to 400 K/hr. The high sensibility against local temperature gradients has to be considered at the furnace construction and feed of high amounts of cold product. At bigger rotary tubes it is recommended to secure measures for minimising the temperature distribution at the tube end (Fig. 5).

**Metallic rotary tube materials**

Common materials are 1.4841 (AISI 314) up to 1,050 °C, 1.4828 (AISI 309) up to 950 °C, 2.4851 (Inconel 601or alloy 601) up to 1,150 °C and newly APM (FeCrAl) up to 1300 °C dependent on application and chemical impact. Metal tubes are mechanical tough, allow high heating up and cooling down rates and internal fixtures are relatively simple to realise. The low hardness can lead however to pollution of the processed material caused by abrasion and can contain critical alloy components i.e. Ni, Cr.

Special alloys are used at the heat treatment of acid containing products as rare earths minerals. For this application the material 1.4562 (N08031) is well-proven up for temperatures up to 700 °C.

**Quartz glass/Fused Silica rotary tubes**

The maximal application temperature for a frequent continuous operation with rotary tubes made of quartz is 1,050 °C. The tubes can be used even at higher temperatures of up to approx. 1,450 °C. At temperatures above 1,050 °C the formation of Cristobalite (polymorph of silica) takes place and leads at cooling down below 600 °C to the destruction of the rotary tube. A prediction regarding the allowed number of cycles or life time of a quartz tube is difficult to make because of a strong dependency on many factors i.e. atmosphere, air humidity, wall thickness etc. Quartz glass as preferred material of the semiconductor industry is available in high purity quality. A contamination is excluded if the quartz itself is not degraded. Furthermore the thermal shock behaviour of quartz is extremely good.

**Fig. 5: Temperature course at the end of rotary tube**

Hybrid rotary furnaces additionally a conventionally heat source is installed which usually is a resistant heating.

**Rotary tube**

Dependent on temperature and processed material different types of rotary tubes can be used. Possible abrasion, pollution of the treated good and reactions (chemical or "backing" to the tube walls) have to be considered. This problem occurs more often at fine powders which is why a pre-granulation for critical substances may be necessary. In the case of powders which tend to stick it might be useful to mount a chain or a scraper.
A zone with exothermic or endothermic reactions which needs energy input or cooling

A holding zone for sintering processes or other reactions which need time where heating losses have to be balanced.

Three zones are usually sufficient for smaller plants. Thus a high temperature uniformity can be achieved. For bigger furnaces or if accurate temperature profiles are required, the number of heating zones have to be increased accordingly. For economical and technical reasons different heating element types may be necessary in the different zones; i.e. adverse operating conditions are in the temperature range 600 to 900 °C for high temperature elements made of MOSi2. For these elements the later tilting angle of the furnace has to be taken into account because these elements can operate at temperatures above 1,300 °C only in a vertical ± 7° installation position.

**Design**

The usual filling degree (amount of filling) of rotary furnace is approx. 10 % of rotary tube volume. Dependent on the kind and shape of the processed material (powder, grains, granulates etc.) the filling degree may deviate strongly. The filling degree can be increased by the installation of chicanes. Decisive for the required furnace size is the necessary residence time of the product in the tube at working temperature. Usually pre-tests are necessary to determine this time because compared to normal batch furnaces the heat transfer in a rotary furnace is much better and reaction times are much shorter. The reason for this is the better exposition of the bulk material to the furnace atmosphere and the shorter heating-up time caused by the improved heat transfer.

For design calculation different formulas are available which take into account the residence time behaviour in a rotary furnace, number of turns of the rotating tube and bulk material properties. These formulas can be used reasonably only if practical experience with different bulk materials is available. Particularly at bulk materials which change at higher temperatures drastically their flow properties (i.e. getting pasty) reliable values for the residence time can only be obtained by tests.

**CONCLUSION**

Rotary tube furnaces can be used at many continuous processes for the heat treatment of bulk material. They also find application in the development of new processes and materials. The design according to scientific formulas only is not possible and needs long-time practical experience of many years which has to be underpinned from case to case by tests.

**AUTHOR**

Dr.-Ing. Peter Wübben
Linn High Therm GmbH
Eschenfelden, Germany
Tel.: +49 (0)9665/ 9140-0
wuebben@linn.de