Development of Rotary Screw Calciner for Automation of Calcination Process

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Development of Rotary Screw Calciner (RSC) was initiated for calcination of heavy metal on continuous mode. The design of RSC was finalised considering the feedback obtained from past experience for ease of operation and maintenance as well as retrofitting of RSC inside active glove box. A compact design was evolved, manufactured and tested with surrogate material for performance evaluation. The system has been delivered to site for further inactive trials and implementation inside glove box.

Introduction

The solvent extraction process of fuel recycling consists of separation and purification of useful heavy metals. In subsequent process the heavy metals are converted back to oxide form. This process makes the product ready to be employed for fuel fabrication for next stage of fuel cycle facilitating the three stage nuclear program adopted by country for optimum use of natural resources for sustained energy requirement.

Recouperation Process

The heavy metals after solvent extraction process is in nitrate solution form. The final product in oxide form is obtained after following the stages of precipitation, filtration and calcination. The present mode of operation is semi continuous process. The precipitation of heavy metal in oxalate form in carried out in a precipitation column which is transferred to batch filter which employs sintered SS filter screen for removal of moisture. The cake is manually transferred to a boat which is placed inside a muffle furnace for calcination. The calcined product is manually transferred, blended and put in a can which is sealed out of glove box and stored in bird cage arrangement.

The criticality concern and extensive manual handling during multiple stages results in limiting the batch size. Further Man rem expenditure has also been a concern during operation and maintenance. For a large throughput plant this will result in multiple stream of production line and corresponding manpower requirement. To address these concerns developmental efforts were initiated to switch over to continuous mode of process which reduces the human intervention. Development of continuous precipitation and rotary vacuum drum filter to automate the precipitation and filtration operation has already yielded encouraging results. Development of Rotary Screw Calciner was also initiated to automate the calcination process and compliment the equipment developed for continuous precipitation and filtration.

Calcination

This process involves conversion of oxalate of heavy metal into oxide under high temperature. Presently, it is achieved using a Muffle Furnace in which a container containing oxalate is kept for specified duration where it undergoes a heating cycle for drying and calcination. However, this involves manual handling of oxalate transfer to ignition boat, insertion of boat inside furnace and later removal of the boat from furnace followed by oxide transfer from the ignition boat. Since the heating elements are mounted on the furnace wall, sufficient residence time is required for oxalate powder in the interior (i.e. centre) to get converted. However, in this process the peripheral material is subjected to high temperature for more duration and this may result in varying product quality within the same batch. Blending operation follows calcination for proper mixing and uniformity of product.

Rotary Screw Calciner (RSC)

The calcination process can be achieved in continuous mode through Rotary Screw Calciner (RSC). The system consists of screw rotating in a long (tubular) furnace. The feed received at one end is pushed forward due to rotary action of the screw and discharged on the other end. The temperature of furnace is maintained such that the moisture in the feed gets removed through one-third length of furnace and subsequently undergoes calcination during the remaining two third length of high temperature zone of furnace.

Development of RSC has been undertaken earlier and unit based on tubular furnace (Fig. 1) with rotary screw and associated drive was manufactured (Fig.2). Multiple operational trials of unit were carried out under simulated conditions. However, the unit being larger in size was not found suitable for installation inside the existing glove box. Further, few modifications were also identified for improvement of operation and maintenance requirement.
Design Features

Since the objective was to retrofit the equipment in an existing active glove box, the sizing of equipment was done accordingly. The only access available in the existing glove box for installation of equipment is a square opening of 450mm x 450mm on the rear side along with access through glove ports from the front side. The RSC has therefore been designed to have a modular construction such that each module can be inserted inside the glove box through available opening on rear side and assembled through glove port from the front side (Fig. 3). The furnace construction was modified to “U” trough with hinged lid instead of earlier tubular design to facilitate easy maintenance of screw and trough. The screw also has been designed as detachable unit which can be easily removed after opening the trough lid. The end shaft on either side of screw has been supported on ceramic bushes considering the operation speed and high temperature condition. The design of power transmission from drive motor to rotary screw through chain drive due to space constraint instead of direct mounting which would have increased the overall length of the assembly leaving no room for manoeuvring during maintenance activity. The furnace has also been designed for accommodating thermal expansion with floating support on one side. The furnace
insulation was also designed as modular panel which can be easily taken inside the glove box through the available opening and assembled inside the glove box. The furnace heating is achieved by rod type element of silicon carbide which can be easily removed and replaced in case of failure of any element.

Inconel 625 was selected as the material of construction for components handling metallic oxalate and experiencing high temperature, like the ‘U’ trough, screw, end shafts etc. All other components were fabricated out of SS 304 L material. Special Ceramic paper has been used as gasket material to maintain negative pressure inside the trough during operation. For insulation of the furnace, special grade microporous insulation have been used which has very low thermal conductivity as compared to conventional insulation material in order to design a compact unit suitable for existing glove box without compromising on final skin temperature.

**Manufacturing**

One of the critical requirements of RSC (Fig. 4) was to minimise the clearance between trough and screw (Fig. 5) to reduce the holding up of material. This demanded precision manufacturing of the trough and screw to achieve the desired results. The U trough was first formed out of Inconel plate after establishing its behaviour through multiple mock trials. Subsequently it was machined in horizontal boring machine to get the circular contour within desire tolerance at the bottom. The screw was fabricated out of multiple circular disc of Inconel formed into helical flight welded in series on machined shaft. The screw outer diameter was later machined to suit the internal circular contour of trough. The manufacture of insulation panel also has been a challenge with fragile nature of microporous insulation which disintegrated on any kind of penetration. It was finally sandwiched within the fibre wool which gave it integrity while making holes for insertion of heating element and thermocouple. The insulation modules were fabricated with cover made of 2mm SS 304 sheets with hooks for handling during assembly and operation.

**Controls and Instrumentation**

The RSC is powered by Silicon Carbide heating element (Fig. 6) controlled by thyristor based compact PID controller based on thermocouples (K-Type) feedback. The rotary furnace is divided into two zones along the length, namely Drying Zone (maintained at 250°C) and Calcination Zone (maintained at 650°C). The zones are maintained by five heating elements of 1.5 kW each located at appropriate location with setting to suit the temperature requirement of zone.

![Fig. 4: Rotary Screw Calciner Assembly](image1)

![Fig. 5: ‘U’ Trough and Screw](image2)

![Fig. 6: Silicon Carbide Heater](image3)

![Fig. 7: Control Panel](image4)

The compact control panel (Fig. 7) is equipped with all required control switches and indicators like RGB phase indicator for incomer, 4-pole MCV (incomer), ammeter
(digital) for individual heating elements, individual heater control switch and thermocouple reading display etc.

The control panel is provided with a knob to control the rpm of helical screw. The speed is controlled through potentiometer with feedback from an inline encoder mounted on driving DC motor.

**Experimental Trials**

The manufactured prototype has undergone extensive trials to establish the intended design performance. These consisted of trials for establishing relation between screw rpm and residence time, repeatability of residence time for a given rpm, dummy heating trials without load and understanding heating element characteristics etc. After establishing necessary initial parameters, performance trial with surrogate material was carried out. Heating elements parameters were set appropriately to obtain well defined drying zone in one-third length and calcinations zone in remaining two-third. Thermocouple reading mounted at appropriate location gave the temperature profile of drying as well as calcinations zone. Multiple trials (Fig. 8) were carried out with simulated feed at a rate of 0.5 kg/hr as well as 1 kg/hr. Temperature of the surface of the RSC was also continuously monitored using temperature gun. The calcined product (Fig. 9) was collected in container at the discharge end.

As mentioned earlier the design of RSC was carried out with objective of retrofitting it in an existing active glove box. To confirm the suitability of design for the same, a dummy glove box (Fig. 10) similar to the dimension of existing glove box was fabricated with similar opening. The complete installation procedure was simulated in dummy glove box (Fig. 11 A-D).

![Fig. 8: Performance Trials](image1)

![Fig. 9: Calcined Product](image2)

![Fig. 10: Dummy Glove Box](image3)

**Results and Observation**

The initial trials carried out on RSC, established various operating parameters like the maximum residence time, effective zoning for drying and calcinations, desired calcinations temperature of 650 °C, skin temperature of equipment within 50 °C for protection of rubber gauntlet of glove port etc.

The performance trials with surrogate material yielded consistent results. The product obtained weighed equivalent to that of its oxide with a residence time of 50 min. The result is similar to what is obtained in calcination of actual heavy metal. Further, the holdup in the RSC after operation was observed was a nominal 25-30gm.

The assembly trials inside dummy glove box established the assembly sequence to be followed while installation in actual glove box. Minor modification in equipment for ease of installation was also carried out. The trials also established feasibility of handling any components within the glove box in case of maintenance.
Conclusions

The task of design, fabrication, assembly and testing of RSC for implementation in an active glove box has been a satisfactory experience albeit challenging. The design has considered the experience obtained from similar equipment manufactured earlier and improved upon for ease of operation and maintenance. The RSC has a significantly higher processing capacity as compare to the present plant requirement. The equipment after undergoing extensive trials at manufacturer’s workshop has been delivered and presently installed in an inactive area for further trials. With the feedback obtained from operating plant the design can be scaled up to meet the requirement of future.

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