FEATURE ARTICLE
High Ash Indian Coals: Gasification Strategy
Prakash D. Chavan

In India, coal based energy generation meets around 70 per cent of our energy needs. However, bulk coal reserves (about 73%) are of inferior grade non-cooking coals with ash contents 45-50%, having moderately high reactivity and high ash fusion temperature. Indian coals are not only high in ash, but also the association of mineral matter with carbon matrix is very close and in dispersed form.

To move towards cleaner energy production mechanism and to attain energy security of the country, while utilising the potential of Indian coals, gasification technology seems to be a promising option. This route can bring out several environmental advantages over conventional coal utilisation technologies. In this direction, the Indian clean energy development policy is emerging with programmes that include intensive investigations on the gasification of high ash Indian coals vis-à-vis development of suitable gasifier.

All three main types of gasifier i.e. Entrained Flow Gasifier (EFG), Fluidised Bed Gasifier (FBG) and Moving Bed Gasifier (MBG) can be used to gasify the coal; however, gasifier efficiency and stability are ensured under a range of values of certain characteristics of the coal. The size of the project may also have an effect.

Gasifiers & Gasification Technologies
Gasifiers are usually classified by the flow regime inside the reactor. There are three main categories viz. MBG, FBG and EFG. Each type of gasifier depending on the operating characteristics can be further classified through operating pressure, the way heat is produced and transferred (Auto-thermal or allothermal), nature of gasification agents employed (air or oxygen), ash removal (Slagging, dry ash or agglomerate), and Gasifier lining (refractory, membrane wall).

Different types of gasification processes and technologies available worldwide are listed in Tables 1 and 2 respectively.

Coal Properties
Proximate analysis: Coal moisture content decides whether the coal fed into the gasifier should be dry or slurry. Volatile matter of the fuel determines the extent and rate of gasification reactions and also affects the syngas generation capacity. Ash content decreases the system efficiency, increases the slag production and disposal cost. It can cause agglomeration/slagging/clinker formation.

Ultimate (elemental) analysis: Carbon, hydrogen, nitrogen, sulfur, and oxygen are important for material and energy balance and decision of gasifying agent feeding per unit mass of fuel.

Mechanical strength: Coals with high Hard Grove Index (HGI) are more suitable for slurry fed EFG. MBG and FBG need sufficient cold and hot strength of fuel.

Specific surface area and porosity: Decides approach of gasifying agents to available active sites and hence gasification reactivity.

Gasification reactivity of coal: Reactivity dictates the dimensions of reduction zone that are required and the residence time required for complete gasification. Coals with low char yield...
### Table 1: Different Types of Gasification Processes

#### Types of Gasifiers

<table>
<thead>
<tr>
<th>Fixed Bed Gasifier</th>
<th>Fluidized Bed Gasifier</th>
<th>Entrained Flow Gasifier</th>
<th>Multi Stage Gasifier</th>
</tr>
</thead>
<tbody>
<tr>
<td>Up draft fixed bed gasifier</td>
<td>Bubbling fluidized bed gasifier</td>
<td>Dry fed</td>
<td>Combination of fixed bed and/or fluidized bed/entrained flow gasifier</td>
</tr>
<tr>
<td>Down draft fixed bed gasifier</td>
<td>Circulating fluidized bed gasifier</td>
<td>Slurry fed</td>
<td></td>
</tr>
<tr>
<td>Cross draft fixed gasifier</td>
<td>Twin fluidized bed gasifier</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Table 2: Gasification Technologies

<table>
<thead>
<tr>
<th>Entrained flow</th>
<th>Fluidised bed</th>
<th>Fixed bed</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dry feed</td>
<td>Slurry feed</td>
<td>Bubbling</td>
</tr>
<tr>
<td>Hitachi Technology</td>
<td>BBP Babcock Borsing Power</td>
<td>BHEL fluidized bed gasifier</td>
</tr>
<tr>
<td>Shell Coal Gasification Process</td>
<td>Texaco (HTW) High Temperature Winkler</td>
<td>LURGI</td>
</tr>
<tr>
<td>Prenflo</td>
<td>E- Gas Philips</td>
<td>IDGCC Integrated Drying Gasification Combined Cycle</td>
</tr>
<tr>
<td>Mitsubishi Heavy Industries</td>
<td>U- Gas Gasifier</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>KRW Kellog Rust Westinghouse</td>
</tr>
</tbody>
</table>


and high char reactivity (as lignites or brown coals) are more suitable for FBG. However, gasifiers with slagging ash can operate with higher rank coals. The reactivity decreases with coal rank and increases with the oxygen functional groups content of the fuel.

**Ash composition analysis:** Analysis of major elements of ash such as Si, Al, Fe, Na, K, Ca, Mg, P, etc. as well as minor elements (Chlorine, fluorine, phosphorus, Mercury) plays important role in ash behaviour inside the gasifier. Certain substances contained in the ash (CaO, SiO₂, Fe₂O₃), Sodium compounds, alkali matter can attack the refractory material and reduce the life of the refractory as well as adhere on the pipes walls at downstream. Agglomeration is another ash-derived problem that can affect the process.

**Ash fusion temperature:** The AFT values under oxidizing & reducing conditions are strongly dependent on the ash composition and the applied atmosphere. Depending on the ash disposal characteristics of the gasifier, operating temperature is maintained above or below the ash fusion temperature. For dry ash removal system gasifier temperature must be lower than the AFT, while for slagging gasifier it should be above AFT. Softening temperature (ST) is considered as the temperature where agglomeration starts. In slagging gasifiers, the slag viscosity should be maintained above the critical viscosity for slag flow between bed particles. In agglomerating gasifier operating temperature must be over the softening temperature and below the fluid temperature.

**Coal Properties vis-à-vis Matching Gasifier**

Selection of gasification technology is based on technical features of gasifier and key coal properties. Following are important properties for each type of gasifier.

**Entrained Flow Gasifier:** For entrained flow gasifier, ash content, ash composition and ash/slag behaviour are important properties as slag flowability is the most important aspect of the EFG. Further, to form flowable slag layer, temperature of gasifier is maintained above the Ash Fusion Temperature (AFT). Slag formed from ash in coal is utilized as a protective layer for refractory or membrane wall lining and quantity of slag, ash composition and viscosity decides the thickness of slag layer.

**Moving Bed Gasifier:** In the MBG, cold & hot mechanical strength of coal, ash content and ash composition are performance affecting parameters. Inside the MBG, reactive mass bed is formed with the help of lump size coal pieces. Specific size of feed material is needed for maintaining desired permeability for flow of the gasifying medium i.e. air-steam blast inside the bed. Therefore, to maintain particle size in desired range in all the zones of gasifying bed, cold as well as hot strength of feed coal becomes most important parameter for MBG. It is very difficult to handle friable materials like lignite in the MBG. Also, ash content and ash composition are responsible for agglomeration and clinker formation related problems in the gasification bed, which causes blockage of the ash material near the revolving grate causing failure of the gasifier.

**Fluidised Bed Gasifier:** In the FBG, granular fuel particles are fed inside the bed and kept in fluidizing condition with the help of gasifying agents. All the fuel particles get mixed very quickly and thoroughly in the fluidizing bed resulting in very short residence time to certain particles. This results in exit of unreacted coal particles from the bed along with discharging ash causing lower carbon conversion and hence lower heat value as well as quality of syngas. Therefore, gasification reactivity of feed coal becomes one of the important parameters affecting gasifier performance. Further, ash generated during gasification is taken out with the help of ash extracting system.

As, coal choice may be the least flexible factor due to economic, geographical and political reasons, so, it is necessary to adapt the gasification technology according to the available coal only.

Further, apart from the above mentioned gasifier selection criteria, techno-economic features of the gasifiers listed below are also important to take decision about suitable gasifier selection.

- **Reliability:** Maturity of technology in view of technological risks, operational and maintenance problems.
- **Feedstock flexibility:** Wide variety feed-stocks, coal, lignite, biomass, etc.
- **Syngas Applications:** Syngas contaminants & impurities, allowed gas purity (S, CO₂, etc.) and cleanliness (tars, soot, ash) for applications such as synthesis of liquid fuels & chemicals, IGCC, IGFC, thermal applications.
- **Efficiency:** Carbon conversion efficiency, Cold Gas Efficiency
- **Economics:** CAPEX & OPEX
- **Unit Capacity:** Fuel Feed Rate/area (Throughput) & Scale up Prospects, Turndown ratio.

**Gasifier Selection Strategy for Indian Coals**

Depending upon coal properties mainly ash content, utilisation of Indian coals towards gasification can be done following below-listed options.

- **Option-I:** Use of limited quantity of low ash containing coals available in India specifically in ECL area or high Ash Coal-Petcoke blend to get desired ash content using slurry fed or dry fed EFG.

  **Preferred Gasification Technologies for Indian coals**

  Membrane wall based high temperature (> 1400°C) EFG technologies such as Shell SCGP for coals up to 30% ash content or low temperature slurry fed EFG such as ConocoPhillips (E-gas), GE (Texaco) for coals up to 20% ash. Further, for entrained flow gasifiers, desired values of slag viscosity are necessary.
However, ash fusion temperature of Indian coals is on higher side (AFT >1300°C) requiring operating temperature to be maintained on higher side to achieve desired values of viscosity. This can be easily achieved in membrane wall based high temperature EFG like Shell, Siemens, etc. where operating temperature is >1400°C. However, in case of low operating temperature slurry fed EFG operating temperature varies between 1350-1450°C, slag flowability may be difficult.

In case of only high ash coal utilisation without blends, coal washing will be required to bring down ash content below desired level causing loss of coal rejects and extra CAPEX, OPEX. Further, thermal penalty through molten slag and more oxygen demand due to high ash content and high fusion temperature will lower thermal efficiency along with inherently high possibility of fouling in syngas cooler and plugging in slag taping area.

Hence, database of AFT under reducing condition & slag viscosity for Indian coals is essential. Further, gasification performance evaluation and assessment of techno-economic feasibility in entrained flow gasification technologies like Shell, ConocoPhillips gasifier at their Demo Units or installations of such units in India is necessary.

• **Option-II:** Utilisation of low ash coals available in India mainly from ECL area or high ash coal washing or blending with low ash coal to desired ash content (~35%) followed by gasification in commercially proven MBG such as Lurgi FBDB. Lurgi FBDB has highest Cold Gas Efficiency & H₂/CO ~2, suitable for liquid fuels and chemical feedstocks such as methanol, fertilizer, FT fuel, SNG.

However, following gaps and key issues may arise while selecting MBG. First of all coal washing is necessary to bring down ash content below 35% causing loss of coals in rejects and additional CAPEX and OPEX. Further, desired Feed Size (+50 and ~6 mm, 5% below 6mm) is necessary; therefore, below 6 mm needs to be briquetted & recycled or utilised for other applications. Tar formation results in extensive syngas cleaning requirements, also limits the carbon conversion to permanent gases like H₂, CO or CH₄ and poses environmental issues. Therefore, assessment of techno-economic feasibility including upstream (coal washing, <6 mm coal utilization) & downstream (tar, liquid product, byproduct separation, processing) is very much essential while considering MBG for Indian coals.

• **Option-III:** FBG is the most attractive option for utilization of high ash coal through gasification route without any washing or blending with lower ash feedstocks. However, non availability of proven technologies in FBG category is a major constraint. FBG technologies like SES (U-Gas FBG), KRW are commercially available but not tested anywhere.

Envirotherm tried their CFBG technology for high ash coals at JSPL, Odisha, but faced issues related to fines. Developments done by BHEL through PEDU & 6.2 MW FBIGCC are important achievements. However, they have also reported gaps like lower carbon conversion, low & fluctuating calorific value of syngas.

CSIR-CIMFR has developed fluidised bed gasification facility having 20 kg/h fuel feed rate capacity in 2009, addressed operational problems like agglomeration and clinker formation, developed operational philosophy for high ash Indian coals and tested few coals. CIMFR has also reported lower carbon conversion and lower syngas heat value. Further, Oxy-blown experience with Indian high ash coal is not available as well as high pressure operation needs to be demonstrated. In this regard, development of Indigenous Fluidised Bed Gasification (FBG) technology is today’s necessity. Organisations like BHEL, CSIR-CIMFR, EIL, Thermax have started development programmes in this direction.

**Gasification Strategy for Indian Coals**

In view of utilisation of Indian coals through gasification route, the following strategy may be adopted.

- Development of indigenous high pressure oxy-blown fluidised bed pilot plants to be established followed by establishing operation.
- Development of membrane-based entrained flow pilot technology for low ash Indian coals and blends of high ash coal & Petcok.
- Performance testing of the above mentioned two types of gasifier pilot plants with high ash Indian coals and identification of suitable type of gasification process based on which a demo plant can be set up at different mine mouths.
- Mapping of Indian coals towards gasification potential and updating coal properties database towards gasification for newly explored coal resources/newly started mines.
- Testing of Indian coals in demo scale facilities of respective technology providers at their end can be preferred. Hence, both the routes demo scale unit development and commercial technology adoption may be conducted in parallel. Programmes need to be executed with joint venture between R&D institutions, engineering houses and industries instead of independent parallel programmes.

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