Clean Solid Fuels Production by Low Temperature Carbonisation for Sustainable Energy Generation

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Abstract

For sustainable and sound economic development there is a strong demand for extended clean power production, which is affordable by cost, utilising existing coal based plants and large volumes of renewable biomass and continuously waste streams as well, offering high level of process safety with comprehensive long term management of all residual streams from the operations. However, the utilisation of these fuels entails the risk of severe environmental impact due to the presence in them of polluting compounds, i.e. N, S, Hg, Cl etc. A preventive technique for the revitalization of the solid fuel industry by removing barriers by development of cost effective preventive pre-treatment of low-grade solid fuels (combined renewable biomass, lignite, coal, derived fuels) through application of low temperature carbonisation technology is described in this work. This pre-treatment process is made in downsized reductive environment for removal of hazardous air pollutants (such as nitrogen, sulphur, chlorine, mercury) prior to burning and by using the clean fuel to improve the combustion efficiency as well. The integrated application is primarily for
the small-scale power plants less than 50 MW power capacity and CHP co-
generation, and medium scale power plants less than 300 MW power capacity as well.

**Keywords:** Clean solid fuels, Carbonisation, Sustainable energy generation

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1. **Introduction**

For sustainable and sound economic development it is required extended clean power 
production, which is affordable by cost, utilising existing coal based plants and large 
volumes of renewable biomass and continuously waste streams. Thus, there is a 
strong demand for continuous improvement of the environmental performance of 
energy production systems towards safer, faster, better, and less costly solutions, 
supported with “3R” Recycle-Reduce-Reuse concept implementation. The open 
energy market demands less costly and commercially affordable electric energy 
production without Government subsidy and financial support, and with long-term 
predictable price development structures.

The regional energy and CHP utilisation of the available biomass (broad biomass 
definition as per 2001/77/EC and narrow biomass definition as per 2001/80/EC) and 
organic feed is often not cost effective as stand-alone installations. Therefore, new 
combinations need to be developed where regionally available low cost, low grade 
feed streams derived fuels and biomass with low caloric value but with high transport 
cost per specific volume are combined with high caloric value feed streams such as 
coal and lignite. However, such combinations must be subject to significant 
improvements in overall environmental performances of solid fuel power generation, 
including improvements on greenhouse gas emissions as per Kyoto Protocol as well.

During the past decade several clean coal (CC) technologies have been developed, 
such as gasification, integrated gasification combined-cycle “IGCC” systems for large 
scale use well over 150 MW_e net capacity and flue gas desulphurisation “FGD”, as 
“end of pipe” solution. Although gasification offers feedstock and product flexibility, 
potential for greater than 60% efficiency, but the achievement of near zero pollutant
emissions technically is rather complicated and costly. IGCC is successfully applied for large power generation systems, usually over 250 MW\(_{e}\), however the total efficiency under 150 MW\(_{e}\) is too low. For flue gases desulphurisation (FGD) several methods have been used, such as was gas scrubbing with lime, ammonium scrubber (Walter), activated carbon adsorption (Uhde), combined SO\(_2\)-NO\(_x\) catalysts adsorption (Beargbau-Forschung), S reduction method (Resox), adsorption of SO\(_2\) into sulphuric acid (Chiyoda) and other methods. To meet the new norms the traditional technologies have increased their complexity, resulting increased cost. However, technical complexity cannot be increased more, therefore these technologies have reached their ultimate limits, while new environmental norms/Kyoto protocol requires for more efforts.

In order to develop the European Union to the most progressive and competitive economical area in the world by 2010, with low cost or at least reasonable cost electric energy availability, with exclusion of energy shortage possibilities, it is necessary to satisfy the ever increasing energy demand, where oil/gas based energy production is preferably substituted to the greatest possible extent with renewable biomass energy sources. There is a need to take long termed and comprehensive considerations for clean energy production, whereas the total life cycle of all material streams including also residual management should be considered.

2. Process Description

Low temperature carbonisation may be defined as carbonisation in the absence of air, which is carried on to a final char temperature below 700°C and aims to convert “dirty” fuels to clean fuels, liquid fuels or pipeline gas and more valuable chemicals. The 3R – Low Temperature Carbonisation (3R – LTC) process converts widely available low-grade fuels to high-grade fuels by value added low temperature carbonisation. The key component of the 3R – LTC method and apparatus is an indirectly heated horizontally arranged closed cycle operating rotary kiln, where material is safely separated in absence of air and decomposed into gas-vapour and solid phase.
The hazardous air pollutants, such as nitrogen, sulphur, chlorine and mercury are removed in the gas-vapour phase and separately treated – recycled in downsized environment, while Clean Multi Fuel – Clean Coal is utilised in the plant’s boiler, which application is resulting a comprehensive and cost efficient revitalization option making fully compatible the open - liberalised energy market demands and the objectives of the sustainable environmental protection. A schematic representation of the 3R – Low Temperature Carbonisation process is given in Figure 1.

**Figure 1.** Schematic diagram of the Low Temperature Carbonisation process

The reactor rotates around its symmetric axle, is horizontally arranged and cylindrically formed with no refractory line installed inside, Figures 2 and 3. The high quality steel mantle is heated from outside through the lined combustion chamber. Inside the reactor body, blades promote the transportation of the material. The reactor is a permanently working vessel; the input material stream enters in at the input-end while the out-gassed solid material and the pyrolysis gas-vapour phase are discharged at the output-end, separately from each other. The reactor and the complete technology do not contain exotic technical solutions and/or construction materials.

The required amount of energy input is basically supplied from hot flue gases that are produced in the combustion chamber from the direct burning of the thermolysis gas vapours and heat the reactor body outside the mantle. Heat transfer happens indirectly through the mantel to the material. The heat transfer contains three phases: Primarily: Energy transfer from heat under the material in the rotary kiln. The material, which is
ground down to have extensive surface area is permanently mixed, which mixing process is promoted by the blades inside the reactor body. The heated material is to be permanently replaced by cooler materials again and again. Therefore the thermal conductivity of the solid material is of less importance and can be within a wider range. This is a very important and vital technical factor, particularly in relation to the carboniferous materials that are bad thermal conductors and are extremely mixed physical and chemical character. **Secondary**: Radiation heat transfer from the inner top surface of the reactor body. **Tertiary**: Over the temperature of 275°C an exothermic reaction starts during the decomposition of the material.

**Figure 2.** Schematic diagram and temperature profile of the 3R – Low Temperature Carbonisation reactor

There are four well distinguished phases concerning the thermolysis process inside the reactor:
(a) Warm up phase, up to 150°C – 160°C. Characterised by the removal of the free and most of the bounded water from the material.
(b) Thermal decomposition phase, up to 270°C – 280°C. Characterised by heavy discoloration of the material and the removal of the remaining, chemically bounded water, with simultaneous development of gasification.
(c) Thermal desorption phase, up to 380°C – 500°C. Characterised by self-carbonisation with exothermic chemical reactions, heavy gasification process and escape of volatile compounds from the material. Thermolysis gas-vapour is continuously removed.

(d) Stabilisation phase, over 500°C. The residual solid phase of the process is charcoal, i.e. “clean coal”.

Figure 2. 3R – Low Temperature Carbonisation pilot plant

The exothermic process is a slow process therefore the extended thermolysis gas-vapour production will not result in an explosive production of gas-vapour. The thermolysis gas-vapour production is of low volume, which production is promptly removed from the reaction space by master fan. The advanced design applies high L/D rotary reactor ratio combined with low filling grade between the feed volume/reaction space volume ratio. Even if such theoretically explosive production of thermolysis gas-vapours happens, the size of the reactor’s inner reaction space and volume, the reductive environment and the adjustable permanent vacuum control compensate the action. The thermal engineering design of the reactor is related the throughput capacity of the reactor and the extremely qualitative variations of the input
material. No matter if the basic material is of organic, inorganic and/or mixed character, the chemical components will be separated at a certain treatment temperature if the boiling point(s) of the primary target contaminant component(s) are under 500°C. The pyrolysis reactions are not only a sequenced series of reactions, but parallel series of reactions as well, with different levels of energy.

This preventive pre-treatment of poor quality solid fuels, by 3R – LTC” removes hazardous air pollutants in a downsized and safe environment before burning in large scale boilers, and combine utilisation with available renewable biomass, which can lead to removal of polluting compounds. The produced solid fuel, i.e. “clean coal”, contains practically no chlorine or mercury, too low sulphur and low nitrogen, as well. The following comparison in Table 1 indicates differences in targeted hazardous air pollutants between the raw fuels and the clean coal.

Table 1. Hazardous compounds in various fuels

<table>
<thead>
<tr>
<th>HAP (%w/w)</th>
<th>Low grade fuels</th>
<th>High grade fuels</th>
<th>Clean coal (3R-LTC)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Organic Sulphur</td>
<td>1 – 3.5</td>
<td>0.65 – 1</td>
<td>0.25 – 0.35</td>
</tr>
<tr>
<td>Nitrogen</td>
<td>1 – 4</td>
<td>1 – 3</td>
<td>0.2 – 0.4</td>
</tr>
<tr>
<td>Chlorine</td>
<td>0.35 – 0.6</td>
<td>0.25 – 0.45</td>
<td>&lt; 0.05</td>
</tr>
<tr>
<td>Mercury</td>
<td>0.05 – 0.1</td>
<td>0.02 – 0.05</td>
<td>&lt; 0.01</td>
</tr>
</tbody>
</table>

3. Process Novelty
The state of the art of the 3R - Low Temperature Carbonisation targets to remove organics sulphur and volatile HAP (Hazardous Air Pollutants) by preventive pre-treatment process in a cost effective way, with significant saving on and offering the following advantages:

- Environmental impact (HAP, GHG)
- Improved process efficiency >3%
- Flexible choice by multi feed
- Total cost reduction >10%
- Extensive use of renewables
- Less corrosion in the boilers
Therefore, the main goal is the environment improvement in coal-renewable biomass energy based clean power generation with increased efficiency, - through application of advanced thermal desorption technology.

The preventive pre-treatment low temperature carbonisation process (3R – LTC) for removal of HAP (primarily S, Hg, Cl) and minimisation of GHG offers significant cost and technical efficiency improvements, as the prime cost by the time of now is not the coal firing assembly but the off-gas treatment unit at the “end-off-pipe”. The greatest advantage of the 3R – LTC pre-treatment process is that by it's utilisation feed contamination are removed by preventive means, supplies clean fuel to main unit, where environmental performance is upgraded, the clean energy production efficiency is increased, total cost of production is decreased, while providing safer and sustainable environment.

The process environment provides true reductive environment in vacuum; the revolutionary key advantages of the indirectly heated low temperature thermal desorption technology is that the (1) heavy metals will be concentrated in the solid phase in metal form and (2) VOC/halogens (except volatile heavy metals, such as Hg) will be separately concentrated in the gas phase. Through this process the HAPs are concentrated in a small volume of flue gas that is much easier to clean. As a result large savings are achieved in the linked main unit, especially at the off-gas treatment and solid residue management stages, as compared to any other thermal treatment technologies.

4. Expected Impact and Exploitation
The innovative 3R – LTC removes existing technical barriers for extended and combined utilization of low grade fuels, renewable biomass and derived fuels, opens new advanced technical and cost reduction opportunities, for safer, better and less costly clean energy production. It utilizes existing agricultural and coal industrial structures by add-on and retrofits, safeguards existing jobs and creates new workplaces. The state of the art of the 3R – LTC aims to remove hazardous air pollutants by a preventive pre-treatment process of low temperature carbonization in a cost effective way, with significant savings and offering the following advantages
towards the ultimate goal of near-zero emissions of overall output streams: removing environmental impacts, improved process efficiency, flexible choice by multi feed, total cost reduction, extensive use of renewable energy sources, less corrosion in the boilers.

The expansion of the EU in 2004 and the applied/recommended new strict emission environmental norms, goals set to meet the Kyoto Protocol, demand for improvement on process safety, cost reduction and public acceptance for solid fuel utilization to produce clean energy, are real challenges requiring new technological solutions. The solid fuel power production is a key industrial element of energy production in several of the EU Candidate countries and all the EU countries have demand for extended low cost energy production. The 3R – LTC is expected to become a critical asset for the EU Candidate Countries, particularly for countries with large coal reserves and renewable biomass potential.

While the energy market is under deregulation, where the real price of the energy production is the only factor that counts, there is a strong demand to take into consideration comprehensive life cycles and environmental aspects for all the processed material streams and resources, and definitely avoid producing low cost energy for short term gains at the “cost” of the environment or human health. The 3R improves the employment prospects in the coal mining, coal utilization and agricultural industries, through extensive utilization of biomass, while improving the quality of life, health and safety, also at the workplace.

5. Conclusions
For sustainable and sound economic development there is a strong demand for extended clean power production, which is affordable by cost, utilising existing coal based plants and large volumes of renewable biomass and continuously waste streams as well. The 3R – Low Temperature Carbonisation (3R – LTC) process converts widely available low-grade fuels to high-grade fuels by value added low temperature carbonisation. The hazardous air pollutants, such as nitrogen, sulphur, chlorine and mercury are removed in the gas-vapour phase and separately treated – recycled in downsized environment, while Clean Multi Fuel – Clean Coal is utilised in the plant’s
boiler, which application is resulting a comprehensive and cost efficient revitalization option making fully compatible the open - liberalised energy market demands and the objectives of the sustainable environmental protection. The preventive pre-treatment low temperature carbonisation process (3R – LTC) for removal of HAP (primarily S, Hg, Cl) and minimisation of GHG offers significant cost and technical efficiency improvements, as the prime cost by the time of now is not the coal firing assembly but the off-gas treatment unit at the “end-off-pipe”. Thus, the innovative 3R – LTC process removes existing technical barriers for extended and combined utilization of low grade fuels, renewable biomass and derived fuels, opens new advanced technical and cost reduction opportunities, for safer, better and less costly clean energy production. It utilizes existing agricultural and coal industrial structures by add-on and retrofits, safeguards existing jobs and creates new workplaces.

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