GASIFICATION TECHNOLOGY ASSESSMENT OF STERILE COAL TO CLEAN ELECTRICAL POWER GENERATION

Francisco Guerrero,Carmen Clemente-Jul
Department of Chemical Engineering & Fuel, Mining School.Technical University of Madrid (UPM), Rios Rosas, 21. Madrid 28003. Spain

Abstract:
Sterile coal is a low-value residue associated to the coal extraction and mining activity. According to the type and origin of the coal bed configuration, sterile coal production can mainly vary on quantity, calorific value and presence of sulphur compounds. In addition, the potential availability of sterile coal within Spain is apparently high and its contribution to the local power generation would be of interest playing a significant role.

The proposed study evaluates the availability and deployment of gasification technologies to drive clean electricity generation from waste coal and sterile rock coal, incorporating greenhouse gas emission mitigation systems, like CO_2, H_2S and NO_x removal systems. It establishes the target facility and its conceptual basic design proposal.

The syngas obtained after the gasification of sterile coal is processed through specific conditioning units before entering into the combustion chamber of a gas turbine. Flue gas leaving the gas turbine is ducted to a heat recovery steam generation boiler; the steam produced within the boilerdrives a steam turbine. The target facility resembles a singular Integrated Gasification in Combined Cycle (IGCC) power station.

The evaluation of the conceptual basic design according to the power output set for a maximum sterile contribution, established that rates over 95% H_2S and 90% CO_2 removal can be achieved. Noticeable decrease of NO_x compounds can be also achieved by the use of commercial technology.

A techno-economic approach of the conceptual basic design is made evaluating the integration of potential unitsand their implementation within the target facility aiming toachieve clean power generation. The criterion to be compliant with the most restrictive regulation regarding environmental emissions is setting to carry out this analysis.

Keywords: CO2, Gasification Technologies, Power Generation, Sterile Coal, Clean Coal Technologies.

Introduction

In the present time, coal is the most intensive resource used to generate electricity and heat but also used for the industry to produce chemicals and materials [1]. Around 80% of the world energy system is based on fossil fuels. Coal accounts in 2010 for about 27% of the world primary energy demand, totaling for 3,475 Mtoe and only overtaken by oil[2]. Electricity and heat generation are coal end use, by far the main source of energy use for this application, this meansabout 46% of electricity and heat generated in 2010 came from coal [2].Trend analysis forecasts that coal remains the backbone fuel for electricity generation globally, and its use for this purpose continues to rise in absolute terms. However, its share of total generation will expectedly fall from about 46 to 33% in 2035 [2].In some countries like China or India, coal remains the dominant fuel in the generation mix and the leading source of incremental generation. Therefore, seems to be crucial to evaluate and monitor the availability of coal as essential energy resource, get through an inventory of what is currently economic to produce, technically recoverable and at what price. By the year 2010, proven reserves of coal in the world are generally agreed to be more than 1,000 billion tons, but recoverable resources reach about 21,200 billion tons.

Looking at coal locally, in Spain 15% of electricity demand was satisfied in 2011 by coal fired power stations, with a power installed capacity of 12% [3]. In 2012, the power installed capacity for coal was 11% of the total, and coal met 20% of the total electrical demand.

Spain is a very dependent country in terms of energy, getting from the exterior over 80% of its energy requirements, and about 80% of its energy system is based on fossil fuels, mainly oil for the transport sector. Hence, local energy resources should be essentially deployed in order to achieve reasonable self-sufficient energy levels.

Apart from coal, and some renewable potential like wind or solar, no large amounts of energy resources sound to be available in Spain, this means no gas, no oil. Traditionally, coal sector in Spain has been a well establish form of activity and business, socially and economically speaking, pushing up the Spanish society from the Industrial Revolution, the country started to industrialise itself, hence making relatively easy to get more coal. At that time, coal was the only form of local energy and most of local energy and electricity demand was met by this coal.

In Spain can be found basically three types of coal in six main coal regions:i) anthracite or hard coal and bituminous coal getting from the Paleozoic basin in the provinces of Asturias, León, Ciudad Real y Córdoba, and ii) lignite getting from the Cenozoic basins in the provinces of Teruel, Cataluña and Galicia. There is a different between lignite getting in Teruel and Cataluña, which is termed black lignite, with the one getting in Galicia termed brown lignite that quit production in 2008. National coal production has been used with imported coal in 40 to 60% bend to run Spanish coal fire power stations [4], crucial to satisfy electricity demand and sufficiency. Total amount of coal production in Spain was 6,2 million tons by 2012 [5], getting down drastically from one decade ago, coal production was almost 24 million tonsin 2000.Should be mention several causes that have driven the national coal sector collapse, for instance [5], electricity demand slowdown due to less industrial activity and economic crisis in general, European decisions that force Spanish government to adopt controversial policies to fairly accommodate coal production rates, determining the coal sector structure definition and decline coal subsides, set in the last national coal plan for period 2006 – 2012 termed “Plan Nacional de ReservaEstratégica de Carbón y Nuevo Modelo de Desarrollo Integral y Sostenible de lasComarcasMineras”, etc. now under negotiation the new Plan for time span 2013 – 2018.

Sterile coal or waste coal is the low-value discard of the coal extraction,mining and coal washing activity. Therefore, the amount of waste coal generated connects directly to the amount of coal produced. It was not when coal productionstarted to get to in 1700, but afterwards when coal was needed in vast quantities during the Industrial Revolution that unwanted waste product from coal mining was dumped into piles, growingto millions of tons in some parts of the globe.At the beginning, mining activity was the one accumulating waste coal, but growing interest inincreasing coal combustion efficiency, increasing coal transport efficiency and

suitable preparation of coal applyingmodern processes, point to coal washing activity like another clear contribution to the waste coal production.
This paper evaluates the use of waste coal to produce electricity, its availabilityand potential energy deployment in Spain, giving an overview of similar initiatives carried out in other countries.

MainFindings and Discussion

Waste coal are termed in Spain “estéril”, and in USA are normally called “culm” in the Eastern Pennsylvaniaanthracite coal region and “gob” in the bituminous coal mining region of Western Pennsylvania, West Virginia or wherever are located bituminous coal basins. Waste coal is also called “boney” or “slate dumps”. Waste coals are rocks composed of other minerals, mainly slates or schistose and sandstones, apart from coal, extracted incidentally along with coal. However, the process of separating waste from coal is imperfect, so waste coal produced during coal washing steps has some coal as well. Basically, waste coal is produce in two stages throughout the coal management process, firstly from extraction stage, which produces approximately 10% of total waste coal and with no carbon content at alland secondly from washing stage, which produces the other 90% remaining [6]. Once produced, waste coals are piled in waste dumps, piles growing normally next to coal basins.
Waste coals piled in waste dumps present a variable size range [6], from oversize (>150 mm), grains (150-10 mm), smalls or undersize (10-1 mm) and fines or (<1 mm), that according to Spanish mining culture can be sorted into black waste coals and brown waste coals, as the ones got self-oxidation and spontaneously combusted. Therefore, from the point of view of waste to energy only black waste coals are of interest.

Anthracite production in Spain has been notably dominant, followed by bituminous and less intensive by subbituminous coals as well as lignite, black and brown type, giving an idea of the kind of culm and wastes produced and piled in dumps in Spain from the beginning of 1700s. Variation of coal production between years is due to the reasons expressed in the introduction. Underground coal extraction produces much larger amounts of waste coal than open-cast.
An evaluation of annual waste coal production during the coal mining activity inSpain is shown in next Figure 1;it splits into mining and washingorigin [5, 7, 8, 9,and 10].

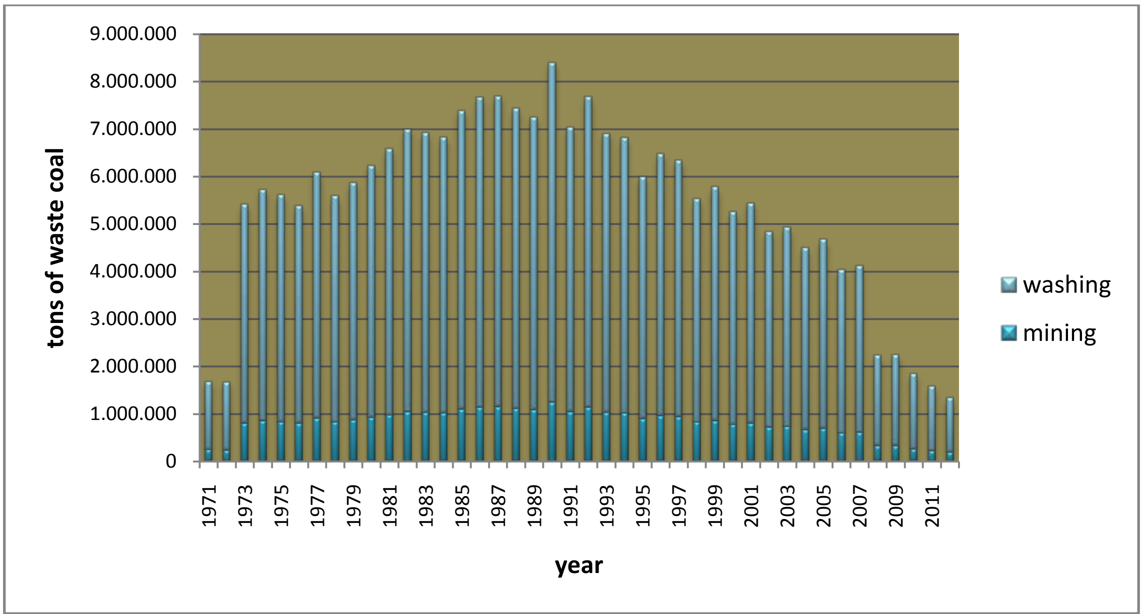

Figure 1: Total waste coal production per year in Spain, contribution of coal mining and coal washing activities (assumptions made by authors) [5, 7, 8, 9, 10].

According to our evaluation, Fig.1, about 228.3 million tons of waste coal has been produced in Spain until 2012, and piling them to form waste dumps present risk to be considered, like unstable slopes when they get too high, when they cannot support vegetation because got so hot when absorb solar heat and heavy erosion from these piles becomes a source of acid mine drainage, which contains heavy metals and acids polluting streams, rivers and aquifers.

Different uses and applications of waste coal are identified, in Spain and abroad, for instance it is deployed by the industry to produce clinker, cement and bricks, for agriculture enhancing fertility of soils, and producing materials for roads construction. But following on with the waste to energy analysis, these piles have still high value as fuel, mainly because of the carbon content and similar characteristics as the coal they come from.Carbon is homogeneously well distributed along the waste coal fine size.Percentage of fines in black waste coal varies from 2 – 75% [6]. Main parameters for the use of waste coal as fuel have been analysed. Contingent on the type of coal producing waste coal and the source consulted, heating values vary between 2,000 and 5,000 kJ/kg [11], and between 6,000 – 10,000 kJ/kg [12]. Proximate analysis of waste coal from lignite in Spain, establishes percentages 15 – 25% of volatiles, 40 – 45% ash, 15 – 25% fixed carbon, and ultimate analysis set 4 – 6% sulphide and 0.5 – 1.5% sulphate [12]. Another metals and hazardous elements, mercury for instance, are contained in different quantities in waste coal. In general, in Spain, waste coal still contains between 15 and 35% of fuel materials [13].

Making certain assumptions have been possible to evaluate the potential total amount of waste coal available in existing piles in Spain susceptible of being used as fuel feedstock, it is showed in green colour on the following Figure 2.

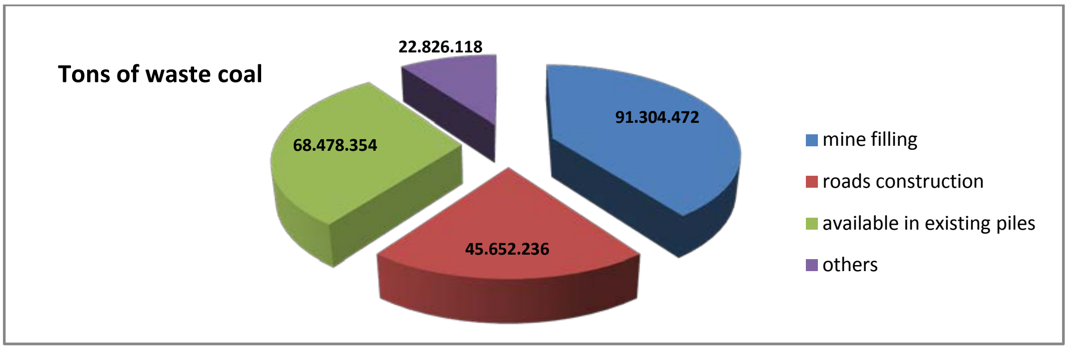

Figure 2: Evaluation of potential total waste coal available in existing piles in Spain, according to potential end use distribution (assumptions made by authors) [11].

Gasification process has been evaluated for the deployment of waste coal [14]. The gasifier recommend for waste coal available is of entrained flow type, it works at high temperature between 1200 and 1600°C, which avoid formation of tars and reach high carbon conversion rates, with short residence times,between 1 and 5s, and molten slags. Waste coal fuel must be fed into the gasifier at very small size, fines <200 μm, hence milling and preparation is previously required. Ash fusion (melting) temperature and fluidization have to be evaluated in order to determine working temperature of the gasifier. For instance, anthracite culm has high ash contents and the ash, which is rich in silicon and aluminum oxide, has a high fusion temperature.Final composition of syngas depends on pressure and temperature performance conditions that depend on the different equilibrium between waste coal feedstock and gasification agents. Energy content in syngas between 9000 and 11000 kJ/$m^3$are achieved [15].

The following Figure 3 shows the simplified process flow diagram of the proposed facility for the evaluation of waste coal to produce electricity.

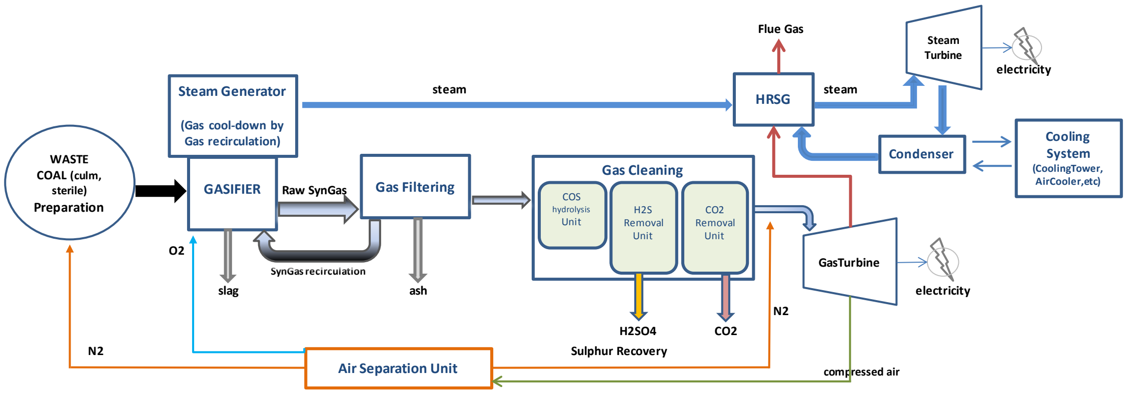

Figure 3. Simplified process flow diagram for electricity generation from waste coal.

The power station resembles to a gasification process integrated in a combined cycle, comprising a gas turbine and steam turbine.Additional units to purify syngas, removing H_2S and capturing CO_2 are evaluated. Integration level between different units is tuned to achieve optimal performance ratios, for instance, full integration brings the highest efficiency but partial integration results in higher capacity output and operation flexibility [14].
The power station proposed in Figure 3 is evaluated for 50 MW of net capacity output, about 7 MW are on-station self-supply, and achieving about 45% efficiency. Considering waste coal with performance as fuel feedstock presented before, between 1,200 and 5,000 tons/day of waste coal is required. If we consider the power station operating time a year is 8,000 hours per year and the amount of waste coal available in existing piles in Spain is about 68,5 million tons (according to analysis Figure 2), then we can see the power station running between 20 or 60 years.

Regarding environmental issues, in some cases waste coal presents 3 times the mercury contained in coal, and even more sulphur compounds but usually less nitrogen. Gasification technology providesrecognised benefits in compared with other technology normally use for the production of electricity from fossil fuels, like combustion for instance [14]. There is commercial technology to remove up to 99% of H_2S, incorporating physical absorption processes like Selexol or Rectisol, and recovering as sulphuric acid. The COS (carbonyl sulphide) are transformed into H_2S via hydrolysis within a Shift reactor. CO_2 removal is favoured in gasification processes because the medium pressure of syngas. MDEA solution in regenerative process configuration or the same Selexol, Rectisol and Sulfinol processes (selective capture processes), can be deploy to remove acid compounds presented in syngas, and the higher the partial pressure of acid compound to remove the higher removal efficiency [14]. Up to 99% of mercury can be also removed, by installing active carbon beds where syngas is forced to pass by. It is a mature technology and its operating cost in gasification stations is about 12 times less than conventional combustion power stations [14].
Another advantage of gasification technology is the possibility to easily produce hydrogen, H_2.

Similar initiative to the one evaluate in the present paper has been identified in USA, the Gilberton Power Plant, in Schuylkill County, Pennsylvania, supported by DOE. It reclaims 1.4 million tons of culm per year to generate 41 MW of electricity and 5000 bpd of ultra-clean liquid transportation fuels using Shell gasification technology (in some sources Texaco Power & Gasification) and Sasol´s FT liquefaction technology. First basic design documents came out in 2001 and in 2007 the NETL pushed forward for constructing demonstration scale plant. It will be able to run on 100% culm and 75% culm – 25% petroleum coke as feedstocks.

In Spain, one initiative of using waste coal to produce electricity started operation in middle 1990s. La Pereda Power Station in Mieres, Asturias, next to one of the most productive anthracite basins in the country, owned by Hunosa, has been using culm and coal at 60% and 40% respectively for ten years, the last three up to 70% culm feedstock, in a circulating fluidised bed to produce 50 MW of electricity and running average 6,000 hours/year.

The 65.8 total million tons coming from evaluation of available waste coal existing in piles in Spain, showed before in Figure 2, has to be slightly reduced because of around 1.2 million tons has been consumedin La Peredaduring its thirteen years of operation

Another initiative in USA burning waste coal, are the circulating fluidised bed of around 50 MW apparently installed throughout Pennsylvania, by the formed Western Pennsylvania Coalition for Abandoned Mine Reclamation in 1982.

Conclusions

Spain applies technology to reduce the large amounts of waste produced by the mining industry. Waste coal has important and several application and uses. Waste to energy is one of the alternatives to be considered by countries dedicated to coal mining in order to cope with electricity scenario and global resource depletion.

Apparently, there is enough waste coal still piled in Spain potentially used as fuel feedstock for thermal processes to produce electricity. Transportation of waste coal from production, pile, to end use place, power station, it is crucial issue for the economic feasibility of the project.

The majority of waste coal produce in Europe has very similar properties, therefore, researching made and projects undertaken by one European country exploring industrial application of waste coal can be applied in other European country.

References

[1] Guerrero, F.; Clemente-Jul, C., Key factors to develop a common methodology towards and appropriate energy mix for electricity generation. Paper, 2013.
[2] International Energy Agency;WorldEnergy Outlook 2012.
[3] Red Eléctrica de España; Informe Sistema Eléctrico Español 2011, Avance del Informe Sistema Eléctrico Español 2012.
[4] Enerclub, Club Español de la Energía, Instituto Español de la Energía; Sectores energéticos, carbón, 2013.
[5] Lapastora, O., CEO ofCarbunión; Balance energético 2012 y perspectivas 2013: Carbón. Presentation 2013.
[6] Ficha Técnica, Estériles de Carbón; Ministerio de Fomento, Ministerio de Medioambiente, Medio Rural y Marino. Spain, 2007.
[7] Gonzalez, J; Perez, J.; Producción, propiedades y utilización de los estériles de hulla en Asturias, Parte I. Hunosa. Energía, Julio – Agosto 1986.
[8] Gonzalez, J; Fernandez, J.A.; Perez, J., La producción de estériles del carbón de España, Parte I: Hulla. Hunosa. Energía, Julio – Agosto 1989.
[9] Gonzalez, J.; Fernandez, J.A.; Perez, J., La producción de estériles del carbón de España, Parte II: Antracita. Hunosa. Energía, Septiembre – Octubre 1989.
[10] Gonzalez, J.; Fernandez, J.A.; Perez, J., La producción de estériles del carbón en España, Parte III: Lignito. Hunosa. Energía, Mayo – Junio 1990.
[11] Gonzalez, J.; Perez, J.; Fernandez, J.A., Producción, propiedades y utilización de los estériles de hulla en Asturias, Parte II. Hunosa. Energía, Enero – Febrero 1988.
[12] Guerrero, J., Planta de generación eléctrica a partir de estériles de mina y carbón con reducción de emisiones. DEA – Thesis, Department of Chemical Engineering & Fuel, Mining School, Technical University of Madrid, UPM, 2011.
[13] Gonzalez, J.; Leininger, D., Propiedades físicas y mecánicas de los estériles del carbón de Europa. Energía, Mayo – Junio 1986.
[14] Guerrero, F., Gasificación. Technical Study, Department of Chemical Engineering & Fuel, Mining School, Technical University of Madrid, UPM, 2006.
[15] Early entrance co-production plant – Decentralized gasification cogeneration – Transportation fuels and Steam from available feedstocks. U.S. Department of Energy, National Energy Technology Laboratory, Technical Progress Report 2001.