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Activated carbon from co-pyrolysis of particle board and melamine (urea) formaldehyde resin: A techno-economic evaluation

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ABSTRACT

The disposal and environmental problems associated with waste resin produced during the production of melamine (urea) formaldehyde and wood waste (i.e. particle board) containing these aminoplasts requires a processing technique which results in products of added value and which meets both ecological and economical needs. Several published results demonstrate that nitrogen incorporation in activated carbon can play a significant role as a key parameter for the adsorption properties, as well as for the catalytical activity and the dispersion of carbon supported catalysts.

The production of high value nitrogenised activated carbon, after thermal treatment in an oxygen deficient environment and subsequent activation, is considered as a possible opportunity.

This research paper investigates the feasibility of a process design for the production of a high added value nitrogenised activated carbon by co-pyrolysing a mix of particle board and melamine (urea) formaldehyde waste. A process design and an economical model for estimating the total capital investment, the production costs, the possible revenues, the net present value and the internal rate of return is developed based on various literature sources. In addition, Monte Carlo sensitivity analysis has been carried out to determine the importance of the main input variables on the net present value. It is assumed that the manufacturing facility obtains its waste from various sources and operates continuously during 7000 h a year. The study investigates the plant's profitability in function of processing rate and mixing ratio.

Even though the current assumptions rather start from a pessimistic scenario (e.g. a zero gate fee for the melamine (urea) formaldehyde waste, a first plant cost, etc.) encouraging results for a profitable production of activated carbon are obtained. Moreover, the ability to reuse two waste streams and possible production of a specialty carbon enhances the value or usefulness of the activated carbon manufacturing facility.

1. Introduction

During the production of melamine (urea) formaldehyde resins (both further abbreviated as MF) for the production of particle board (PB) a considerable amount of waste resin is produced that cannot be re-used or recycled at this moment.

In addition, classical thermo-chemical conversion (e.g. combustion) of wood waste containing these aminoplasts resins might cause pollution because it results in the production of toxic gases like ammonia, isocyanic and hydrocyanic acid and nitrous oxides [1–3].

A sustainable solution is more and more required to avoid environmental problems and landfilling costs, and to turn this waste stream in a rather profitable material resource. A possible opportunity, is the production of high value activated carbon (AC) after thermal treatment in an oxygen deficient environment and subsequent activation.

ACs are produced for a large number of dedicated applications both as structural and functional materials. ACs are generally used for air, water and gas purification, chemical and pharmaceutical processing, food processing, decolourization, solvent vapour recovery, fillers in rubber production, refractory materials, catalysis and catalyst support [4–6].

Marsh and Rodriguez-Reinso [5] estimated the world annual production capacity of AC to be around 400 kt in 2006, excluding countries without accurately known figures like China and

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some other Eastern countries. Furthermore the market is increasing constantly, due to the environmental awareness and the growing industrialization. Girods et al. [7] expect a growth of 5.2%/year to 1.2 Mt by 2012. In Europe, Japan and the USA the growth is 1–5%/year, whereas this rate is much higher in the developing countries. The price of AC is a function of demand, quality, production cost, etc. A typical price range is 1.4–6 kUSD/t, but for very special carbons the price can increase to 20 kUSD/t [5,8]. Girods et al. [7] state that the average production cost of AC from the major producers was on average 2.5 kUSD/t.

The wide range of applications exists thanks to the high volume of pores, high surface area and the variety of surface chemistry of ACs. The final properties of the AC are related to the precursor material and the activation process (physical or chemical). It is stated that the physicochemical properties of the ACs are strongly influenced by the presence of heteroatoms like oxygen, nitrogen, sulfur, etc. In normal conditions the amount of nitrogen in the AC is negligible [4,6]. Several published results however, demonstrate the positive effect of nitrogen incorporation as a key parameter for the adsorption properties of the AC [9], especially for the removal of acid gases like hydrogen sulfide, sulfur dioxide and phenolic compounds [2,3,7]. Nitrogen incorporation can also play a significant role for the catalytic activity and dispersion of carbon supported catalysts [9]. According to Girods et al. [2] the value of such a nitrogenised activated char from PB (in 2006) is on average 2.5 kUSD/t (≈2.0 kEUR/t), whereas normal ACs are sold (in 2008) at prices between 0.8 kEUR/t and 1.7 kEUR/t (≈1.2–2.5 kUSD/t) [10]. According to Infomil [10], impregnated ACs (i.e. including pick-up of the saturated carbon) have a higher selling price (in 2008) of 4.0 kEUR/t to 6.0 kEUR/t (≈5.9–8.8 kUSD/t) due to higher costs incurred by the impregnation step.

Because the chemical properties of the PB and MF waste materials result in in situ nitrogen incorporation during char formation and activation, the production cost of nitrogenised activated char is considerably reduced in comparison with post impregnation of nitrogen containing components on AC. In addition, these waste materials have the economic advantage of representing a negative cost [1] for a waste processing company, which means that the latter does not have to pay for obtaining resources such as PB and MF waste, but instead receives a *gate fee* for processing the waste material.

The objective of this work is to identify the crucial variables for rendering the production of AC from PB and MF waste profitable. For this purpose, a preliminary economic feasibility study has been carried out for a process design especially developed for the production of AC from PB and MF waste. After developing a process diagram of an AC production technique (co-pyrolysis combined with physical activation), the net present value of the cash flows generated by an investment in co-pyrolysis and char activation has been calculated. The minimum selling price of the produced AC has been determined, taking into account uncertainties by performing Monte Carlo sensitivity analysis. Finally, this preliminary economic feasibility study is used to identify the key variables for the profitability of the production of AC from PB and MF waste.

2. Process design

The preliminary process design for the production of AC from PB waste co-pyrolysed with MF is shown in Fig. 1. The process can be divided in four parts: pretreatment, pyrolysis, activation and packaging. After shipping the raw materials to the AC production facility, they are first mixed and milled into a smaller particle size (a few millimetre), dried and transported to a silo. It is difficult to predict the moisture content of the incoming waste. Girods et al. [2] determined the moisture in wood board to be about 7%. Next, the grinded and dried waste will be transported to a rotary pyrolysis furnace (operating at 800 °C). Here the waste is pyrolysed in an oxygen-free environment for a few minutes (2–5 min). The developed chars (solid fraction) are then transported to a second rotary kiln furnace where they are activated during 30 min at a temperature of 800 °C in the presence of steam as activation agent. The pyrolysis and activation are carried out in two separate but connected furnaces to achieve a continuous system. Both the pyrolysis and activation kiln have a cross-sectional area occupied by material which is 10% of the cylinder's length to ensure an adequate heat transfer and mixing [11,12]. The produced pyrolysis gases and aerosols are conducted to a thermal combustor followed by a cyclone for complete combustion at a temperature of around 1000 °C with a residence time of at least 2.5 s. This reduces formation of harmful compounds or promotes their breakdown [13]. By using a multiple zone oxidizer the formation of NO_x can be further controlled by managing the oxygen inflow in the different zones, but this is not implemented at this stage. The hot flue gases are used as a heat source for pyrolysis/activation and the steam generator. After cooling, the produced AC is transported to a storage silo before screening and packaging. The remaining gases are cooled to recover water from the steam generator. After cooling they are discarded. A pelletisation device and an extra gas cleaning unit before emission can also be installed, but are at the moment not incorporated in this analysis. The possible extra investment costs for this equipment can be found in recent literature e.g. Lima et al. [11] and Lemmens et al. [14].

3. Economical feasibility model

Poor capital investment decisions can alter the future stability of an organisation. Investors deal with this problem by using investment decision rules which evaluate the profitability of the project or investment. Biezma and San Cristóbal [15] have categorized many various investment criteria methods. Two of these criteria, the net present value (NPV) and the internal rate of return (IRR), are used to evaluate the economics of the MF–PB pyrolysis/activation. The NPV is the best criterion for selecting or rejecting an investment, either industrial or financial [16,17]. The NPV is today's value of current and future cash flows, which are the result of an investment using a predetermined discount rate [17,18]. The NPV is calculated with Eq. (1) [17–20].

$$NPV = \sum_{n=1}^{T} \frac{CF_n}{(1+i)^n} - I_0 \quad (1)$$

With:

- CF_n = cash flows generated in year n;
- I_0 = initial total capital investment (see Table 1, row 19) in year 0;
- T = the life span of the investment;
- i = discount rate.

The cash flow in a given year is the difference between revenues (R) and expenditure (E) after tax (t) generated by the investment. To calculate the cash flow, depreciation (D) also needs to be taken into account because it lowers tax payments [19,20]. According to Kuppens et al. [19] and Thewys and Kuppens [20] cash flows can be calculated using the following equation:

$$CF_n = (1-t) \times (R-E) + t \times D \quad (2)$$

The discount rate of the invested money is set at 9% incorporating the market interest rate and some risk premium [19,21]. Taxes on profits to be paid amount up to 33% in Belgium (t = 0.33). The life span of a reactor is described as 20 years [19,20,22]. Because MF is easy to coke, all the results are based on a rather