J.J.J.M. Goumans, H.A. van der Sloot and Th.G. Aalbers (Editors)

Re-use of colliery spoils in construction materials using Fluidized Bed Combustion

J.J.M Heynen[a], H.N.J.A. Bolk[b], G.J. Senden[c] and P.J. Tummers[d]

[a]IWACO B.V., Consultants for Water and Environment, P.O. Box 525, 5201 AM 's-Hertogenbosch, The Netherlands

[b]Heijmans Milieutechniek B.V., P.O.Box 377, 5240 AJ Rosmalen, The Netherlands

[c]NOVEM, Netherlands Agency for Energy and the Environment, P.O. Box 17, 6130 AA Sittard, The Netherlands

[d]COMAN B.V. Consulting Engineers, P.O. Box 198, 6400 AD Heerlen

Abstract

This article describes a plan to upgrade colliery spoils to construction materials. The plan is based on the idea that the mineral composition of which colliery spoils are made of are similar to the composition of construction materials. However, colliery spoils also contain carbon and sulfides whilst construction materials mostly do not. By thermal treatment, i.e. burning out the carbon and oxidation of sulfides, the mineral part can be upgraded into a form, suitable for production of construction materials. An optimized Fluidized Bed Combustion (FBC) technology in combination with treatment of coarser particles in a shaft-furnace, is regarded the most suitable method for this purpose. An integrated processing facility based on proven technologies will be able to upgrade colliery spoils into (1) basic minerals to be used for the production of construction materials (a high valued re-use), simultaneously recovering the remaining energy-content, i.e. (2) electricity and (3) heat. The facility itself can very likely be a basis or crystallization point for innovative building material industry, thus causing an economic stimulus for the region.

Furthermore, the removal of colliery spoil deposits will prevent groundwater contamination caused by percolate which may contain sulphuric acid resulting from the oxidation of sulfides.

A feasibility check for this project has been carried out for FBC capacities up to 200 MW-fuel, aimed at the removal of an uncovered colliery spoil deposit of about 30 million tonnes in Limburg, the southernmost province of The Netherlands. Production of ceramic limestone as an end-product was found to be a very interesting option.

1. INTRODUCTION

In Limburg, the most southern province of the Netherlands, large scale coal mining activities were carried out until 1975, leaving considerable amounts of colliery spoils in the direct environments of the former collieries. Most of these colliery spoil heaps have been covered and integrated in the landscape, but some 36 million tonnes are still uncovered and not integrated, thus forming an obstacle in the landscape.

More important, the groundwater quality is threatened by these uncovered heaps. Colliery spoils and minestone contain a considerable amount of pyrite (ironsulfides) which can be oxidized to sulphuric acid. Moreover, the oxidation can be accelerated by thiobacilli bacteria, especially at lower pH values. As a result of this biological catalyzation, the oxidation process can be speeded up, at pH-values below 2.5, by 10^5 - 10^6 times [1]. As long as the colliery spoils contain enough lime, the sulphuric acid will be buffered. However, when the lime buffer is exhausted, pH values in the percolate will drop (and boost accelerated biological oxidation) and form a threat for the groundwater quality as a result of acidification of the percolate[2-3].

In order to prevent groundwater pollution in the future, the best solution is to remove the colliery spoil heaps. An appropriate approach to accomplish this aim is to upgrade the colliery spoils by thermal treatment towards basic materials for production of construction materials, thus accomplishing a total, high valued re-use of colliery spoils and recovery of the remaining energy content. The basic ideas of this approach can, in principle, be used in any region where colliery spoil and/or low-grade coal deposits are available.

In this perspective Novem, the Netherlands Agency for Energy and the Environment, and Mauran B.V. investigated a plan for a relatively small upgrading unit (50 MW-fuel) in the municipality of Kerkrade, Limburg.

This moment this approach, based on upgrading by thermal treatment, is being further developed and implemented by Heijmans Milieutechniek B.V., aimed at a location in the municipality of Brunssum, The Netherlands, at a scale of about 150 MW-fuel. A feasibility check is being finalized and more detailed cost calculations and engineering are planned for 1994.

2. PRINCIPLES OF THE COLLIERY SPOIL UPGRADING FACILITY (CSUF).

2.1. General

It is known that by using the proper upgrading technologies, colliery spoils can be used as a basic material for the production of high-valued construction materials [4]. As colliery spoils can still contain a relatively large amount of coal (especially older, low-efficient washed minestone can contain up to 40 % coal), energy recovery is also an interesting feature.

In the Netherlands, the development of a Colliery Spoil Upgrading Facility (CSUF) was initiated[5]. This facility will be an integrated colliery spoil processing plant producing:

- construction materials;
- electricity;
- heat (which can be used in greenhouses and/or municipal heating systems).

The CSUF is based on a combined Fluidized Bed/Shaft Combustion reactor in which the colliery spoils are burnt-out to a sufficient high extent. As a result of the carefully chosen burning conditions the combustion products are suitable for producing high-valued construction materials, whereas the produced electricity and heat are useful by-products.

2.2 Fluidized Bed Combustion

Fluidized Bed Combustion (FBC) is a proven technology especially suitable for the combustion of smaller particles containing a relative low caloric value. Coarser particles > 20 mm can be burnt in a shaft furnace [6]. For completeness the FBC technology will be briefly explained.

Simplified, a FBC-furnace can be described as a cylindrical vessel with a porous bottom plate. The combustion air is blown through this bottom plate with a such velocity that the particles in the furnace will be lifted and be whirled: they get in a so-called "fluidized" condition. When fluidized the solids behave almost like a liquid. Because of this, process conditions like temperature, heat exchange, residential time etc. can be well controlled. Furthermore additives (such as limestone for SO_2 emission reduction) can be added easily. In figure 1 a principle scheme for a FBC furnace is drawn. This is a so-called "slow" or "bubbling" fluidized bed. There are several other types (e.g. the "fast" or recirculating fluidized bed) which will not be further discussed here. Further details on FBC-technology are available in literature [6].

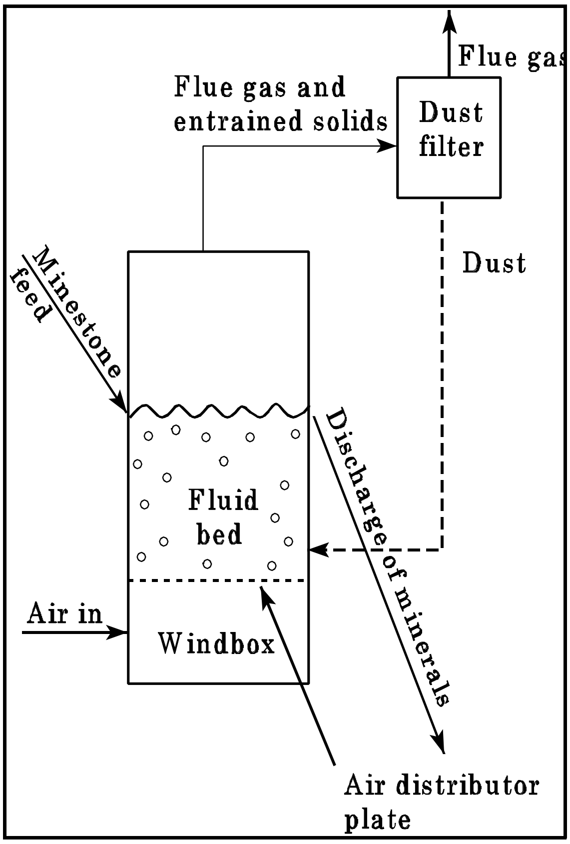

Figure 1. Principle scheme of a Fluidized bed system.

2.3. The Colliery Spoil Upgrading Facility (CSUF)

The CSUF in the Netherlands is planned to be situated in the municipality of Brunssum on the site of a colliery spoil deposit of about 30 million tonnes. These colliery spoils will be fed into a pre-treatment unit (drying, breaking, sieving, grinding) from which the fines (0-6 mm) will be fed into the FBC-unit. The coarser particles (20-45 mm) will be fed into the shaft-furnace. This will result in two types of mineral product: calcinated clay, applicable as a raw material for production of construction materials and broken burnt-out minestone, for direct use as gravel and fillers.

Simultaneously, a minestone washery plant has just been taken into operation on this colliery spoil deposit as well. By use of gravitational separation techniques, this washery plant separates the colliery spoils into:

- washed minestone (usable as filling material);
- low-grade coal;
- washery sludge.

The low-grade coal and the washery sludge can very well be used as an additional feed for the FBC, thus acting as a replacement for a caloric equivalent of unwashed colliery spoils. If done so, the CSUF can be operated complementary to the washery-plant, thus increasing the possibilities for re-use of the colliery spoils.

A flow-sheet the CSUF has been drawn in figure 2.

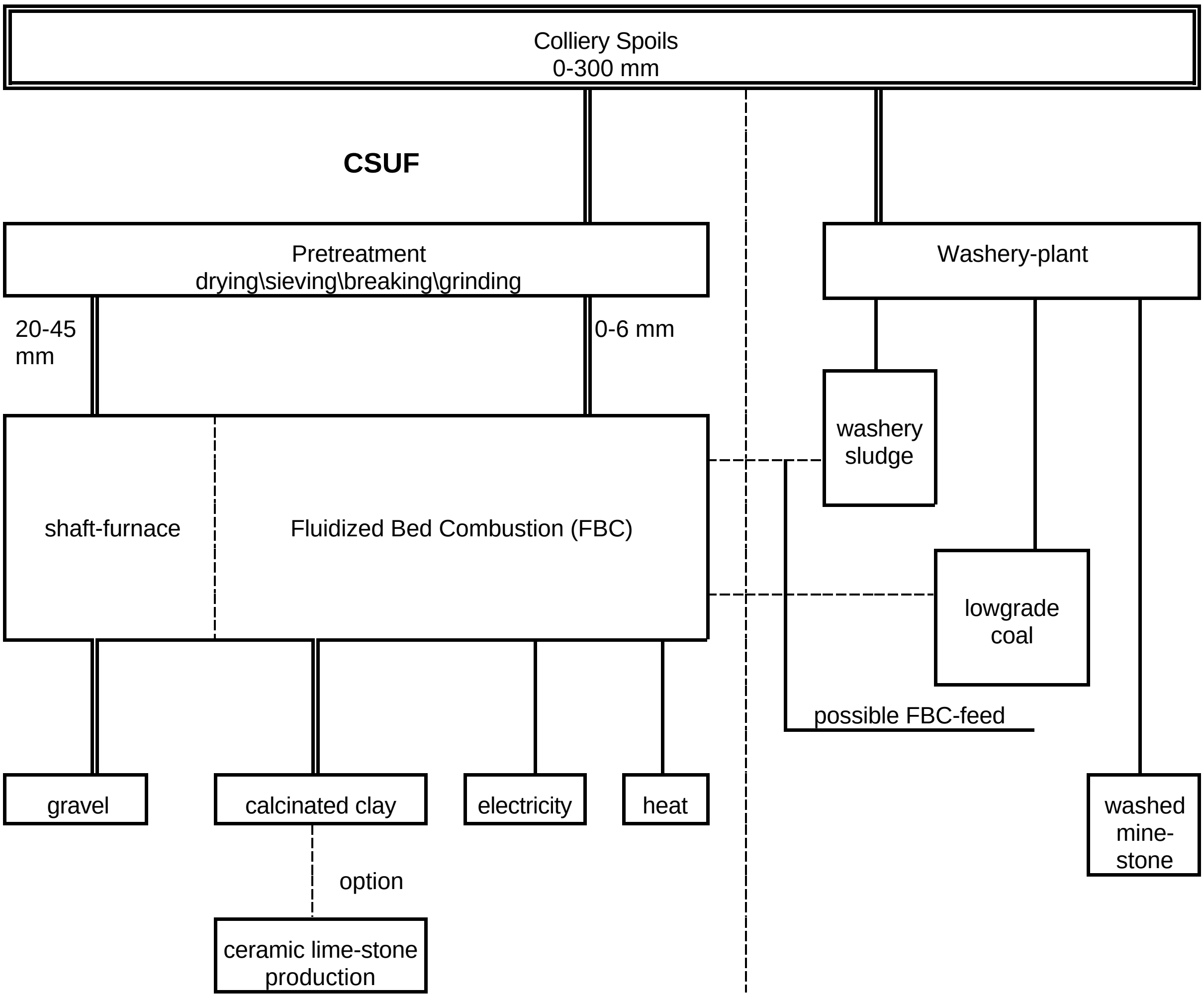

Figure 2. Flow-sheet of the Colliery Spoil Upgrading Facility (CSUF).

At the time of writing, a feasibility check was carried out by Heijmans Milieutechniek B.V., COMAN B.V. and IWACO B.V. under supervision of LIOF (Limburg regional economic development institute) and NOVEM. In the next chapters a brief overview of this feasibility check will be given.

3. FEED OF THE COLLIERY SPOIL UPGRADING FACILITY

In table 1 properties of the feed of the CSUF are given:

Table 1
Approximate composition of feed of the CSUF

	Ash content (%-weight)	Combustion value (MJ/kg)
Untreated colliery spoils	90	4.25
Low-grade coal	40	18
Washery sludge	60	12

These values have been used for the feasibility check, however, they need to be further investigated for verification.

4. PRODUCTS AND APPLICATIONS

The feasibility of the CSUF depends largely on possibilities to actually sell the products that are made. In table 2 some potential products are given.

Table 2
Potential products of the CSUF

Product	Application	Market potential in The Netherlands (tonnes/year)	Estimated revenue (Dfl. per tonne)
broken burnt-out minestone	- bulk-fill material	40,000,000	5 to 6
	- aggregate material for road-bases	8,000,000	7 to 8
	- supplementary materials for asphaltic concrete (warm production)	1,200,000 (gravel) 1,700,000 (split)	13 17 to 26
	- supplementary materials for cementous concrete	9,000,000	13 to 26
calcinated clay	brick industry	25,000 to 50,000	15 to 30
ceramic limestone (via end-production using calcinated clay)	construction industry	500,000*	80 to 100

*: based on 20% of the market volume of ordinary limestone and 75% replacement of primary raw materials by calcinated clay; ceramic limestone is a new product with improved properties.

Remarks on table 2

- the mentioned market volume of 8 million tonnes for aggregate materials for road-bases is a very competitive market, where also many demolition debris products are used;
- in the estimate for the market potential for supplementary materials for cementous concrete (9 million tonnes/year) a maximum use of demolition debris granulates is already assumed.
- in the estimate for the market potential for supplementary materials for asphaltic concrete (3 million tonnes/year) maximum recycling of secondary asphaltic concrete is already taken into account.

Regarding the applications of broken burnt-out minestone, applications like supplementary materials for cementous and/or asphaltic concrete seems to be most interesting because of the higher revenues to be obtained.

With regard to applications for calcinated clay, ceramic limestone is an especially interesting material because it can be directly produced from calcinated clay (as estimated by TNO [7]). For ordinary production, natural clay has to be calcinated whereafter ceramic limestone bricks can be produced by pressing, by use of an autoclave. The FBC, however, produces calcinated clay as a ready-to-use product, not needing further pre-treatment. This overall process of FBC-combustion (in which calcination is integrated) followed by autoclave production of limestone bricks seems to be a very attractive option which is planned for further detailed investigation in 1994.

5. ENVIRONMENTAL ASPECTS OF THE CSUF

The operation of the CSUF will lead to positive effects on the environment:

- a likely long term groundwater pollution source can be eliminated;
- by using upgraded colliery spoils as a basis for the production of construction materials, primary raw material resources (sand, clay, gravel etc.) can be preserved and the amount and/or size of landscape destroying sand/clay/gravel exploitations can be reduced;
- burnt-out minestone can be produced without uncontrolled emissions (e.g. SO_2) to the air;
- large obstacles in the landscape (the colliery spoil heaps) will be removed.

With respect to the environmental effects of the upgrading process itself, the following precautions will be taken:

- reduction of emissions to the air by process-integrated measures; lime supplied in the reactor-feed will cause a significant SO_2-emission reduction (85 to 90%); NO_x-emission reduction can be reached by staged combustion at low temperatures (down to 200 mg/m^3) and dust emissions can be reduced by a dust filter (to 20 mg/m^3). These measures together will assure low emission concentrations.
- minimization of the needed amounts for process and cooling water, since the Dutch government's policy is to restrict further use of groundwater; at the planned location, no surface water is available.

The potential leachability of the CSUF-products has been looked at. Based on available information on the composition and a few cascade leaching tests of locally available colliery spoils, it is deducted that the composition and leachability of the (at low temperatures, 850 °C) burnt-out CSUF-products will be similar to natural clay soils and thus will fully comply with the Dutch Construction Materials Act. This however should be confirmed by tests at the actual CSUF-products.

In the Netherlands an Environmental Impact Assessment (EIA) is compulsory and will be dealt with by the authorities together with the demand for legally required permits. By carefully balancing the complementary environmental effects and costs of extra emission reducing measures, the authorities will have to impose well-considered requirements (described in the permits to be given). Eventually, the EIA should balance the positive and negative environmental effects and compare several variants with each other and with the so-called zero variant: when nothing at all will be done.

At this moment (January 1994) the actual Environmental Impact Assessment has not yet been carried out. The preliminary inventory has been made and discussions with governmental authorities confirmed that no major constrains are to be expected.

6. ECONOMIC ASPECTS OF THE CSUF

6.1 Financial calculations

Based on literature [8-9], expertise and experience with similar projects, preliminary economic calculations for a CSUF have been made based on the location in Brunssum. Financial data were calculated over FBC capacities in the range of 50 to 200 MW fuel. Because most of these figures are regarded as confidential, at present, they will not entirely be described in this paper. However, a brief overview of the assumptions will be given below as well as the resulting Costs of Mineral Product (COMP).

Assumptions have been made on investment costs regarding:

- fuel preparation: excavating, transport, breaking, sieving, drying and grinding;
- FBC-unit;
- shaft-furnace;
- civil works, infrastructure.

Annual costs comprises:

- capital costs: calculated from annuities of investment costs at an interest rate of 8 % and a life-time of 20 years. Also governmental investment premiums were taken into account, ranging from 0 to 50%
- energy costs of fuel-preparation;
- maintenance: 2 to 8% of respective investment costs
- personnel (a total of approx. 80 persons);
- miscellaneous;
- risk and profits.

Further, electricity revenues are calculated assuming:

- 54 MW electric power at 200 MW (FBC) fuel capacity;

- 13.5 MW electric power at 50 MW (FBC) fuel capacity;
- 8000 production hours per year;
- electricity prices (supply to local electricity distributing company) ranging from Dfl 0.06 to 0.12 per kWh; Dfl 0.084/kWh is considered as a basic minimum price to be obtained.
- potential revenues from produced heat are until now not taken into account.

After calculating the annual costs and subtracting the electricity-revenues the Costs of Mineral Product (COMP) remain. Several variants in the above mentioned ranges including variants where colliery spoil is partly replaced by washery sludge and/or washed low grade coal (at zero prices) have been calculated.

In table 3 a brief overview of some variants for a CSUF with a capacity of 150 MW-fuel (40.5 MW electric) is given. In the 150 MW_{fuel} -variant the total amount of CSUF-product will be about 1,4 million tonnes of product/year. In the case of replacement of colliery spoils with washery sludge and washed-out low grade coal (both approx. 80,000 tonnes/year) from the on site present washing facility, the total product amount will be about 700,000 tonnes/year.

Table 3
Overview of Costs of Mineral Product in some selected variants at 150 MW-fuel

Electricity price (Dfl/kWh)	Costs of mineral product (Dfl/tonne, total average)			
	Input: Colliery spoil only (1,564,000 t/a) Output: calcinated clay (915,000 t/a) and burnt-out minestone (493,000 t/a)		Input: Colliery spoils (695,000 t/a) plus washery sludge and low-grade coal (80,000 t/a each) Output: calcinated clay (487,000 t/a) and burnt-out minestone (219,000 t/a)	
	No investment premium	40 % investment premium	No investment premium	40 % investment premium
0.06 to 0.12	30 to 17	22 to 8	45 to 17	30 to 3

Remarks on table 3

Replacement of a caloric equivalent of colliery spoils with washery sludge and low grade coal results in higher COMP at lower electricity prices. Because of the higher caloric content of the washery product less total feed is needed. This results in a lower amount of product over which the total remaining costs are divided. At lower electricity prices this is not sufficiently compensated by lower investment costs in handling equipment.

6.2 Economic feasibility

The facility is feasible if the revenues obtained from products to be sold equal the COMP. If broken burnt-out minestone and calcinated clay are the only products (described in chapter 4) from the CSUF, the revenues of the products can be estimated at about Dfl. 13 to 26/tonne. In this perspective, the option for producing ceramic limestone is very interesting from a financial point of view. The revenues for ceramic limestone can be estimated at Dfl. 80 to 100/tonne. However, costs of the autoclave end-production process still have to be added to the COMP. Because the produced calcinated clay does not need further pre-treatment and the CSUF produces heat, which can be used for the autoclave-process, it is estimated this option could be economic feasible. This should, however, be further investigated. In particular, the market potential of this new product and technical details should be further analyzed. However, by granting an investment premium and/or higher electricity prices, the regional government can encourage an elegant way to remove the remaining colliery spoil deposits. In that way a future threat for groundwater quality will be removed and the economic development of the region will be stimulated.

7. CONCLUSIONS

A Colliery Spoil Upgrading Facility (CSUF) offers a realistic opportunity for a high-valued 100% re-use of colliery spoils and/or low grade coal. Furthermore, in this way an obstacle in the landscape can be removed and future groundwater quality deterioration can now be prevented at probably lower costs than curing will require after acidification of the deposit's percolate. A CSUF is especially interesting for regions with large colliery spoil and/or low grade coal deposits and where a need for building materials is present. Once realized it will probably form a regional stimulus for economic development and innovative construction material industry.

Economic feasibility mostly depends on:

- revenues: dependent of the size and accessibility of the market and kinds of construction materials; revenues are also dependable on possibilities to sell or use the surplus of electricity and heat.
- investment and exploitation costs;
- environmental requirements.

These parameters will undoubtedly differ for each considered region, and should be investigated in an at the target region aimed feasibility study.

In the investigated case of the Brunssum location of the CSUF, the option for production of ceramic limestone appears very interesting: the CSUF-product will be a ready-to-use basic material for this purpose and the in the CSUF recovered energy can find a direct application in this end-production. This idea should be further investigated. Local government supports (investment premiums and/or higher electricity prices) could tip the feasibility balance into a clearly positive scale. Such support will stimulate economic development and employment (directly approximately 80 men, excl. ceramic limestone end-production) and can very well stimulate further development of innovative ceramic industry.

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