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#### PRODUCTION OF OIL AND ACTIVATED CARBON BY CONVERSION OF SEWAGE SLUDGE

**Summary:** The paper presents the results of investigations on sewage sludge conversion in a fluidized bed reactor. Other methods of sewage sludge conversion are presented. Different types of sludge were used: raw sewage sludge, sewage sludge conditioned with lime, anaerobically or aerobically digested sewage sludge, pre-precipitation sludge and chemical sludges. Own results are compared with the results obtained by other investigators. The method of fluidal sludge conversion gives good results, which are better for sludge and with low content of ash. The oil has a high viscosity and at ambient temperature it is paste-like. Heavy metals are mainly trapped in the pyrolysis char, with the single exception of mercury due to its volatility. Digestion and conditioning with lime or fly-ash should be avoided. The quality of the coal remains poor. Unit conceptual flowsheets and research results are presented. In the appendix there are presented some economical characteristics.

#### INTRODUCTION

For centuries the recycling of wastes has attracted the attention of the more innovative minds amongst manhood. In contrast to usual raw materials, however, wastes have a low value, a variable composition and uncertain specifications. Therefore, many ventures in the conversion of waste materials into useful products have stumbled over such factors as:

- too limited an availability (!) of the raw material, waste
- difficult uncertain or unproven technologies
- unsuitable specifications of the products obtained
- erratic markets for the reclaimed products
- poor economics of the conversion method.

Sewage sludge has inspired numerous studies in order to improve its dewatering characteristics, to reduce its putrescibility, foul smells, and volume. It has been applied to land as an organic fertilizer, proposed as a source of proteins, and also, as early as 1937, as a source of oil and chemicals.

This last possibility has again been demonstrated at a laboratory scale by Prof. Bayer University of Tübingen. His work has also been duplicated in several laboratories. Thus, our department has been charged by CEEP to assess the technical and economic feasibility of this process when conducted in a fluidized bed reactor. In this paper the

results are presented of the first months of these efforts.  
CEEP - Centre Europeen d'Etudes des Polyphosphates

## I. PRODUCTION OF OIL BY PYROLYSIS OF SEWAGE SLUDGE

### I.1. Survey

A pyrolysis process can be regarded as a thermal method for separating volatile matter from a charring residue. The volatile matter is composed of permanent gases and condensable vapours, i.e. oil and tars.

The nature and relative quantities of the various products are determined by the nature of the feedstocks, by thermodynamic and by kinetic factors. The most important operational parameters are:

- the physical constitution and chemical composition of the feedstock
- the moisture and ash content, which respectively report to the volatiles and the residue
- the operating temperature and the heating rate (reactor configuration)
- the presence of catalysts.

In order to maximize the production of oil from biomass the following operating conditions are normally considered to be optimal:

- a medium-low temperature of pyrolysis
- a low moisture content (cf. Hitachi's results on municipal refuse)
- an optimized heating rate, reaction pressure and residence time.

### I.2 Sludge pyrolysis studies

Although several studies on sewage sludge pyrolysis are available, only four of them relate specifically to the production of oil.

Bayer University of Tübingen [1,2] using a screw type reactor, found the optimal pyrolysis temperature to be around 300°C. Sludges with an ash content below 35 % gave oil yields of 20 to 30 %. Digested sludge ash content 57 %, on the contrary, gave a much lower oil yield 10.7%

Canadian research work Environment Canada [3,4] was carried out in a batch as well as in a continuous reactor. Sludges with an ash content of about 30 % gave oil yields comparable to Bayer's findings. The optimal temperature was found to be 450°C. The temperature also has a profound effect on the viscosity of the oil.

At the University of Hamburg [5,6] finally, sludge pyrolysis was studied in a fluidized bed reactor. The sludge had an ash content below 30 % and produced two types of oil: high and low boiling. At temperatures below 500°C very little low boiling oil was formed. The yield of high boiling oil attained 40 % around 500°C.

The STONS project sponsored by EPA [7] used a pressurized (up to  $146 \cdot 10^5$  Pa) internally stirred tube reactor with a feed containing 80 % water. The reactor was heated at 275 to 305°C. The oil yields were highly variable and ranged from 7.1 to 36.3 %.

The following conclusions can be drawn:

- The quality of the sludge ash content has a dominant effect on the oil yields.
- The type of reactor significantly affects the process.
- There is no general agreement on the optimal pyrolysis temperature.
- In most of the studies very small scale units 1 kg/h were used. Effects of upscaling are largely unknown.

The low temperature pyrolysis of sludge has several advantages

- sludge is converted to a low volume, sterile residue
- a high value product oil is formed
- the process produces little secondary pollution. Because of the low temperatures, the generation of tars, carcinogenic polyaromatics and dioxins is prevented
- heavy metals are trapped in the solid residue.

A conceptual flowsheet of a sludge drying/pyrolysis plant is shown in Figure 1.

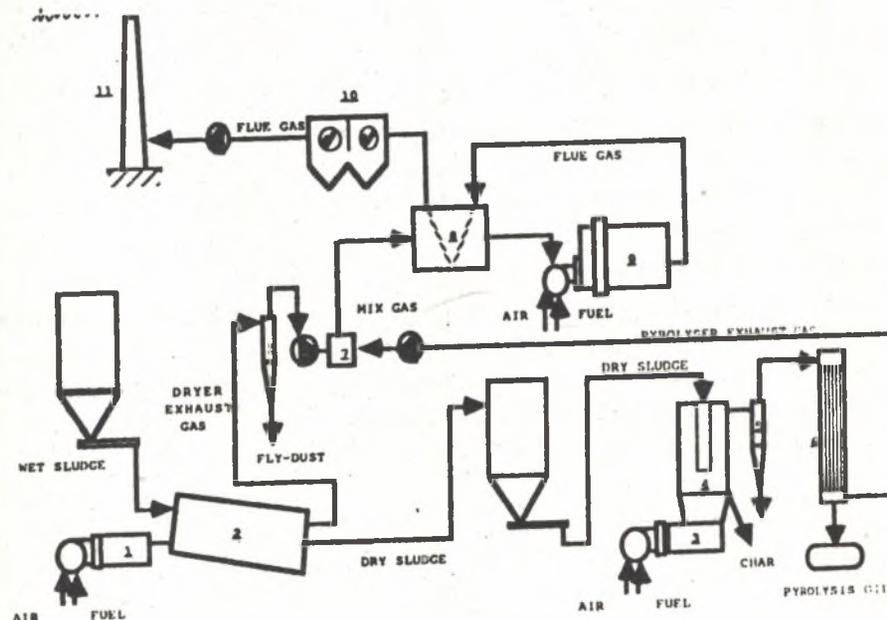


Figure 1. Conceptual flowsheet of the sludge drying/pyrolysis process

Rys. 1. Schemat technologiczny procesu suszenia

The sludge is dried in a rotary kiln drier (2), heated with heavy fuel oil (1). The exhaust gases, which consist of water vapour and combustion gases, are cleaned roughly from entrained dust in a cyclone (5). They are then mixed (7) with the gases from the pyrolysis reactor and fed to an aftercombustor deodorizer (9) or eventually stored for later use. The pyrolysis reactor is heated by hot fluidizing gas produced in a heavy fuel combustion furnace (3). The pyrolysis residue (char) is stored for subsequent activation. The pyrolysis gases are cleaned in a cyclone separator (5) and oil is condensed in a shell and tube heat exchanger. The condenser operates at an outlet temperature of 150°C so that water vapour, pyrolysis gas and combustion gas is then mixed with the dryer gas. The gas mix is heated to a temperature above 800°C in the afterburner (9) with is heated with heavy fuel oil. The unit is equipped with a heat recuperator (8) which preheats the incoming mix gas and reduces the temperature of the flue gas from the afterburner to about 350°C. The flue gas is finally cleaned in an electrostatic precipitator and evacuated through a stack.

Alternative schemes, featuring indirect drying of the sludge, are also possible and should be evaluated on a basis of mass and heat balances and of investment and operating cost.

### 1.3. Pyrolysis experiments

#### 1.3.1. Experimental set-up (figure 2)

The sludge pyrolysis experiments are performed in the fluid-bed unit in Figure 2.

It consists of a 15 cm I.D. fluidized-bed reactor (2) with a capacity of up to 5 kg dried sludge/h.

It is electrically heated and filled with 4 litres of silica sand.

The sludge used for the experiments described here was raw centrifuge sludge treated with polyelectrolytes and dried in a multiple hearth furnace, from in the wastewater treatment plant of Bruges. It has a moisture content of 3 to 10 % and an ash content of 33.0 (Type 3) to 49 % (Type 2B) on a dry basis.

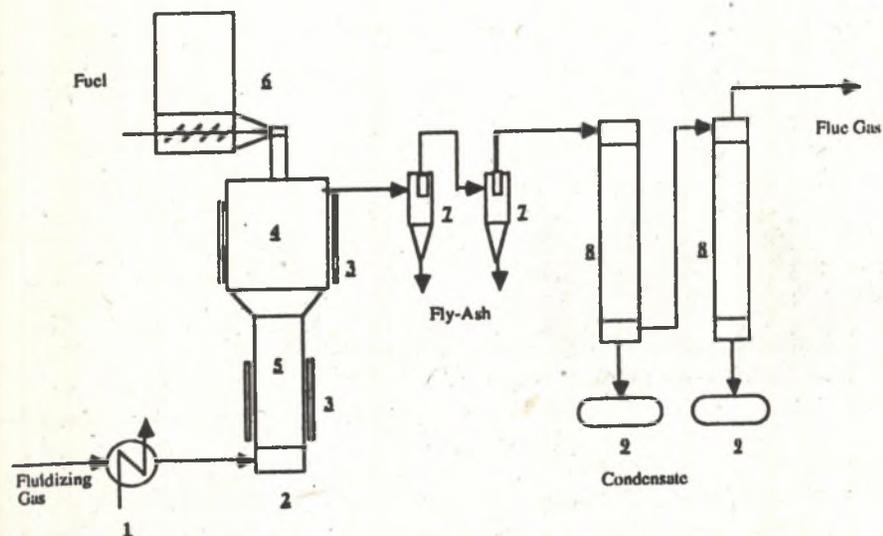


Figure 2. Continuous fluid-bed unit

- 1-Preheater, 2-Reactor, 3-Heating blankets, 4-Freeboard zone, 5-Reactor zone, 6-Sludge feeder, 7-Cyclones, 8-Condensator, 9-Condensate receiver

Rys. 2. Urządzenie fluidalne o działaniu ciągłym

- 1-Ogrzewacz wstępny, 2-Reaktor, 3-Płyty grzejne, 4-Strefa separacyjna, 5-Strefa reaktora, 6-Dozownik szlamu, 7-Cyklony, 8-Skraplacz, 9-Odbieralnik skroplin

#### 1.3.2. Results

##### 1.3.2.1 Effect of pyrolysis temperature

The oil yield is a strong function of pyrolysis temperature (Figure 3). It increases from 16.2 % at 300°C to 29.6 % at 468°C.

During the experiments it was observed that the recovery of the oil from the pyrolysis gas was incomplete, because of the generation of an oil mist. This explains the large amount of "unaccounted for" in the figure, which occurs especially at high temperature.

These results are compared to data of other investigators in Tabela 1. The oil yields are comparable with those of Environment Canada, but somewhat lower than those of Prof. Bayer and the small scale laboratory experiments at the University of Hamburg. It is however expected that when the oil recovery can be improved, we will be able to obtain the same results.

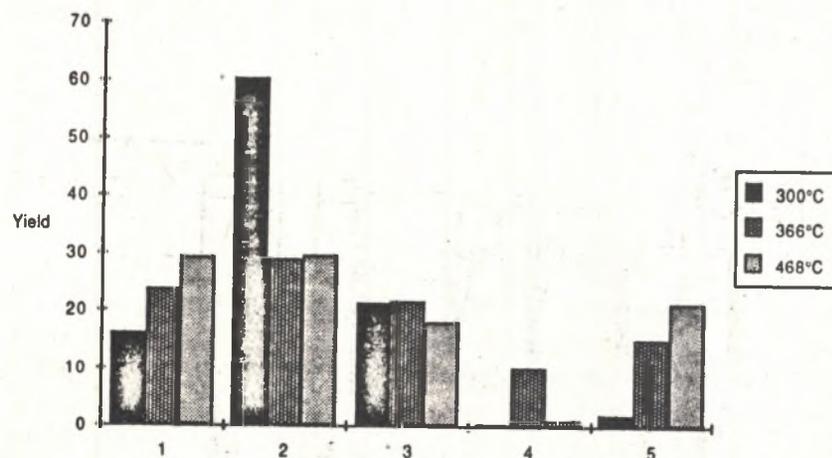


Figure 3. Effect of temperature on product distribution

1-Oil, 2-Char, 3-Gas, 4-Condensate, 5-Unaccounted for

Rys. 3. Wpływ temperatury na skład produktu. 1. Olej, 2. Pozostałość  
3. Gaz, 4. Kondensat, 5. Straty pozostałe.

Comparison of oil yields (kg/kg dry and ash free sludge)

Table 1

Temperature	Bayer	Canada	Uni. Hamburg	This work	
				Meas. 6	Max. 7
300	25 <sup>1</sup> - 40		25.4 <sup>4</sup>	16	18
350		18 <sup>2</sup>		24	39
400			38.2 <sup>4</sup>		
450		32 <sup>2</sup> - 36 <sup>3</sup>		30	41
500			42.1 <sup>4</sup>		
600			42.6 <sup>4</sup> - 24.0 <sup>5</sup>		

1-Dependent on origin of sludge, 2-Small batch unit, 3-Continuous laboratory unit, 4-Laboratory fluid bed, 5-Pilot plant, 6-Incomplete oil recovery, 7-If unaccounted for equals oil

### 1.3.2.2 Oil Properties

The recovered oil is a viscous, paste-like material which does not flow at ambient temperature.

The higher heating value (table 2) ranges from 28.8 to 29.1 MJ/kg. It increases slightly with temperature. Bayer found 38 MJ/kg and Env. Canada 32 to 37 MJ/kg.

Table 2

### Properties of pyrolysis oil

Type of sludge	Temperature of pyrolysis (°C)	Higher heating value (MJ/kg)		Flash point <sup>1</sup> (°C)
		As Rec.	Water free	
2B	300	28.8	33.1	100
3	366	29.0	32.1	80
2B	468	29.1	33.9	59

### 1-Pensky Martens open cup

The heating value is rather low compared to conventional fuel oils. This is probably caused by the presence of:

- water, or
- oxygenated compounds in the oil.

The flash point of the oil is a strong function of pyrolysis temperature. Low temperature oil (300°C) gives a flash point above 100°C. This is a value typical for heavy fuel oil (Table 3). For high pyrolysis temperatures the flash point of the oil becomes comparable to values for light fuel oil.

Table 3

### Properties of pyrolysis oil

Type of Sludge	Temperature of Pyrolysis (°C)	Water Content (%)	Sulphur Content (%)	Nitrogen Content (%)
2B	300	13.0	0.66	5.2
3	366	9.6	0.72	7.7
2B	468	14.2	0.86	5.7

The nitrogen content of the oil is high and reflects the high nitrogen content of the original sludge. When burning the oil, a means of NO<sub>x</sub> reduction should be foreseen.

Heavy metals were measured in the char produced in some selected pyrolysis experiments.

Table 4 gives the heavy metal content of the char together with the % recovery in the char.

In general the main part (above 70 %) of the heavy metals is recovered in the pyrolysis char. Moreover, it is not yet established how much has remained unaccounted for.

The only exception is mercury Hg which, because of its volatility, is mainly evaporating almost completely as is evidenced by its low recovery in the pyrolysis char.

Table 4

Heavy metal content and recovery<sup>x</sup> in pyrolysis char  
mg/kg char (as received)

Destruction with aqua regia and analysis by atomic absorption

	Cu	Cr	Cd	Pb	Zn	Ni	As	Hg
mg/kg	40	1270	57	570	2000	58	3.3	0.15
Recovery <sup>x</sup> in char	55 %	72 %	85 %	76 %	70 %	81 %	75 %	1 %

More systematic experiments and analyses are still required to establish the behaviour of these heavy metals during the pyrolysis process and to assess their possible influence upon the yield and quality of the products.

#### 1.4. Preliminary Economic Evaluation

Based on the flowsheet in figure 1 a preliminary economic evaluation of the drying/pyrolysis process was performed. The base data for these calculations are given in Appendix I. The net disposal cost is the sum of the capital cost (amortization) and operating cost minus the revenues from the pyrolysis oil. It is given in BF/kg of dry sludge (BF/kg DS). It includes drying and pyrolysis but not the mechanical dewatering or the eventual disposal cost of the pyrolysis residue. The calculations are made for a plant capacity of 4000 kg DS/h, a moisture content of 65 %, an ash content of 30 % and a pyrolysis temperature of 400 °C, unless stated otherwise.

The net disposal costs decrease with plant capacity as shown in Table 5. The practical size of a sludge treatment plant depends on the local production rate of sludge.

$$^x \text{ recovery} = \frac{\text{concentration in char} \times \text{char flowrate}}{\text{concentration in sludge} \times \text{sludge flowrate}}$$

Table 5

• Effect of plant capacity on disposal costs (BF/kgDS)

	Capacity (kgDS/h)	2000	4000	6000	8000
Total investment cost 10 <sup>6</sup> Bf	255.9	404.6	531.6	646.6	
Capital cost	1.07	0.84	0.74	0.68	
Operating cost	5.76	5.03	4.68	4.55	
Oil revenue	1.78	1.78	1.78	1.78	
Net operating cost	5.04	4.09	3.63	3.44	

A usually accepted production rate of sludge is 0.08 kg of dry sludge per inhabitant and per day.

If the treatment plant operates 250 days/year Table 6 gives the sludge production as a function of the number of inhabitants served by the sewage water treatment station.

Table 6

Sludge production rate as a function of the number of inhabitants

Inhabitants served	Sludge production kgDS/h
100,000.	487.
200,000.	973.
400,000.	1946.
500,000.	2433.
1,000,000.	4867.

The moisture content of the sludge fed to the dryer varies with the nature of the preliminary mechanical dewatering system. The performance of the dewatering system depends on various factors such as the ratio primary/secondary sludge, the possible use of digestion or of chemical or thermal conditioning.

With a conventional plate and frame filter press, a dry solids content of 35 % based on the original sludge is obtainable. A centrifuge gives a sludge with about 25 % dry solids.

Figure 4 illustrates the effect of initial moisture content of the sludge on the net disposal costs.

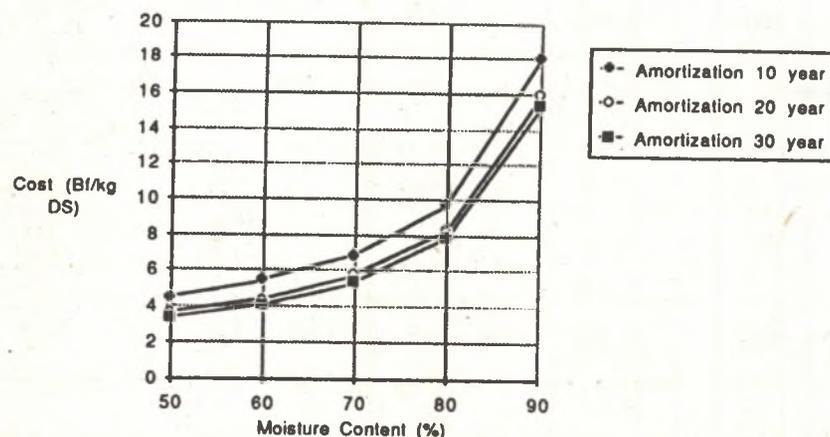


Figure 4. Effect of moisture content on net disposal costs  
Capacity = 2000 kg DS/h

Rys. 4. Wpływ zawartości wilgoci na koszt przeróbki ścieków.  
wydajność 2000 kg os.ferm./h

With a plate and frame filter press 35 % DS a net disposal cost of 5.04 Bf/kgDS for a capacity of 2000 kgDS/h and 4.09 Bf/kgDS for a capacity of 4000 kgDS/h is calculated. With a centrifuge dry solids content of about 25 % a net disposal cost of 6.82 Bf/kgDS 2000 kgDS/h to 5.80 Bf/kgDS is obtained. This increase in disposal cost is, however, partially compensated by the lower cost of the dewatering system. Moisture contents of more than 80 % should be avoided since they result in unacceptable disposal costs.

Calculations on the effect of ash content of the sludge show that conditioning with lime, fly-ash or other inorganic coagulants and filter aids should be avoided in case sludge pyrolysis is to be applied. Where necessary, organic coagulants polyelectrolytes should be employed to assist in the dewatering.

An increased ash content not only increases the disposal cost per unit of dry sludge but also increases the total amount of sludge to be disposed of. It will also negatively affect the quality of the activated carbon produced from the pyrolysis residue.

Phosphorus preprecipitation with ferrous sulphate or aluminium sulphate will increase the ash content by 1 to 5 % [2], which will not significantly affect the economics of the process.

## II. PRODUCTION OF ACTIVATED CARBON

### II.1. Survey

Activated carbon is a porous material, with an extremely high specific surface typically 1000 - 1500 m<sup>2</sup>/g of carbon and strong adsorptive and decolouring properties. It is available under a granular and a powdered form, in reusable and one-way qualities.

The adsorptive power of activated carbon is determined by its specific surface, its texture and the nature of its superficial bonds. The rate of adsorption also depends on the ease of access of molecules to the adsorptive sites and hence on the dimension and shape of the molecules and those of the macro- and micropores.

Commercial brands of activated carbon may be produced either from fossil fuels, such as anthracite, lignite or peat, or from biomass, especially coconut shells, other nutshells and beechwood have a suitable structure for generating a high quality activated carbon.

The production of activated carbon by the thermal method proceeds in two stages :

- pyrolysis at moderate temperatures, typically of 400 - 600 °C
- thermal or chemical activation of the pyrolysis char.

Thermal activation typically takes place at 800 - 1100 °C in the presence of steam, carbon dioxide and possibly some oxygen. It is in fact a mild gasification, conducted with the aim of creating a maximum of porous structure with a minimum of carbon loss. More rarely activation takes place at lower temperature using air only. The char can also be activated chemically, in which case the gaseous activating agents, i.e. O<sub>2</sub>, H<sub>2</sub>O, and CO<sub>2</sub> are partially replaced by acids, such as phosphoric acid, or salts, such as sodium or potassium sulphate. These additives assist in the activation even when added after carbonization.

Activated carbon has three major fields of application :

- the purification of gaseous streams, e.g. the recovery of solvent vapours from process air, the elimination of contaminants sulphur compounds, mercury from industrial gases
- the removal of trace contaminants from drinking water, process water and waste water
- the decolouring of various solutions, sugars and other foodstuffs.

Activated carbon is produced in different qualities.

Usually, the granular carbon has better qualities than powdered carbon. Therefore it is almost always regenerated while powdered carbon is rejected after use.

Table 7 gives the range of the most important index values for usual qualities of powdered and activated carbons.

Commercial activated carbons. Range of indexes

Table 7

	Powdered carbons	Granulated carbons
Iodine index (mg/g) I.I.	500-600	1000
Methylene blue index (g/100 g) M.B.I.	10-15	20-26
Phenol index (%)	30-35	35

The I.I. gives an indication of the amount of pores larger than 10 Å. It is also proportional to the amount of internal surface area (BET-area). The I.I. is defined as the amount of iodine, in mg, adsorbed by one gram of active carbon in equilibrium with a final concentration of 0.02 molar.

The M.B.I. gives an indication of the amount of meso- and maxi-micropores (pores larger than 15 Å). It is correlated to the quality of the coal for aqueous-phase adsorption. The M.B.I. is expressed in g MB/100 g carbon. This test reveals the adsorptive properties of a carbon towards larger molecules.

The phenol index is a standard method used by waterworks. It is a significant parameter for the applicability of the carbon for the preparation of potable water e.g. removal of micropollutants and odorous compounds.

## II.2. Activation Experiments

### II.2.1. Introduction

The char produced in the activation experiments can be converted into activated carbon by reacting it with steam at elevated temperatures.

A deeper activation may be expected to result in a higher activity, but also in a lower yield of the carbon.

The first set of activation experiments described in this report is intended to determine the effect of burnoff or reaction time on the activated carbon yield and quality and to obtain a first estimate of product value and possible revenues from the process.

### II.2.2. Experimental

The activation is carried out in a batch fluidized bed reactor (Figure 5).

The fluidizing gas is a mixture of steam and nitrogen.

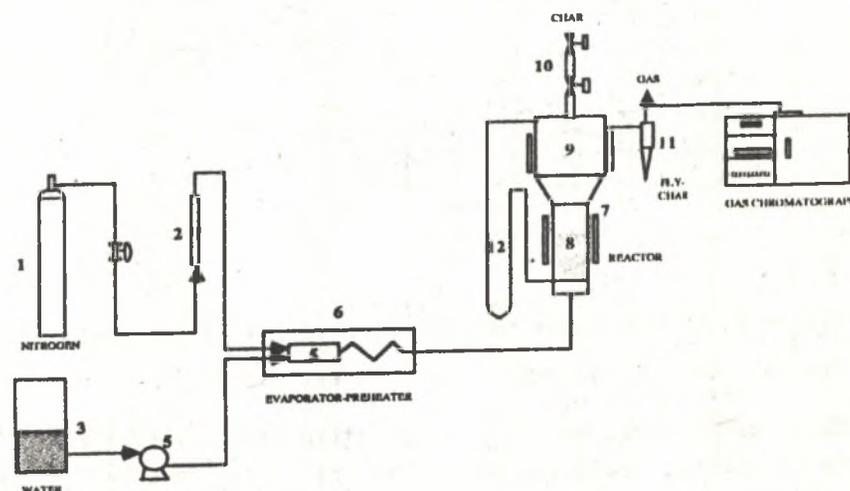


Figure 5. Fluidized bed activation unit

- |                 |                      |
|-----------------|----------------------|
| 1. Gas bottle   | 7. Heating blanket   |
| 2. Rotameter    | 8. Sand bed          |
| 3. Water supply | 9. Freeboard zone    |
| 4. Pump         | 10. Sludge           |
| 5. Evaporator   | 11. Cyclone          |
| 6. Furnace      | 12. U tube manometer |

Rys. 5. Urządzenie fluidalne do aktywacji

- 1- Butla gazowa, 2- Rotometr, 3- Zasilanie wodą, 4- Pompa, 5- Parownik, 6- Piec, 7- Płyta grzejna 8- Warstwa z piasku, 9- Strefa separacyjna, 10- Śluzka, 11- Cyklon, 12- U-rurka

### II.2.3. Results

Some results, of one series of experiments are given in Table 8. The activation time was varied from 0 to 30 minutes. This corresponds to conversions of 0 to 70 %.

During activation, the ash content of the char increases continuously from an initial 72 % at zero conversion to a final 89 % at 70 % conversion.

The quality of the carbon was determined by its methylene blue (M.B.I.) and iodine indexes (I.I.) (Table 8 and Figure 6).

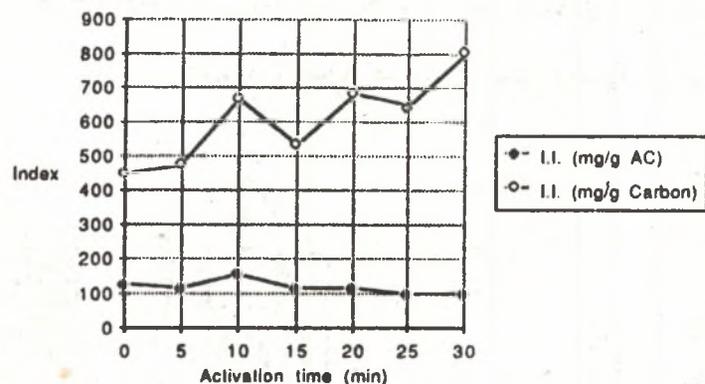


Figure 6. Iodine index as a function of activation time

Rys. 6. Wskaźnik jodowy w funkcji czasu aktywacji

The iodine indexes based on total active carbon weight are rather low. If the indexes are based on the unit weight of ash free carbon, the activities of the coal are comparable to those from other investigators (Table 9).

The methylene blue indexes based on total activated carbon weight are fairly good up to 12.8 g/100g. They approach the values for commercial powdered carbons 10 to 15 g/100g.

When the methylene blue index is based on unit weight of carbon (ash free), they become extremely high. The reason is probably that methylene blue is also adsorbed by or reacts with ash components. It follows that the finely divided ash, available in the carbon, may well have adsorptive properties in its own right.

An experiment was included (B7) in which the carbon was heated slowly to the final activation temperature of 800 °C. The results of this experiment are not conclusive. The M.B.I. increases with slow heating but the I.I. is lower.

If the iodine index is based on total weight of activated carbon (including ash), the iodine index apparently does not change with conversion (or activation time).

If the iodine index is expressed on unit weight of ash free carbon, a net increase of activity with time is noticed (Table 8 and Figure 6).

Table 8  
Characteristics of activated carbons as a function of activation time (second series)

Exp.Nr.	t min.	Conversion %	MBI	I.I	Ash content wt %	
			g/100g A.C. <sup>x</sup>	mg/g A.C. <sup>x</sup>		mg/g C <sup>xx</sup>
B7 <sup>xxx</sup>	0	-	11.4	107	334	68
B0	0	0	2.6	126	450	72
B1	5	19.0	6.1	114	475	76
B2	10	29.5	7.4	153	665	77
B3	15	33.8	12.8	112	533	79
B4	20	49.9	10.5	116	682	83
B5	25	60.4	12.2	97	647	85
B6	30	68.8	10.4	97	808	88

<sup>x</sup> A.C. = activated carbon (including ash)

<sup>xx</sup> C = carbon (ash free)

<sup>xxx</sup> = experiment with slow heating

Table 9

Comparison of iodine index with J.P.L. study [8]

	Iodine index mg/g ash free carbon
This study	450 - 1140
J.P.L. study	350 - 1000

#### II.2.4. Discussion - Conclusions

The activated carbon produced in the process has a low quality if the indexes are based on total carbon weight (iodine index between 100 and 150 mg/gAC). If the iodine index (which is a measure of internal surface area) is based on ash free material, a good quality is obtained (up to 1000 mg/gC). These results agree with previous investigations.

In order to apply the process in practice two possibilities exist

1. Use an additional commercial activated carbon: this process is similar to the J.P.L./ACTS system. In this case, the activated carbon produced from the sludge merely acts as a compensation for the carbon lost

during regeneration of the spent carbon.

## 2. Upgrade the carbon by extraction of the inorganics

Extraction of ash e.g. by an acid wash will produce a material with a higher activity. Of course, the cost of the additional treatment must be compensated by the increased value of the carbon.

At present insufficient data are available on the actual possibilities of both options.

### III. GENERAL CONCLUSIONS

The liquefaction of sewage sludge has been carried out in a fluidized bed reactor. Different types of sludge are used : raw sewage sludge, sewage sludge conditioned with lime, anaerobically or aerobically digested sewage sludge, preprecipitation sludge and chemical sludge.

The pyrolysis experiments allow to conclude that :

- the oil yields based on dry and ash free sludge are comparable to the results of other investigators,
- the oil yield increases with temperature in the range of 300 to 470 °C.
- the composition of the oil conforms to Bayer's findings.
- the oil has a high viscosity, at ambient temperature it is paste-like.
- heavy metals are mainly trapped in the pyrolysis char, with the single exception of mercury.
- in order to maximize the oil yield, the ash content of the sludge should be kept low, digestion and conditioning with lime or fly-ash should be avoided.

Activation experiments were performed in a fluid bed reactor. The char was activated with steam at 800 °C.

The quality of the produced carbon per unit of ash free carbon increased with activation time : the iodine index varied from 350 to 1000 mg/g of ash free carbon..

Still, because of the high ash content of the carbon, the quality of the coal remains poor iodine index 100 to 150 mg/g of total carbon so that only a local usage can be contemplated.

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Recenzent

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### Appendix : Cost data

#### 1. TOTAL FIXED CAPITAL COSTS

The total investment cost is calculated from the major equipment cost using the Factored Estimate Method with a Lang factor of 3.78. Calculation of depreciation is based on a life time of 20 years.

#### 2. OPERATING COSTS

##### 2.1. Fuel cost

The fuel consumption is calculated from the mass and energy balances. A unit price of 10 Bf/liter is used (specific gravity = 0.86).

## 2.2. Power

An average power consumption of 0.4 kWh/kg DS is assumed. The unit price of electricity is 2 Bf/kWh.

## 2.3. Labour

The plant operates in three shifts. The availability is 250 days/year. The amount of labour depends on the total investment cost of the plant:

$$\text{number of people per shift} = 3 + \text{INT}(I_{\text{tot}}/2 \cdot 10^6 \text{ Bf})$$

For a capacity of 4000 kg DS/h this gives a total of 6 men/shift.

A unit cost of  $10^6$ /year is assumed.

## 2.4. Maintenance, Taxes, Insurance

The total of these costs is a fixed fraction (5%) of the total investment costs.

## 2.5. Oil Revenue

The value of the oil is directly proportional to its fuel equivalent. This value was decreased by 8% to allow for possible refining operations (e.g. sulphur and nitrogen removal).

## 3. REACTION PRODUCTS

The reaction products are:

- oil	yield = $T_{\text{pyr}}/10 - 5$	if $T_{\text{pyr}}$	400°C
	yield = 35 %	if $T_{\text{pyr}}$	400°C
	$T_{\text{pyr}}$ = pyrolysis temperature	(°C)	
	yield = kg oil/kg dry-ash free sludge	(%)	

- gas	yield = 20 %		
	Composition (wt %)		
	CO <sub>2</sub>	95 %	
	CH <sub>4</sub>	1 %	
	CO	3 %	
	H <sub>2</sub>	1 %	

- water yield = 5 %

- char balance

Heat of pyrolysis = 500 kJ/kg organic matter converted

Heating value of oil = 29000 kJ/kg

## KONWERSJA SZLAMÓW DO PRODUKCJI OLEJU NAPĘDOWEGO I WĘGLA AKTYWNEGO

### Streszczenie

Artykuł przedstawia wyniki badań nad konwersją osadów ściekowych w aparatach fluidalnych w celu uzyskania oleju i węgla aktywnego. Przedstawiono krótki przegląd technologii przeróbki osadów ściekowych po klasowaniu i porównano z wynikami uzyskanymi w instalacjach fluidalnych. Stosowano różne rodzaje osadów ściekowych: surowe, kondycjonowane z wapniem, przefermentowane w obecności powietrza i bez dostępu powietrza, osad przedwydzielniczy oraz chemiczny. Porównanie wyników badań świadczy o możliwości wykorzystania osadów do produkcji oleju i węgla aktywnego, przy czym lepsze wyniki uzyskuje się przy stosowaniu osadów nie zawierających popiołu. Olej ma dużą lepkość, w temperaturze otoczenia jest substancją pastowatą, metale ciężkie w większości (z wyjątkiem rtęci, a to z uwagi na jej lotność) pozostają w osadzie popielolitycznym. Z uwagi na zawartość pyłów w osadzie, należy unikać prowadzenia fermentacji osadu w obecności wapienia. Jakość węgla aktywnego określono jako niską. Przedstawiono schematy instalacji badawczych i podano zestawienie wyników badań. Załącznik do artykułu zawiera charakterystykę ekonomiczną procesu.

## КОНВЕРСИЯ ШЛАМОВ ДЛЯ ПРОИЗВОДСТВА ГАЗОВОГО МАСЛА И АКТИВНОГО УГЛЯ

### Резюме

В статье рассматриваются результаты исследований сточных осадков во флюидальных аппаратах с целью получения масла и активированного угля. Приведён краткий обзор технологии переработки сточных отходов после осветления и сравнён с результатами, получаемыми на флюидальных установках. Применялись разные виды сточных отходов: сырые, кондиционированные с известняком, ферментируемые на воздухе и без воздуха. Следует избегать ферментации осадков в присутствии известняка в виду содержания пыли в осадках. Качество активного угля низкое.