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AUTOMATIC SORTING AND CONTROL IN SOLID FUEL PROCESSING: OPPORTUNITIES IN EUROPEAN PERSPECTIVE

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(8 figures and 2 tables)

ABSTRACT. On-line automatic inspection of solid fuel has been known for several decades and continues to develop. Automatic sorting of solids is currently applied in upgrading a variety of resources and wastes: ore, recycle glass, scrap metals, plastics, and foods. Inspection and sorting use the same technology for both coal and refuse derived fuel. Sensors inspect a flow of solids and a particular fraction is successively manipulated, e.g. by reject of a particular load or by automatic removal of contaminants by means of controlled air jets. Applications are:

- On-line ash and particle size control of coal
- Automatic dry cleaning
- Automatic control and reduction of contaminants

Transmission theory and experiments carried out at Delft University illustrate the potential of dual-energy X-ray transmission imaging for the on-line determination of ash content and size distribution of bituminous coal. Based on this technology and combined with existing methods, sensor controlled sorting systems may in future be applied as cost-effective methods for control and improvement of the quality of solid fuel.

Keywords: Coal, preparation, processing, separation, density, automatic, sorting, X-ray.

1. Introduction

In Europe coal is an important primary non-renewable energy source and raw material. In 2002 the total bituminous coal consumption in the European Union amounted approximately 250 Mt, of which 77 Mt (this is 31%) was produced within the current EU (European Commision, 2002). Coal mining in Western Europe is faced with an on-going decreasing production. Refuse derived fuel (RDF) is an alternative renewable domestic energy resource and in that sense it partially compensates a decreasing production of coal. Utilisation of waste for energy is applied in waste incinerators, RDF fired units, co-incineration in coal-fired power plants, cement kilns, and in metallurgy. In European perspective it would be particularly useful to focus on the optimisation of solid fuel use on system level. This would include optimisation of coal production, extension and optimisation of RDF production, with for both the objective of maximum efficiency at a minimum environmental impact.

Co-incineration of biomass and RDF together with coal may replace a part of the traditional coal market. Biomass and RDF potentially provide a secure supply at competitive prices as an alternative domestic energy carrier. In addition, from a waste management perspective, thermal utilisation by means of co-incineration of RDF in highly efficient power generators is considered, by many, as an economically as well as environmentally attractive option at low technological risks (Schoën et. al.; ESSENT, 2001). An example is the co-incineration of the organic component of mixed municipal solid waste with coal in a conventional power plant, as currently practised by Essent in the Netherlands. This material amounts approximately 115,000 t/y and contributes to 3% of the 600 MWe power. This material is separated from waste by means of screening, and successively prepared by means of biological drying and dry density separation at the waste preparation plant in Wijster, the Netherlands.

However, a stable supply of high quality RDF is yet limited. The quality of the source, waste, is variable and strict quality targets are difficult to maintain by the emerging preparation technology for RDF. Apart from consistent legislation strict feed selection, efficient upgrading, and reliable and regular quality control are essential preconditions for a further replacement of coal by RDF. Only after this has been achieved can RDF be blended to a feed of optimal physical properties and composition. The problems in maintaining and controlling RDF quality are mainly caused by the high variability in material origin and distribution in particle size, shape and composition, that is in general more variable than that of coal. For these materials a new generation of controlling and upgrading systems must be developed. Current progress at Delft University of Technology in the development of on-line control and automatic sorting based on sensors are reported and potential effect and possible future opportunities of this technology on optimising solid fuel use are discussed.

2. On-line systems for sorting and control

On-line quality control is applied in coal preparation for measuring control properties such as ash and moisture content and the presence of foreign material. Despite this, current technology does not permit resuming from routine sampling and laboratory control, parallel to on-line monitoring. The latter has primarily a control function in processing, blending and loading. Automatic sorters that separate particles into different fractions by means of controlled actuators are not or hardly applied to coal. The major disadvantage is the fundamental inability to effectively sort <10 mm coal, where for >10 mm conventional water-aided concentration is usually satisfactory at relatively low costs.

In the 1950's and 60's, the processing of coal was often performed in a dry manner. Today, the majority of the coal processing proceeds along water-aided techniques. About 1 % of the coal is still processed in a dry manner. With the increasing scarcity of process water, increasing attention for environmental aspects, and the increasing burden of processing residual slurries, the call for dry processing is becoming stronger. In improving dry separation circuits automatic sorting may be effective in additional cleaning of pre-concentrated flows, a role for which they are already successfully applied in recycling technology. In this way dry separators extended with automatic sorters may obtain a comparable separation quality as conventional wet separation.

Where CPP (Coal Preparation Plant) technology relies on more than a century of experience, the preparation of RDF, only in the last decade started to develop on a larger industrial scale. In the waste processing and recycling market, in some cases wider margins (metal value, waste treatment tariffs), larger variability of feed, and initially modest capacity demands led to introduction of advanced automatic sorting systems, that effected a considerable extension of the technical possibilities of a mechanical preparation process. Ongoing technical development, and in particular the increased availability of low priced sensors and computing power, increased unit capacity and lower costs per tonne. For instance, for gravel operating costs of colour sorting amounts 1.0 to 1.5 €/t at unit capacities ranging from 5-20 t/h for 4- 60 mm and from 15-100 t/h for 10-200 mm sized material (Wotruba et al., 2000). For coal with a lower bulk density the costs of the same technology would be 2.0 to 3.0 €/t. Current systems are able to sort several hundreds to several thousands of particles per second, depending on the size distribution of the feed (Fig. 1).

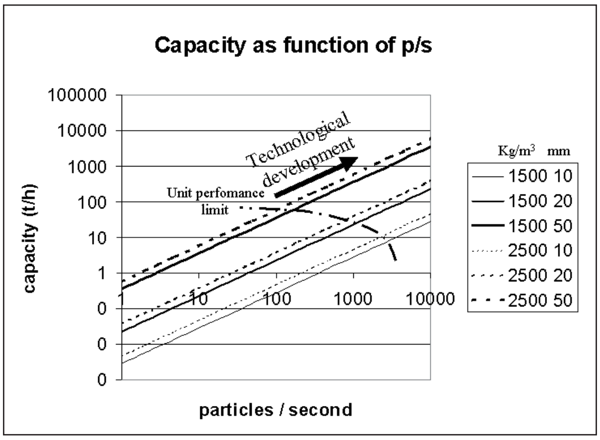

Figure 1. The capacity of automatic sorting systems. The current approximate limit in unit performance regarding capacity as function of density and size is given by the curved line.

With continuing developments, automatic inspection and sorting may in future become an important unit operation in CPPs. Systematic on-line sampling and control in RDF preparation may become more advanced, parallel to similar developments already in use at modern CPPs. The prospect and opportunities of automatic sorting and control in solid fuel processing will be discussed by first covering available technology (Section 2), by discussing system objectives (Section 3) and successively by describing some developments at Delft University of Technology in automatic sorting and control techniques (Section 4) and their possible applications (Section 5).

2.1. On-line ash control systems for coal

On-line quality control monitors continuously inspect a representative amount of material. This amount depends on density and particle size distribution of the material and the inspected component, and on the (expected) content of this component. Gy's method is frequently applied to establish the amount to be inspected at a given reliability of the monitored values (Gy, 1982). Automatic and statistically engineered samplers are a pre-condition to achieve the desired reliability. Not all on-line techniques require sampling of the main stream. They inspect the total stream, in some cases up to several thousands t/h. Dual-energy γ-ray transmission, or natural γ-ray for the ash content and microwave or capacitance measurements for the moisture content can be monitored on-line on loaded conveyor belts of considerable capacity (Kirchner et al., 1994). Despite the availability of a number of monitoring devices, with present technology some crucial variables are difficult or impossible to measure on a continuous basis, in particular size distribution, mineral matter content, and specific density distribution. Because of this and because of unavoidable feed fluctuations in terms of size and property distributions, mass flow control to ensure process optimisation is still difficult to achieve (Couch, 1996).

Compared to coal, the preparation of secondary fuels still is a young and relatively small-scale industry, where mainly routine sampling and subsequent laboratory analysis establish quality control. Calorific value, ash, metal and especially chlorine content are important variables for monitoring.

2.2. Sensor-controlled automatic sorting

Automatic particle sorting is the separation of a bulk flow of particles based on detected particle properties (Jong et al., 2000). Controlled air jets remove the undesired particles (Fig. 2). The majority of sensor controlled sorting systems is equipped with a horizontal array of sensor elements. The following sensors are potentially useful for coal and RDF preparation:

- *Optical camera;* reflection rate of visible light (Mogensen 1997, Wotruba et al. 2000).
- *Electro-magnetic sensor;* conductivity, metal detection, eddy current (S+S; MSS, 1985; Mesina et al., 2002).
- *X-ray transmission; average atomic number, thickness* (Kirchner et al., 1994; Dalmijn, 2002).

Application of a camera is only useful when a significant difference in reflection or colour occurs. In addition shape and texture assist in classifying the material (Jongeneel, 1997; Kattentidt, 2000; Kattentidt et al., 2003). Which sensor or combination of sensors is optimal depends on the composition and desired grades of the fractions to be sorted. Speed and performance of the data-processing system determine the maximum capacity of the sorter. Many present-day sorters rely on real-time data processing, for instance systems that detect particles during free fall (Fig 2, B). The system triggers a valve when a sensor element reaches a pre-adjusted critical value. A minimum number of triggered sensor elements neighbouring in the space – time plane can be set. The sensitivity for particle size of the system can be adjusted.

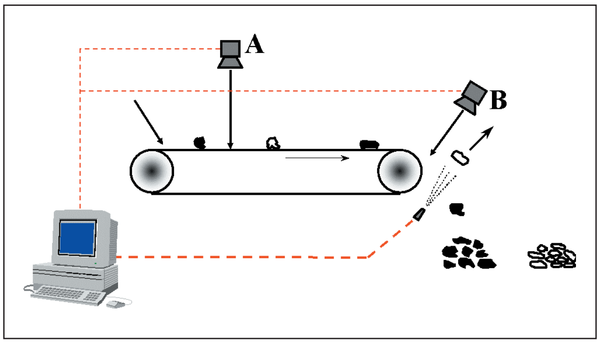

Figure 2. Principle of a pneumatic particle sorter, with two possible locations for a sensor (A: on the conveyor, B: inspection of free falling particles). The effective width of the system usually varies between 1 and 1.5 m.

3. Control and sorting objectives

Economic value and environmental performance of coal is for the main part determined by a set of key properties. Two types of characteristics are defined: general characteristics that determine fuel quality, and characteristics that determine the efficiency of the preparation process, e.g. a size distribution that results from crusher performance. General characteristics are usually determined by means of proximate, ultimate and ash analysis:

Proximate analysis

- Moisture (a: as present, b: after 24h in water)
- Ash
- Volatile Matter (VM)
- Fixed carbon (by difference)
- Optionally:
- Heating value (when VM> 30%)
- Ash fusion temperature (relevant for furnace design and operation)

With this the coal rank (or type) can be determined, e.g. anthracite, bituminous, lignite etc.

Ultimate analysis

- Percentage C, H, S, N, Cl and O

Ash analysis (pure ash components).

- Percentage of: SiO_2, Al_2O_3, Fe_2O_3, CaO, MgO, TiO_2, Na_2O, K_2O, SO_3, P_2O_5, + Remainder

According to current practice at many CPPs only some of these analyses are carried out on routine basis (at fixed time intervals): e.g. density distribution by means of float-sink analysis, and total moisture and ash content. Apart from the general characteristics, insight in operational parameters is relevant for optimised control of the different units of a CPP and for control of the handling ability of the product (e.g. flow behaviour of the coal, dust generation):

- Particle size distribution
- Density distribution
- Particle shape distribution
- Mechanical strength, abrasiveness, dust generation etc.
- Moisture control

In principle, sensor based systems enable continuous instead of periodical monitoring, avoiding time delay, work hours, and reducing or eliminating sampling errors (Section 2.1). Automatic process control becomes possible only when reliability of the automatic systems approach routine laboratory analysis. In addition, continuous recording of the process data is especially relevant for tracing back eventual quality problems.

Apart from on-line quality control, sensor controlled systems can be applied for meeting the following sorting objectives for both coal and RDF (Section 2.2):

- Reduction of ash content
- Reduction of other contaminants, e.g. sulphur, chlorine

- Removal of disturbing objects (waste: metal, wood, plastics etc.). This can be relevant in order to prevent damage of crushers or other downstream units.

4. Dual energy X-ray transmission for on-line size, density and composition control

X-ray transmission appears particularly effective for monitoring the ash content of coal. Dual energy γ-ray transmission is applied in ash-content monitoring by transmission of streaming solid material. Its potential lies in its ability to monitor streams varying in size and composition distribution. The detection is thickness independent and the measurement reflects all transmitted volume. For instance, ^{241}Am (59.5 keV) for the low, and ^{137}Cs (661.7 keV) for the high energy level are applied as sources (Kirchner et al. 1994). In other applications (liquid cooled) electrical tubes are used, which avoids use of nuclear material.

The detection is explained by considering basic X-ray transmission theory. The Lambert law governs the absorption at a specific wavelength λ:

$$I_{\text{det}} = I_0 e^{-\mu(\lambda)\rho d} \qquad (1)$$

I_{det} is the detected intensity, I_0 the intensity of the undisturbed beam, μ(λ) the mass absorption coefficient, ρ the solid density, and d the thickness of the irradiated sample. The variations in d that are observed in particles prevent accurate identification with a monochromatic X-ray transmission system. μ(λ) of the elements can be determined from data available in the literature (Bertin, 1978). For a given λ, the effective μ of material of mixed elemental composition is only a function of the elemental composition. For a sample with the elements i = 1 to n, μ_{eff} is given by:

$$\mu_{eff} = \sum_{i=1}^{n} f_i \mu_i \qquad (2)$$

f_i is the mass fraction of element i, and μ_i the according μ. μ_{eff} is independent from the phase or state of the material.

4.1. Detection of materials

Consider the dimensionless detected intensities $I_1=I_{det1}/I_{01}$ and $I_2=I_{det2}/I_{02}$ at two different wavelengths. Lambert's law gives the relationship between I_1 and I_2:

$$\frac{I_1}{I_2} = e^{-\rho d \Delta\mu} = (e^{-\rho\Delta\mu})^d = C_m{}^d \qquad (3)$$

C_m represents a constant that only depends on the chosen wavelengths and the material properties. If C_m of two materials is different, they can be distinguished from each other. In a dual energy X-ray measurement the relative magnitude of I_1 relative to I_2 determines C_m, and hence the material, while the absolute value of I_1 (or equivalently I_2) determines d.

Table 1 and 2 demonstrate the detection of various levels of iron and ash contamination for coal, and chlorine contamination in secondary fuel by giving calculated C_m values for a two-source system of 124 kV and 62 kV. As appears from the calculations, differences in chlorine and ash levels can be recognised. Determination of the achievable accuracy is an important subject of current experimental investigations. The accuracy depends on machine performance, sample thickness and especially

	90% Carbon	Carbon 1%FeS	Carbon 3%FeS	Carbon-Shale	Shale	SiO_2
g/cm^3	1.3	1.3	1.3	1.85	2.4	2.4
H	10.00%	10.00%	9.00%	5.00%	0.00%	
C	90.00%	88.00%	85.00%	45.00%	0.00%	
O				24.70%	49.39%	55.00%
Na				0.11%	0.22%	
Mg				0.81%	1.63%	
Al				7.15%	14.29%	
Si				13.33%	26.65%	45.00%
S		1.00%		0.04%	0.08%	
K				0.89%	1.78%	
Ca				0.75%	1.50%	
Ti				0.36%	0.72%	
Mn				0.04%	0.08%	
Fe		1.00%	3.00%	1.47%	2.94%	
W				0.36%	0.71%	
Cm	1.055	1.065	1.083	1.148	1.296	1.211

Table 1. C_m values of modelled coal and gangue compositions.

	90% Carbon	Carbon with 1% Cl	Carbon with 5%Cl	Carbon with 10%Cl	Carbon with 25%Cl	Carbon with 50%Cl
H	10%	10%	10%	9%	8%	5%
C	90%	89%	85%	81%	68%	45%
Cl	0%	1%	5%	10%	25%	50%
Cm	1.055	1.057	1.066	1.076	1.108	1.164

Table 2. C_m values of a modelled RDF Chlorine range.

amount of unknown variance of (disturbing) elements. For instance, it is known that non-ash related variations in Fe content reduce the accuracy of dual energy ash determination. For higher accuracies in on-line monitoring (of 1% accuracy in ash content and less), it is expected that only a sophisticated system design, combined with as much as possible advance knowledge of the inspected material will lead to satisfactory results. In this respect it should be noted that for on-line applications instant knowledge of level fluctuations and trends is often more important than achieving an equal accuracy as in an extensive laboratory analysis. Periodic calibration of on-line systems by means of laboratory analysis remains necessary. Secondly, by inspecting larger amounts or even the full stream, sampling errors will be less compared to laboratory analysis.

4.2. On-line DE-XRT image scanning

DE-XRT imaging has the ability of simultaneous on-line measurement of overall quality parameters of the coal (ash distribution) and parameters describing the effect on the separation (size, shape distribution). The particle size distribution can be derived from the on-line image stream. In that it distinguishes from other on-line tools. DE-XRT for airport security applications operates at wavelengths between 50 and 150 - 250 keV and relies on a low power electrical tube as generator (Fig. 3). For inspecting a 2-dimensional stream, which is prerequisite for size monitoring, the transmission intensity of 10 - 100 mm sized coal appears particularly effective.

Current systems that are applied for safety inspection analyse the material volume at a speed of approximately 0.5 m/s with approximately 1 - 2 mm resolution and detect in real time several categories of solid matter, based on differences in atomic composition. Besides, the X-ray imaging data reveal additional properties of the inspected materials, such as internal structure, texture, and shape.

Recent investigations at Delft University of Technology indicated that X-ray imaging is particularly suitable for high-speed identification of coal and RDF (Dalmijn et al., 2002). A transmission X-ray beam has a higher intensity than an induced fluorescent beam, which means that within a few milliseconds an image line can be recorded. The detector, an array of scintillation crystals, needs a sufficient number of counts on each element of the array for an accurate reading. Transmission imaging enables sufficiently fast and sharp reading with X-ray tubes that are common in X-ray imaging equipment. Conveying speeds of over 1 m/s are possible at a sample thickness of well over 10 cm for coal. A second advantage of transmission is that the particle volume is detected and not just a surface layer, as is the case with optical and XRF analyses. A disadvantage in relation to XRF is that there is no direct detection of specific elements. However, modern dual energy X-ray scanners enable a fast determination of the average atomic number. In combination with the high-resolution image this gives an estimation of the content and properties of the scanned materials. In this way several materials can be automatically classified into the desired fractions. The standard identification algorithms of dual-energy X-ray transmission imaging are usually optimised for luggage inspection, which will lead to suboptimal results for coal. Therefore before commencement of the experimental program the resolution of the atomic number identification was improved by developing detection algorithms that are specifically optimised for coal.

Figure 3. An airport security X-ray system that is converted for continuous inspection of bulk solids at the laboratory of Delft University of Technology. It combines dual energy XRT data with dedicated imaging algorithms for identification of a variety of materials. A typical belt speed for the system shown is approximately 0.5 m/s, belt width is 60 cm.

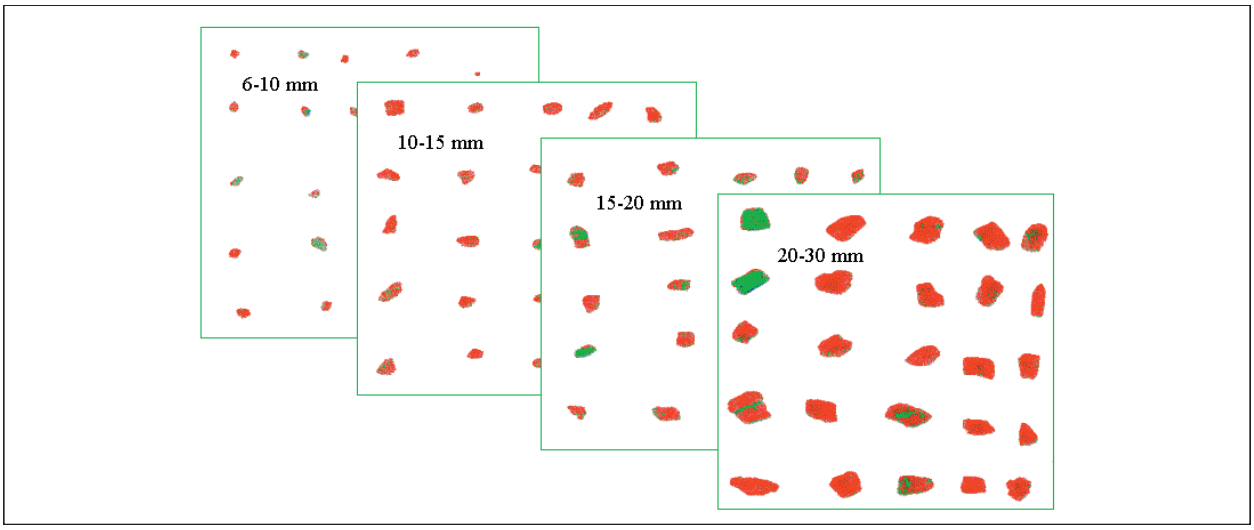

Figure 4. Scans of 4 different size fractions, Saarwellingen coal product.

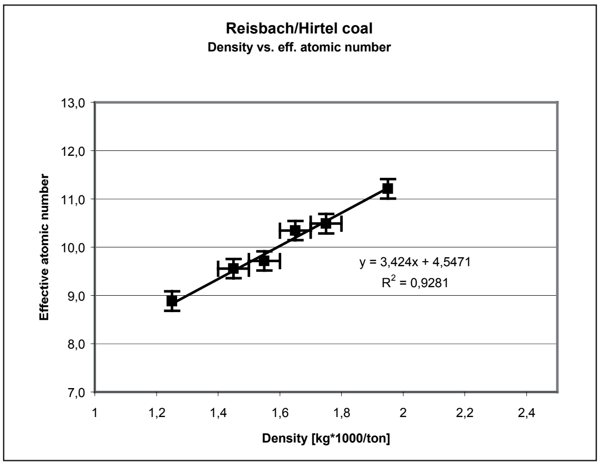

Figure 5. Correlation between average atomic number (Z_{eff} on y-axis, as generated by the scanner and software) and density classes (x-axis, determined by float-sink analysis).

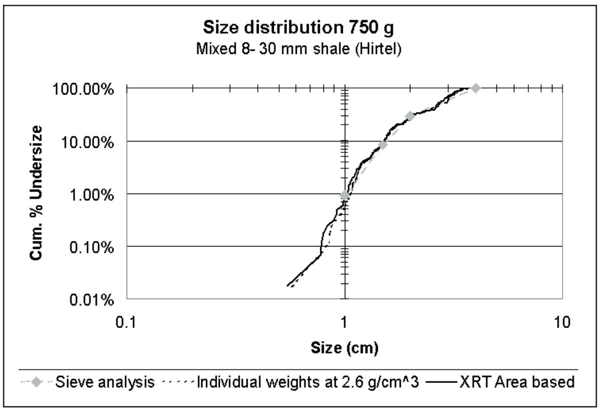

Figure 6a. Size distribution of the Saarwellingen coal, with use of the projected equivalent sizes that are automatically derived from the X-ray images.

Images obtained with a 6-30 mm coal sample from the dry coal preparation plant at Saarwellingen in Germany, operated by Dr. Arnold Schäfer Bergbau GmbH, are shown in Fig. 4. Not visible in Fig. 4 are the average atomic numbers. The average atomic numbers of 6 different density classes of the same coal, separated by means of float-sink analysis in Polytungstate solutions of different concentration, were determined, and show an approximately linear correlation (Fig. 5). The samples varied in weight between 0.2 kg and 1.0 kg. The X-ray scanning enables automatic classification in density classes with an estimated error of less than 50 kg/m^3 related to an inspected amount of around 0.5 kg.

About 75 particles, comprising in total 0.75 kg of the 10-15, 15-20 and 20-30 mm fractions of the same coal were screened and individually weighted (Fig. 4). From the X-ray images, the diameter of a sphere with an equal projected surface as the particle image was determined. With the sieve analysis and the individual weights the X-ray size distribution was calibrated (Fig. 6a). The dis-

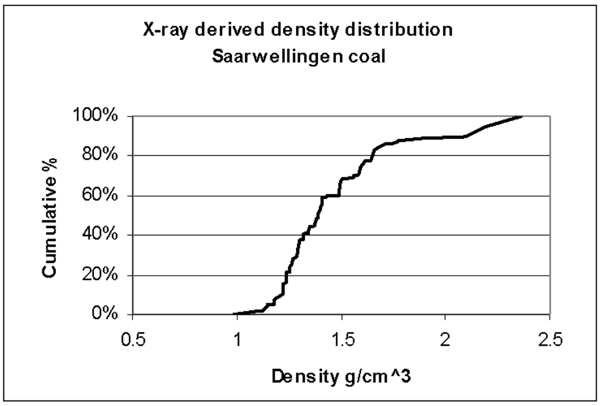

Figure 6b. Density distribution of the same sample, with use of the previously determined density/Z_{eff} correlation (Fig. 5).

tribution was obtained by introducing a correction factor for the equivalent projected sphere diameters derived from the X-ray image and by successively minimising the difference between the actual size distribution and the X-ray derived distribution. Below 8 mm sizes the X-ray derived distribution becomes less reliable due to resolution limitations of the X-ray camera. By using the correlation shown in Fig. 5, the density distribution can be subsequently derived (Fig. 6b). After this calibration procedure a dual energy line scan camera enables the continuous provision of size and density distribution from a free falling stream of particles. This may save considerable laboratory costs and assists in better control of the preparation process.

In another experiment, 2.0 kg of the same coal and 2.0 kg of waste from the dry density separation circuit of the Saarwellingen CPP was sampled and scanned separately, resulting in a Z_{eff} of 9.4 for coal and of 12.3 for waste (Z_{eff} equals the effective atomic number on the y axis of Fig. 5). Their ash content (on water free basis) was determined by means of incineration in the laboratory at 18% for coal, and 74% for waste[1]. After determining the Z_{eff} of the coal and waste, the waste percentage of the coal was increased in portions of approximately 0.2 kg and scanned until over 50% of the waste was added back into the cleaned coal (Fig. 7). The 100% coal and waste were scanned 10 times and each mixture 5 times. Between each successive scan of the same material, the sample was mixed and reoriented on the conveyor. The average standard deviation of the experiments for each mixture was approximately 0.3% of the measured Z_{eff}. A 95% reliability interval (2σ) results in an ash content error of 1%. This is the system inaccuracy at repeated measurements of the same material as successively scanned after reorientation. Based on the data of Fig. 7, the average deviation between correlation and data points expressed in ash content was determined at 0.5%, and the maximum error at 1.4%. The ash content of the added 0.2 kg portions is not necessarily constant due to particle-to-particle variations in composition. Therefore the average deviation decreases when larger quantities are scanned and particle-to-particle variations become negligible. For this coal, it seems reasonable to assume a maximum error in ash content determination of approximately 1%, also given the fact that in practice much larger quantities will be inspected. This may be different for other coal types due to variations in elemental composition.

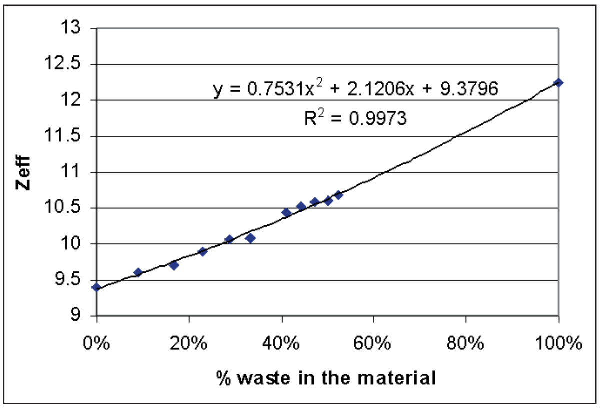

Figure 7. Results of the back mixing experiment of the coal and waste fraction of the dry separation circuit at Saarwellingen. The value at 0% waste added corresponds to the 18% ash content of the investigated coal product, while 100% corresponds to the 74% ash content of the pure waste.

4.3. Advanced processing and modular multi-sensor systems

Development and application of a modular multi-sensor sorting system with universal system components for applications in recycling were described in previous studies (Kattentidt, 2000; Jong et al., 2001; Kattentidt et al., 2003). Two or more different sensor arrays can be attached to a single system. During earlier development for glass quality control, a standard PIII PC achieved a detection rate of 200 particles / second with peak rates over 1000 p/s. Present investigations focus on connecting a dual energy X-ray transmission sensor array to a similar data-processing system. The prototype that is now being constructed enables scanning of a 50 cm wide flow of coal and RDF at speeds between 25 and 100 cm/s.

5. Applications in solid fuel processing

For solid fuel production on-line quality monitoring is important for coal as well as RDF producers. The examples below that could be realised with the technology described in Section 4 illustrate how the proposed applications may contribute to more efficient fuel preparation.

5.1. On-line ash control

Further improvements are possible in accuracy and detection possibilities of the ash content in the coal end product. Examples are better volume inspection of the flowing material, a higher image resolution (e.g. 1 mm^2), as well as automatic detection and compensation for the presence of disturbing elements, e.g. iron, sulphur, chlorine etc. Systems based on standard parts and PC components may considerably reduce unit costs, and hence promote more frequent application. By using 1 – 2 mm resolution dual energy X-ray arrays and imaging software presence

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[1] These are values for the particular samples of this experiment, and do not represent a represenative amount for the overall system performance.

of specific components can be detected, e.g. metal parts, support wood, and other disturbing waste. The system enables continuous data storage and hence certification of the coal product. In principle in case any problems may arise in its utilisation the cause may be traced back.

5.2. Automatic ash, sulphur, and chlorine reduction of >10 mm solid fuels

After conventional preparation fluctuations in ash, chlorine, sulphur or other contaminants may still exceed specifications. Automatic sorting with a system such as shown in Fig. 2 can decrease the contamination, when equipped with an appropriate (combination of) sensor(s). A precondition is that the contaminants are concentrated in a fraction of the material, and the material itself is predominantly larger than 5 mm. This fraction should typically not exceed a few percents in order to reduce losses and keep processing costs low. An additional advantage of automatic sorting techniques is the absence of a water circuit. Instead of replacing them, automatic sorting can be applied as addition to conventional concentration techniques for obtaining better product qualities (Fig. 8). This provides new opportunities for conventional dry concentration techniques. The dry concentrator produces pre-concentrated fractions that are cleaned to final specifications by means of automatic sorting. In addition to X-ray sorting, electro-magnetic sensors provide a cost effective alternative for the detection of shale in a coal product. This was confirmed by measurements of individual coal and shale pieces on an S+S MAG 2048 metal detector.

5.3. Simultaneous size and ash control for optimised coal production

The productivity of the European deep mines remains, in global perspective, low on average. Fundamental reasons are the relatively high ash content in the seams, depth and more complex geology of the reserves (Hessling, 1991; Walker, 1996). Integration of mining and preparation using advanced technology, in which automatic sorting and control play an important role, may lead to better efficiency of production in future mining operations (Klein, 2002). An example is the on-line monitoring of coal composition and size distribution of the producing face(s). Consider a large coalmine with several producing faces of different coal seams. When sizing, composition or dilution of coal from a single face becomes unfavourable it can be quickly decided to change to more favourable faces to keep a constant average output. Unfavourable over-crushing or dilution can be recognised faster and measures to prevent it can be taken earlier and more effective. A second example is on-line size and ash control of in- and output of a jig, in order to ensure optimised performance at variable feed compositions.

6. Discussion

Further developments in on-line inspection and sorting tools may contribute to Europe's solid fuel resource base in several ways. In the first place, better process and product control lowers costs and hence increases viability of coal production. Secondly, it opens the door for larger scale introduction of "second generation" solid fuels, or RDF. The main issue is automatic removal and inspection of chlorine and other toxic or disturbing components. Apart from stability in supply and quality, systematic control of these is a fundamental prerequisite before larger scale application can be established. Finally environmental performance increases by reducing coal losses as well as increasing secondary solid fuel recovery and simultaneously decreasing its toxicity.

Besides increasing technological performance and quality, further development of the described technology may play an important role in developing energy policies

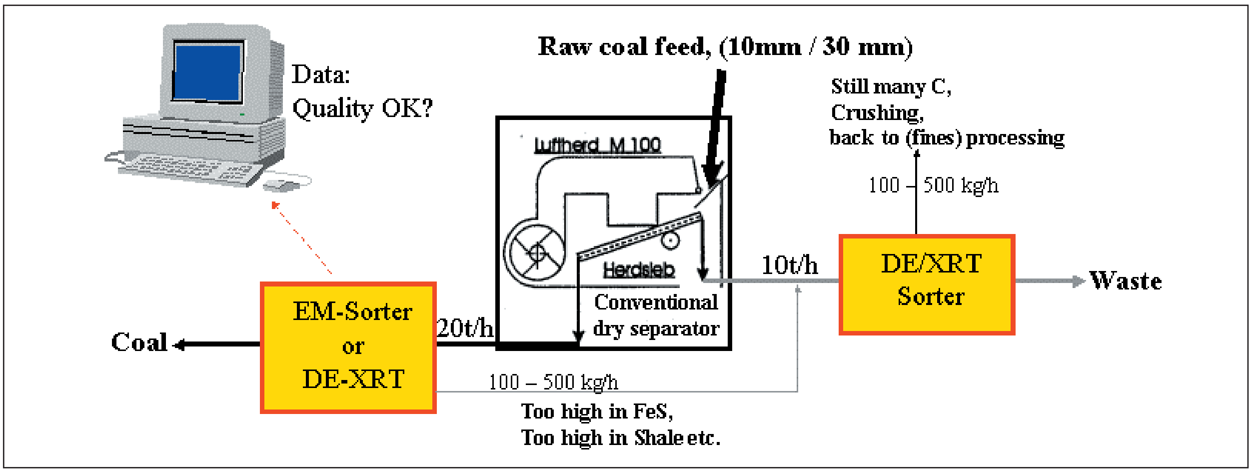

Figure 8. Improving dry separation results to higher grades by means of automatic sorting. DE-XRT = Dual Energy X-ray Transmission. EM-Sorter = Electro-magnetic sorter.

for solid fuels in Europe. Control tools play a crucial role in optimising solid fuel circuits on system scale, where several unit operations are connected and fuels of different origin are combined.

7. Acknowledgements

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