J. S. Afr. Inst. Min. Metall., vol. 90, no. 6.
Jun. 1990. pp. 125-131.

Petrographic characterization of coal by use of the IBAS image analyser

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SYNOPSIS

Petrographic analyses of coal rank and maceral-group composition are widely used in the characterization of coal. This paper describes the use of an image analyser (IBAS Kontron) for fully automated measurements of the rank and maceral groups of seam coals. The rank is then derived from reflectance histograms, or 'fingerprints', of coal-reflectance distributions (being expressed as the mean random reflectance of vitrinite). The volume proportions of the maceral groups are calculated from the histograms.

The results obtained with the IBAS were generally in agreement with those obtained by conventional methods of reflectance measurement and point-count analysis. However, the results were inconsistent for coals with a bimodal character or a wide V-class distribution.

The rank of the analysed coals ranged from 0,50 to 1,10 per cent mean random reflectance. The lowest reflectance that can be analysed with the IBAS is 0,4 per cent.

The speed, objectiveness, and repeatability of this technique make it exceptionally suitable for use in the quality control of large numbers of samples.

SAMEVATTING

Petrografiese ontledings van die steenkoolrang en maseraalgroepsamestelling word algemeen by die karakterisering van steenkool gebruik.

Hierdie referaat beskryf die gebruik van 'n beeldontleder (IBAS Kontron) vir ten volle geoutomatiseerde metings van die rang en maseraalgroepe van laagsteenkool. Die rang word dan afgelei van reflektiwiteithistogramme, of 'vingerafdrukke', van steenkoolreflektiwiteitverdelings (wat uitgedruk word as die gemiddelde willekeurige reflektiwiteit van vitriniet). Die volumeverhoudings van die maseraalgroepe word aan die hand van die histogramme bereken.

Die resultate wat met die IBAS verkry is, stem oor die algemeen ooreen met dié wat volgens die konvensionele metodes van reflektiwiteitmeting en punttellingontleding verkry is. Die resultate was egter inkonsekwent vir steenkool met 'n bimodale karakter of 'n breë V-klasverdeling.

Die rang van die steenkool wat ontleed is, het gewissel van 'n gemiddelde willekeurige reflektiwiteit van 0,50 tot 1,10 persent. Die laagste reflektiwiteit wat met die IBAS ontleed kan word, is 0,4 persent.

Die spoed, objektiwiteit en herhaalbaarheid van hierdie tegniek maak dit besonder geskik vir gebruik in die gehaltebeheer van groot getalle monsters.

Introduction

Worldwide the applicability of coal in technological processes[1-6] is assessed on the basis of coal petrography. Coal evaluation includes the determination of coal rank, and the analysis of maceral groups and blends. The measurements are usually carried out by conventional optical microscopy.

The maceral count requires the microscopic identification and grouping of 500 points per sample, two or more independent analyses being required to reduce or eliminate operator bias. In the determination of the rank of single coals, a maximum of 100 reflectance readings are taken on the vitrinite.

Image analysis automatically measures the distribution of reflectance and the volume proportions of coal components by recording several million reflectance readings on micrometer-sized areas of a polished coal surface[7-12].

The Division of Energy Technology in the CSIR undertook an in-depth study into the use of the IBAS image analyser for the automation of maceral-group analysis of South African coals. The aims of the investigation were as follows:

- to evaluate the potential of the IBAS image-analysis system in the determination of coal rank and maceral groups for South African coals;
- to compile the necessary software program to determine the relevant instrumental parameters and the reproducibility of the measurements; and
- to develop suitable techniques of sample preparation.

This paper describes the performance of the IBAS automated image analyser. The results for 58 South African coal and product samples in the range 0,50 to 1,10 per cent mean random reflectance are compared with those obtained by conventional petrographic techniques. The advantages and disadvantages of the former technique, its possibilities and limitations, and the parameters influencing the results obtained, are discussed.

Instrumentation

Experimental Parameters

The hardware consists of a Zeiss universal microscope linked to an IBAS (Kontron Electronics) software-controlled image analyser.

A Chalnicon TV camera is used to transform the optical image to an electronic image. The high sensitivity of the camera to green light, and its linear response characteristics in the low-reflectance region of less than 7 per cent, make this camera suitable for coal reflectance studies.

The image from the optical microscope has a total magnification of 600 times (300 times by means of the microscope and 2 times by means of the TV camera-image analyser). This image is transferred to the image analyser, where it is digitized into an array of 768 by 512 pixel points[13]. Every pixel point on the TV monitor is

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ISSN 0038-223X/3.00 + 0.00. Paper received 27th June, 1989.

measured and classified according to its grey level. As a result of this, a reflectance histogram (reflectogram) is obtained.

The internationally recognized standards GGG, YAG, and synthetic sapphire, with their respective reflectivities in oil of 1,684, 0,893, and 0,579 per cent, were used in the calibration of the apparatus.

The image analyser is further equipped with all the algorithms that were necessary for the study, such as erosion, dilatation, and reflectance transformation.

Sample Preparation

Representative samples of raw coal collected from eleven collieries were crushed to minus 1 mm top size. Care was taken not to produce too many fine particles (less than 10 per cent of minus 60 μm material). Each sample was subjected to heavy-medium separation at relative densities of 1,35, 1,65, and 2,0. A middling fraction of 1,35 to 1,65 relative density, the floats at relative densities of 1,35, 1,65, and 2,0, and raw coal from each colliery were analysed.

A total of 58 pellet mounts (32 ml of crushed coal mixed with 16 ml of epoxy resin), polished according to the standard procedures[15], were prepared and moulded[10,12] into blocks measuring 32 by 23 mm. As the reliability of petrographic analysis is highly dependent upon the quality of the polished surface, a scratch-free surface with as little relief as possible was aimed for.

A focusing algorithm was applied where focusing was carried out independent of light intensity. Three points on the periphery of the sample were focused interactively to define the focusing plane, and the values were stored. Corrections to the height of the focusing plane were calculated by computer for each field, and were executed by the automatic focusing mechanism.

Precision of the Method

The precision of the method depends on various parameters such as light stability, consistency of focus depth, sample preparation, quality of polishing, and the subjectivity of the operator during segmentation of the reflectogram. This has been determined by measurement of the vitrinite content of coals that are known to be rich and poor in vitrinite (about 80 per cent vitrinite in the first instance and 25 per cent in the second).

Altogether, 100 fields were automatically scanned with the IBAS for each of the 13 independently prepared mounts. The size of the analysed field was 375 by 250 μm, covering an area of about 9 mm^2 out of a total of about 700 mm^2 for the entire sample.

The standard deviation was calculated according to the IUPAC rules (1972), which recommend general terms, units, and definitions for workers in the analytical field[16].

Method of Measurement

To cover the reflectance range of the coal and to obtain maximum resolution with the available 256 grey levels of the instrument, three measuring programmes were compiled with the following reflectance ranges:

- 0,4 to 2,5 per cent reflectance for the low-ash products of coals washed at a relative density of 1,35,
- 0,4 to 3,0 per cent reflectance for raw coals and other density fractions, and
- 0,5 to 4,0 per cent for heat-affected coals with wide vitrinite-reflectance distributions.

The uniformity of illumination of the measured area is affected by the components of the optical microscope and the uniformity of the TV-camera target. By the application of shading correction algorithms, a uniformity of illumination within 3 grey levels was achieved. This limits the classification of 256 grey levels to approximately 80.

The reflectogram was (manually) segmented with the aid of threshold brackets, and the operator assigned the areas to the relevant maceral groups. The setting of threshold brackets is subjective, and differs from one operator to another since the borders between the maceral groups cannot be clearly defined.

The first step in the evaluation of the reflectograms was the determination of the lower and upper limits of vitrinite distribution. That was done by the superimposition of visual Gaussian distribution over the vitrinite peak, which was then cut off at about 95 per cent confidence levels. The arithmetic mean of this interval was taken as representative of rank, and the area under distribution was treated as representative of the vitrinite content. The area from the lower cut-off point of the vitrinite distribution towards zero on a reflectivity scale was allocated to the exinite, and the area from the upper limit of the vitrinite distribution up to maximum reflectance corresponds to the inertinite content.

From the reflectogram, the coal rank, $\bar{R}oV$(rand), is expressed as the midpoint between the lower and the higher reflectance margin of the vitrinite peak. In cases where the vitrinite reflectance showed no Gaussian distribution, the vitrinite peak was segmented two or three times and the weighed mean random reflectance was calculated.

A statistical method known as errors-in-both-variables[17] was employed to find the relationship between the results obtained by the image analyser and those obtained by means of the conventional point-counting microscopic method.

Results and Discussion

Analysis of Maceral Groups

The reflectance of maceral groups increases with increase in rank. For a polished pellet mount of bituminous coal, the following reflectance trend was observed:

binder/low-reflecting minerals < exinite < vitrinite < inertinite < pyrite, and high-reflecting minerals.

The reflectances of the above components overlap to a greater or lesser extent. The program for the measurement of the organic components was compiled in such a way that the reflectance of the mounting medium, as well as the low- and high-reflecting mineral matter, was rejected. To minimize the contribution of undesirable reflectance levels caused by the relief and coal particles smaller than 5 μm erosion, dilatation algorithms were used. The grey values of the remaining organic and inorganic components at every pixel point were measured, classified, and summarized in the coal reflectogram and are regarded as being a 'fingerprint' of the coal.

The results of the maceral-group analysis obtained by image analysis were compared with those of the conventional point-counting method carried out by two independent petrographic laboratories. The reflectograms of the raw coals that were investigated are given in Figs. 1 and 2.

Vitrinite

The superimposition of the Gaussian curve over the vitrinite peak with its cut-off points at the 95 per cent confidence level proved to be an acceptable technique for the determination of vitrinite, and the results obtained in this manner compared well with those obtained by conventional optical microscopy.

The exception to this fitting technique would be coals with long 'tail-like' distributions of vitrinite reflectances, or coals that show bimodal vitrinite-reflectance distributions caused by the heat introduced during the coalification process, such as with dolerite intrusions.

The proper extraction of the vitrinite portion from the reflectogram affects not only the accuracy of the vitrinite quantification, but also that of the exinite and inertinite groups since their volume percentages add up to 100.

A Pearson correlation coefficient for the vitrinite content was calculated for IBAS versus the point-counting results obtained in Laboratory 1 and IBAS versus the results from Laboratory 2. It was of the order of 0,98 in both cases, the standard error of estimation being 3,8 for IBAS versus Lab 1 and 3,6 for IBAS versus Lab 2 (Figs. 3 and 4).

The standard deviation at the 95 per cent confidence level was 2,0 for a vitrinite content in a range of 25 per cent (sample 83/1251), and 2,5 for a vitrinite content of about 90 per cent (sample 84/1100). A comparable degree of precision was achieved by the conventional point-counting method when 1500 points were counted in the first case and 500 in the second[18].

The statistical analysis of errors-in-variables regression indicates that the two methods of determination are equivalent, the relationship between the results of the automated method and those of Lab 2 being consistent and being represented by a straight line with a slope of 1 that intercepts zero (at 0 per cent measured maceral content)[17].

Exinite

The exinite results for all the measured coals were influenced by the reflectance spectra of the mineral matter because it was not possible to reject the spectra completely.

In general, the exinite values obtained from the reflectogram corresponded well to the results of the conventional methods. The overlapping of the reflectance spectra between the exinite and the vitrinite was not as definite as it was between the vitrinite and the inertinite. South African coals are not very rich in exinite, and its effect in technological processes is therefore not substantial.

Inertinite

The accuracy of the inertinite determination is affected by the setting of the upper vitrinite boundary. A distinct boundary between reactive vitrinite and non-reactive inertinite is difficult to establish because the transition from the reactive to the inert is continuous.

Reactive Semifusinite

The intermediate phase between vitrinite and inertinite is called reactive semifusinite. The reactive properties of reactive semifusinite change gradually with an increase in reflectance. It is very difficult to determine reactive semifusinite; there is no internationally accepted definition of this material, laboratories applying the conventional method differing in their interpretation.

Methods have been reported in the literature[19–21] in which the total reactive matter of coal, including the reactive semifusinite, is calculated from the total coal reflectogram.

Rank

The results for coal rank expressed as a mean random reflectance, $\bar{R}oV(rand)$, of vitrinite as obtained by image analysis are presented in Table I. The results obtained by two petrographic laboratories using the conventional method are also included. The results are in agreement within one half of a V-class[22,23], except for samples 737 and 738, which have a wide V-class distribution.

TABLE I

COMPARISON OF COAL RANK (RANDOM) BY IBAS, LAB 1, AND LAB 2

	Coal rank (random)					
	Raw coal			Float 1,35 r.d.		
Sample no.	IBAS	Lab 1	Lab 2	IBAS	Lab 1	Lab 2
1244	0,66	0,69	0,69	0,66	0,63	0.68
1245	0,62	0,65	0,63	0,61	0,63	0,63
1248	0,75	0,79	0,76	0,75	0,80	0,76
1249	0,54	0,55	0,54	0,55	0,54	0,56
1251	0,70	0,72	0,72	0,68	0,73	0,71
1100	0,61	0,62	0,63	0,61	0,62	0,65
736	0,96	0,91	0,91	0,94	0,92	0,91
737	0,90	1,10	1,26	0,87	0,86	0,85
738	0,85	1,00	0,93	0,83	0,88	0,84
739	1,07	0,98	1,02	1,07	1,00	1,02

In conventional optical microscopy, the reflectance is determined on vitrinite particles and the mean of 100 readings is taken to be representative of the coal rank. In the coal reflectogram obtained by automated image analysis, a bimodal, widespread vitrinite distribution overlaps the reactive semifusinite and inertinite group, so that an accurate reflectance distribution and mean value cannot be obtained.

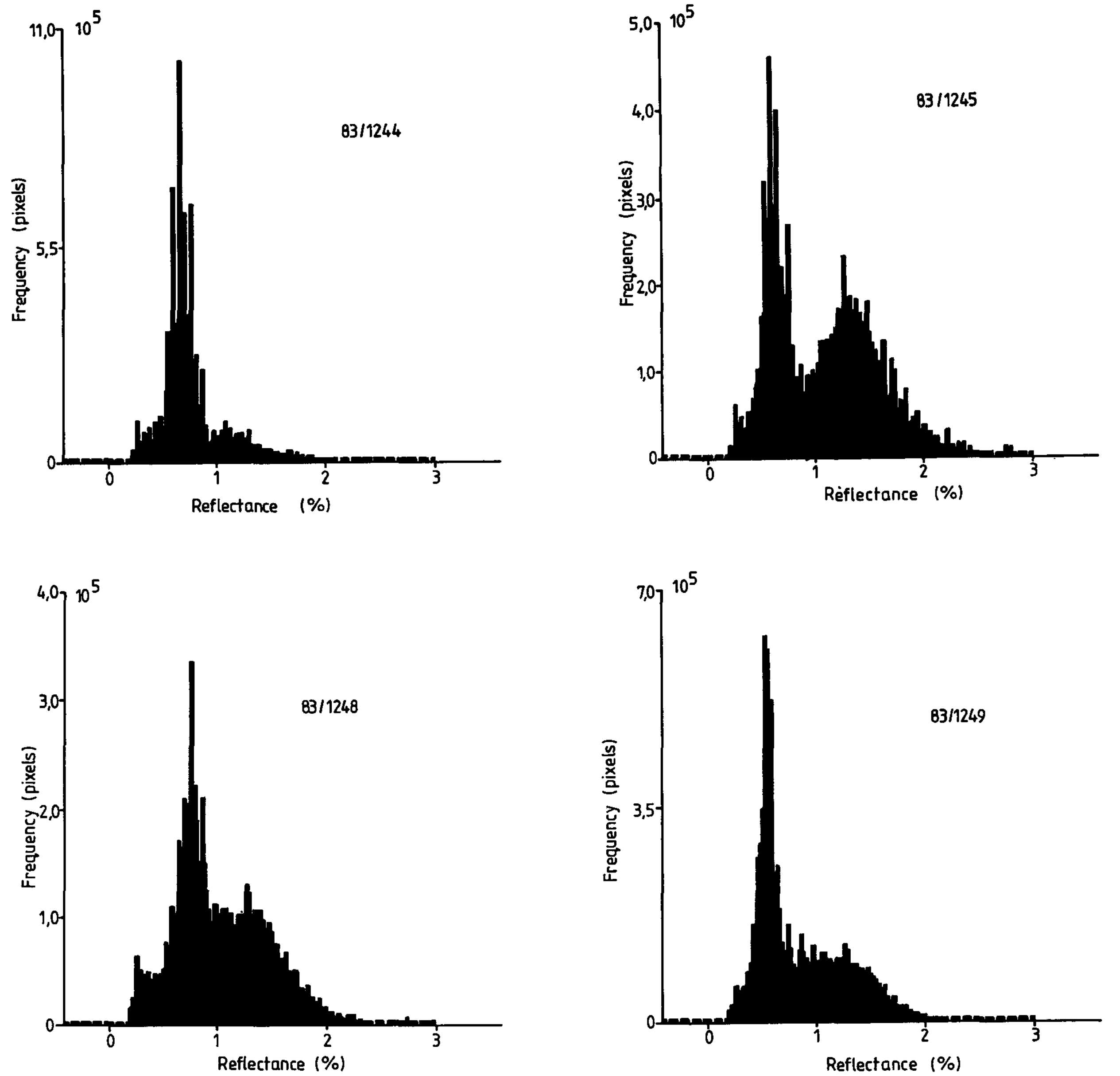
Studies are under way on the extraction of the total vitrinite distribution from a reflectogram by the application of suitable image-processing algorithms.

Conclusions

Automatic image analysis can provide quantitative information on the type (maceral groups) and rank of South African coals, and the system is also suitable for conventional petrographic analysis.

The maceral-group analysis of homogeneous coals in which the vitrinite, exinite, and inertinite contents are derived from reflectance histograms agrees with the results of manual optical microscopy.

The values for exinite, vitrinite, and inertinite deduced from a reflectogram are influenced by the accuracy of



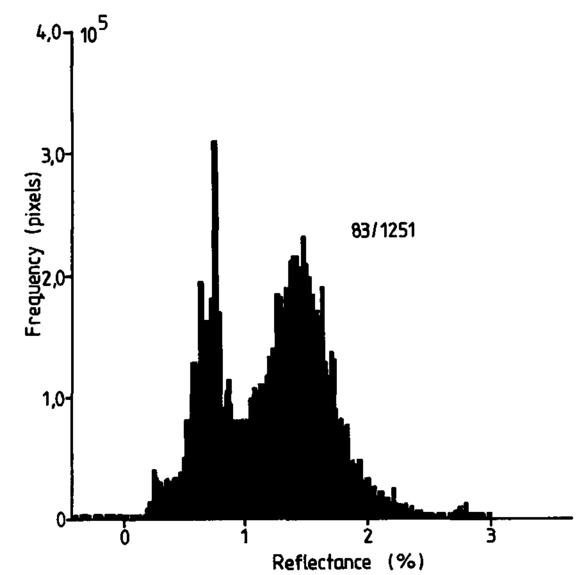
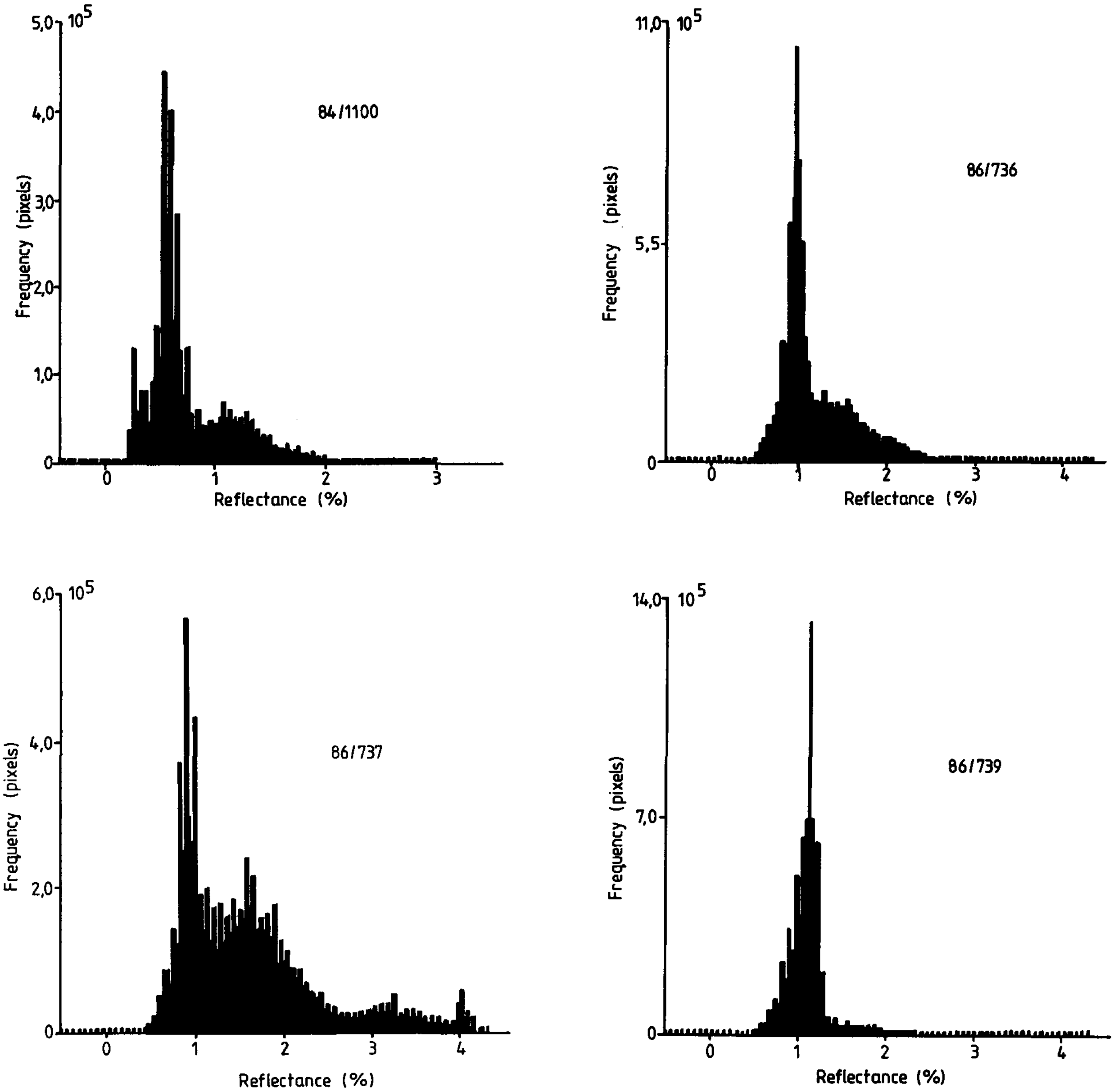


Fig. 1—Reflectograms of five samples of raw coal obtained by automated image analysis



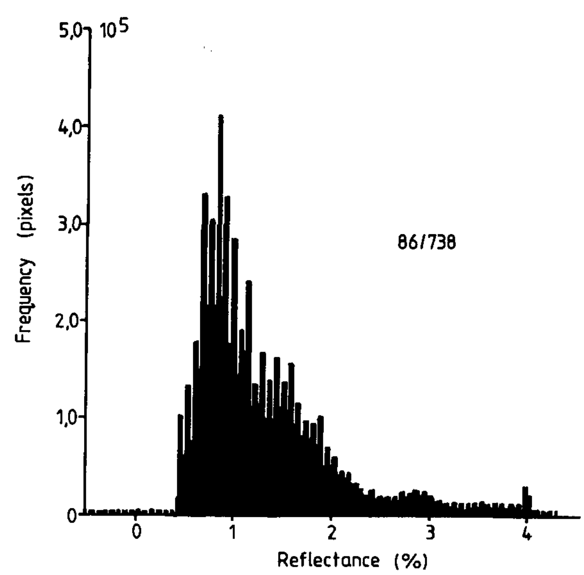


Fig. 2—Reflectograms of the remaining samples of raw coal obtained by automated image analysis

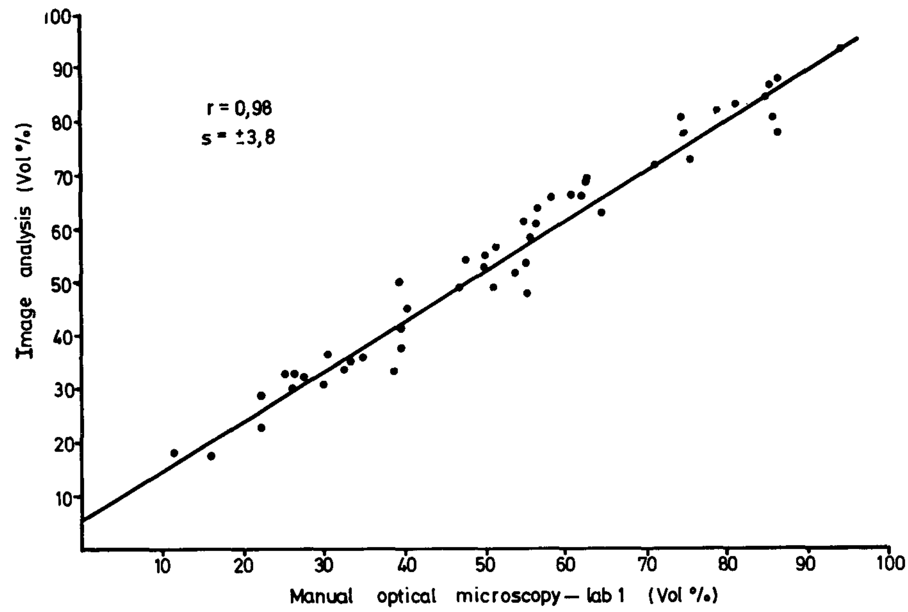


Fig. 3—Comparison of vitrinite content as obtained by automated image analysis and by Laboratory 1

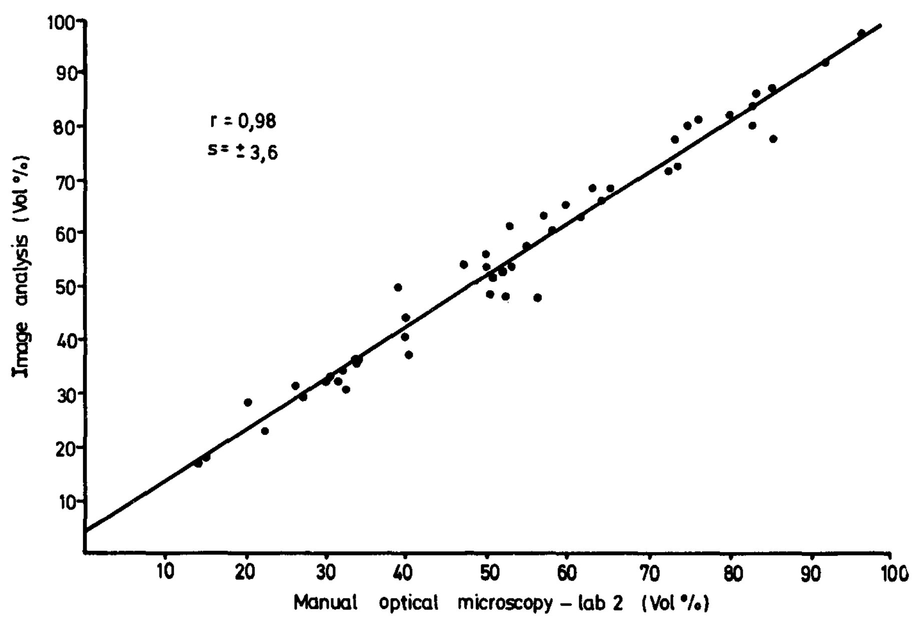


Fig. 4—Comparison of vitrinite content as obtained by automated image analysis and by Laboratory 2

the boundary setting, the amount and type of the mineral matter, and the degree of overlapping between the reflectance spectra of the maceral groups.

The rank, as given by the mean random reflectance of vitrinite and expressed as an arithmetic mean of the vitrinite distribution, can be determined with a considerable degree of confidence.

On the basis of a statistical evaluation, the results obtained by automatic image analysis and by conventional petrographic analysis are equivalent. For coals with a bi-modal character or a wide V-class distribution, the results obtained by automatic image analysis are inconsistent.

The highest coal rank analysed had a mean random reflectance of about 1,10 per cent. The upper reflectance limit and the application for high-ranking coals are still to be established. The lower reflectance limit for image analysis is about 0,4 per cent.

The technique offers a new approach to the characterization of coal in the form of a complete reflectance distribution of coal components from which the reactive content of a coal can be calculated. A comparison of coal reflectograms allows for fast and effective quality control of single coals.

The capability of the IBAS instrument could be improved by an increase in the number of grey levels to accommodate a wider reflectance range with a simultaneous improvement in grey-level resolution.

Acknowledgements

The authors thank their colleagues for the valuable assistance they provided: Miss L. Erasmus of the Petrographic Section of the National Institute for Coal Research for manual coal analyses; Messrs M.C.J. van Vuuren and J.M. Barnard, and Dr K. Kruszewska for their constructive criticism and valuable discussions; and Mr I.

Mtombeni for the preparation and polishing of samples. The assistance received from Iscor in the sample selection and manual measurements, and in the discussions with Mr H.J. Roux, is also gratefully acknowledged.

References

1. MACKOWSKY, M.T., and SIMONIS, W. Die Kennzeichnung von Kokskohlen fuer die mathematische Beschreibung der Hochtemperaturverkokung im Horizontalkammerofen bei Schuettbetrief durch Ergebniss Microscopischer Analysen. *Glueckauf-Forschungshefte,* vol. 30, no. 1. 1969. pp. 25-37.
2. WOLF, M., and WOLFF-FISCHER, E. Kohlenpetrographische Untersuchungsmethoden in Forschung und Praxis. *Glueckauf,* vol. 119, no. 17. 1983. pp. 808-814.
3. SNYMAN, C.P., VAN VUUREN, M.C.J., and BARNARD, J.M. Chemical and physical characteristics of South African coal and a suggested classification system. *Coal 8306.* Pretoria, National Institute for Coal Research, 1983.
4. SMITH, W.H., ROUX, H.J., and STEYN, J.G.D. The classification of coal macerals and their relation to certain chemical and physical parameters of coal. Johannesburg, The Geological Society of South Africa, *Special Publication* 7. 1983. pp. 111-115.
5. FALCON, R.M.S., and SNYMAN, C.P. An introduction to coal petrography:Atlas of petrographic constituents in the bituminous coals of Southern Africa. Johannesburg, The Geological Society of South Africa, *Review Paper* 2. 1986. pp. 1-27.
6. STEYN, J.G.D., and SMITH, W.H. Coal petrography in the evaluation of S.A. coals. *Coal, Gold and Base Minerals of Southern Africa,* 1977.
7. LEE, J.B., and MIKKA, R.A. Automated microscopic characterization of coal and coal blends. *BHP Tech. Bull.,* vol. 26. 1982.
8. CHAO, E.C.T., MINKIN, J.A., and THOMPSON, C.L. Application of automated image analysis to coal petrography. *Int. J. Coal Geol.,* vol. 2. 1982. pp. 113-150.
9. ENGLAND, B.M., MIKKA, R.A., and BAGNALL, E.J. Petrographic characterization of coal using automatic image analysis. *J. Microsc.,* vol. 116, pt 3. 1979. pp. 329-336.
10. RIEPE, W., and STELLER, M. Kohlecharakterisierung durch automatische Bildanalyse. *Fresenius, Z. Anal. Chemie,* no. 316. 1983. pp. 239-241.
11. UESUGI, M., ISACA, N., and MATSUNAGA, H. *Petrographic analysing system of coal with image processing technique.* System and Control Research Centre (Nippon Kokan K.K., 1 – 1 Minamiwataridacho, Kawasaki-Ku, Kawasaki, Japan).
12. RIEPE, W., and STELLER, M. Characterization of coal blends by automatic image analysis. *Fuel,* vol. 63. 1984. pp. 313-317.
13. BRANDT, M.P., and KORWIN-KOSSAKOWSKI, L.E. Evaluation of the instrumental parameters of image analysis for geometric and light densitometric measurements of coal samples. *Coal 8506.* Pretoria, National Institute for Coal Research, 1985.
14. Microscopische Untersuchungen an Steinkohlen, Koksen und Briketts. *BB* 22020. Dec. 1970.
15. AMERICAN SOCIETY FOR TESTING AND MATERIALS. *Standard method of preparing coal samples for microscopical analysis by reflected light.* ASTM D2797-72 (reapproved 1980).
16. IUPAC (International Union of Pure and Applied Chemistry). *Information Bulletin* no. 26, Nov. 1972.
17. GALPIN, J.S., MARE, M.B., and VAN DER LINDE, N. Analysis of automatic and laboratory measurements of the maceral content of coal. Pretoria, C S I R, CWISK 84, NRIMS.
18. VAN DER PLAS, L., and TOBI, A.C. A chart for judging the reliability of point counting results. *Am. J. Sci.,* no. 263. Jan. 1965. pp. 87-90.
19. PEARSON, H., and PRICE, J.T. Reactivity of inertinite (coal-typing) of western Canadian coking coal. *International Conference on Coal Science.* Sydney, Pergamon Press, 1985, pp. 907-908.
20. RIEPE, W., and STELLER, M. Bergbau-Forschung GmbH. Private communication.
21. KRUSZEWSKA, K.J. The use of reflectance in the determination of the reactivity and maceral composition. In press. (Pretoria, National Institute for Coal Research.)
22. STACH, E., *et al. Coal petrology.* Berlin, Gebrüder Borntraeger, 1982. p. 331.
23. STEYN, T.C.D., and SMITH, W.H. Coal petrography in evaluation of SA coals. *Coal, Gold and Base Minerals of South Africa,* vol. 25. 1977. pp. 107-117.

Applications of expert systems

A conference on the above topic, 'Expert Systems Applications', will be held in Hollywood, Los Angeles, on 7th and 8th November, 1990.

Organized by the Institute for Industrial Technology Transfer (IITT-International) in co-operation with the international journal of *Expert Systems with Applications,* the Conference will consist of the following sessions chaired by the experts listed:

- Selected expert system applications. Dr Francisco J. Cantu, Director of Informatic Research Center, ITESM, Mexico
- Expert system verification and validation. Mr Chris Culbert, NASA Johnson Space Center, Houston, USA
- Expert systems in business. Dr Daniel Schutzer, Citicorp Investment Bank, New York
- Applying neural network technology to expert systems. Dr Larry R. Medsker, Dept of Computer Science and Information Systems, The American University, Washington DC
- Integrating decision support with expert systems. Dr David King, Director, Artificial Intelligence Applications, Execucom System Corporation, Austin, USA
- Expert systems in learning. Professor Brian Reiser, Princeton University, USA.

The keynote speaker will be Dr Daniel O'Leary of the University of Southern California, who will talk on knowledge acquisition techniques and methodologies.

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New engineering facilities at Wits*

What used to be the KWV Building at the old Milpark showgrounds today serves a very different purpose. It has been converted into modern laboratory, workshop, and storage facilities with the help of a R1,5-million donation to the Engineering Faculty at the University of the Witwatersrand from Genmin, Gencor's independent mining company. These facilities, together with the new Chamber of Mines Building next door, are expected to meet the university's mining and electrical-engineering educational needs well into the next century.

Speaking at the official opening of the converted building, renamed The Genmin Laboratories Building, Genmin Chairman, Mr Brian Gilbertson, remarked that, in the long-term, the strength of the mining industry would depend critically upon highly qualified personnel.

'We will need geologists, engineers, and executives of vision to take South Africa into the era of ultra-deep-level mining', he said. Genmin alone requires 22 new mining engineers annually and more than 40 graduates in other engineering disciplines.

Pointing out that the demand for technicians and engineers in South Africa increases by 22 per cent annually, Mr Gilbertson stressed the need for investment in programmes to alleviate the country's shortage of skills and qualified manpower. 'In most disciplines the supply is approximately half of what the demand will be in the foreseeable future. The problem is not a labour shortage but a skills shortage,' he added.

The renovation of the KWV Building, completed at a total cost of R3 million, has enabled the Departments of Mining and Electrical Engineering to set up a wide range of specialist laboratories for teaching and research purposes at both undergraduate and postgraduate levels.

Professor Alan Kemp, Dean of the Faculty of Engineering, said the Genmin Laboratories also provided expanded opportunities for collaborative research with industry. 'Co-operation between Genmin and the Faculty is already reflected by existing research projects and continuing education activities in both environmental and power engineering', he added.

Professor Kemp said he looked forward to the day when outdated barriers between the different branches of engineering could be absorbed into a single multi-disciplinary faculty. 'This would bring us in line with overseas trends, which emphasize the integrated nature of all major engineering projects and the expanding role of engineering faculties in responding to this.'

The Department of Mining Engineering has established laboratories for rock mechanics, ventilation, excavation engineering, mine safety, and mine design in the converted building. The new electrical-engineering facilities include an undergraduate machines laboratory, a final-year and postgraduate project laboratory, a postgraduate computer room for software development, and a workshop.

* Released by Lynne Hancock Communications, P.O. Box 1564, Parklands 2121.

Pictured at the official opening of The Genmin Laboratories Building are (from left) Professor Alan Kemp, Dean of the Faculty of Engineering; Mr Brian Gilbertson, Chairman of Genmin; Mr Derek Keys, Chairman of Gencor; and Professor Robert Charlton, Vice-chancellor of the University of the Witwatersrand.