Aqueous suspension based abrasion resistance assessment for particulate activated carbons*

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Abstract

A generalized technique for assessing abrasion resistance has been developed, which is applicable to all types of particulate activated carbons, including extruded and granular particle forms. The method is based on measuring the abrasion losses (i.e. particles <0,25 mm) incurred when an aqueous suspension of activated carbon is agitated by a rotating plunger. The direction of rotation is alternated on a cyclical basis, and all other operating conditions are fixed at predetermined values, e.g. suspension concentration at 40 vol. %, peak rotation speed at 1 200 r/min and duration of agitation at 12 h. The results can be used to compare different particulate carbon types in terms of expected abrasion resistance, and shed light on the likely resistance to abrasion of different carbons during hydraulic transport conditions (when carbon-metal interactions predominate) and during such operations as adsorber filling and backwashing (when carbon-carbon interactions predominate).

Introduction

A major cost component of activated carbon treatment derives from losses relating to the physical strength of the carbon, which are incurred during usage and regeneration. Physical strength seems to have been slighted in favour of good adsorptive properties, a choice which has frequently had severe economic repercussions. Cairo *et al.* (1982) indicate that some 80% of the total annual operating and maintenance cost of a granular activated carbon facility may be attributed to regeneration related elements, and of these regeneration costs, 50% may be ascribed to the loss of carbon in the furnace or transport system. Clark (1983) presents extensive cost data for granular activated carbon adsorption and regeneration, which *inter alia* underscore the substantive contribution that make-up for carbon loss makes to overall costs: For example, the total annual operating and maintenance cost for a 40 Ml/d gravity steel contactor system with multihearth furnace regeneration will double for an increase in carbon loss per regeneration cycle from 3% (superior carbon and/or operation) to 12% (inferior carbon and/or operation).

A variety of test methods are currently available for testing abrasion resistance of activated carbons, categorised in the following two groups –

Dry impact hardness tests

- Ro-tap abrasion test (Standard for Granular Activated Carbon; AWWA, 1974)

- Stirring abrasion test (AWWA, 1974)

- Impingement method (Laboratorium für Adsorptionstechnik, 1978)

- Vibration method (U.S. Naval Research Laboratory; Deitz 1978)

Wet abrasion resistance tests

- 'Rad van Avontuur' method (Norit Research Laboratory; Egtberts, 1976).

The first three methods are conducted in air, and are based substantively on the generation of attrition losses through carbon-metal interactions. The Ro-tap and stirring abrasion tests are restricted to granular particle types, and do not accommodate extruded carbons. Minor modifications of the Ro-tap abrasion test will permit to measure fines produced during the testing of extruded carbons. This method, however, has the inconvenience of not measuring the change in average particle diameter, as is done for granular carbons.

The vibration method is conducted in air, and includes ultrasonic vibration of the carbon particles to simulate expected conditions during dry transport of carbon and the particle-particle interactions encountered in gas-phase applications.

The 'Rad van Avontuur' method, developed to test the hydraulic transport of particulate activated carbon, has the advantage of using water as test medium instead of air, and is based on the measurement of fines formed through particle-particle as well as particle-container interactions. It is applicable to granular and extruded particle types. Owing to the relatively gentle hydrodynamic conditions that prevail during testing, however, very low levels of fines are generated ($\simeq 0,5\%$), suggesting that the method may not be sufficiently harsh. Nevertheless, it does represent a novel endeavour to simulate hydraulic transport of carbon, and may be developed as a useful predictive tool in this context.

The method presented here for evaluating abrasion resistance is based on the generation of particle-particle and particle-steel interactions through the action of a cylinder, or plunger, rotating in an aqueous activated carbon suspension. All types of particulate carbons can be evaluated and compared. Abrasion loss values typically range between 0,3% and 15% for different carbon types and base materials.

Materials and methods

Abrasion resistance test unit

A schematic diagram of the experimental arrangement is depicted in Fig. 1. The test unit consists of a 0,4 kW electrical motor connected to a tachometer. The motor drives a 316 stainless steel cylinder (plunger), which agitates the carbon suspension. The aqueous carbon suspension is held in a container

Figure 1
Schematic arrangement of abrasion resistance testing equipment

also made of 316 stainless steel. In order to introduce or remove carbon batches, a device by means of which the container may be raised or lowered, was provided. The container fits snugly into a circular recess in a platform, which also moves up and down with the container. The movement of the platform (and container) is guided by accurately machined slots and grooves. The position of the plunger is maintained by a set of bearings, which also provide for its smooth rotation. The net result is that the spatial geometry

of the container and plunger is reproduced exactly for each experiment. Details of construction of the plunger and container are given in Fig. 2. These units were precision manufactured, and polished to a 2 μm surface quality profile.

The main support frame of the test unit is of heavy steel construction and is supported on a rubber base. The coupling between the motor and the plunger shaft is flexible, providing for smooth, vibration-free operation.

Figure 2
Construction details for abrasion resistance testing container and plunger

Control unit

The electronic control unit (Fig. 1) provides for control of acceleration time, deceleration time, cycle time, maximum rotation speed and speed stability. Rotation speed is indicated.

Defining unit

An acrylic wash column was constructed to provide for the proper defining of new carbon prior to testing, and for separation of fines from a carbon suspension which had undergone abrasion resistance testing (Fig. 3). Special ports have been provided for the addition and removal of carbon. The lower (support) and upper (defining) screens are made of 316 stainless steel with 0,25 mm apertures.

Methods

A representative sample of activated carbon is washed with distilled water for the removal of fines. The size cut-off point for fines is set at 0,25 mm. A potentially serious problem arising during washing is the classification of particles, which will lead to the use of different particle sizes in subsequent experiments. Accordingly, the carbon must be washed in batches of approximately the re-

quired size for one experiment. After washing, the carbon is remixed and dried at 110 °C for a minimum of 24 h, after which it is cooled to room temperature in a desiccator and stored in sealed, glass-stoppered containers.

To obtain a suspension of a given concentration (e.g. 5 to 60 vol. %) the appropriate amount of dry carbon is weighed and soaked in distilled water for 24 h at 20 °C (mass = volume x particle density). The wet carbon is transferred to the container of the test unit and distilled water added to make up the volume to 1 285 cm³, which is the fixed total suspension volume for the test procedure. Particle densities required for calculation of the mass equivalent of a desired volume per cent of carbon were determined by means of water displacement of particles that had been wetted and centrifuged at 2 600 r/min in a 20 °C environment.

The suspension is stirred in alternate directions for 12 h at 20 °C, after which the carbon is again washed to a 0,25 mm cut-off point for removal of the fines generated during the testing procedure. The carbon is then dried under the same conditions as mentioned before, cooled to room temperature in a desiccator and accurately reweighed. The difference between the initial and the final mass value is a measure of the degree of abrasion (expressed as % abrasion loss). Operating conditions are summarized in Table 1.
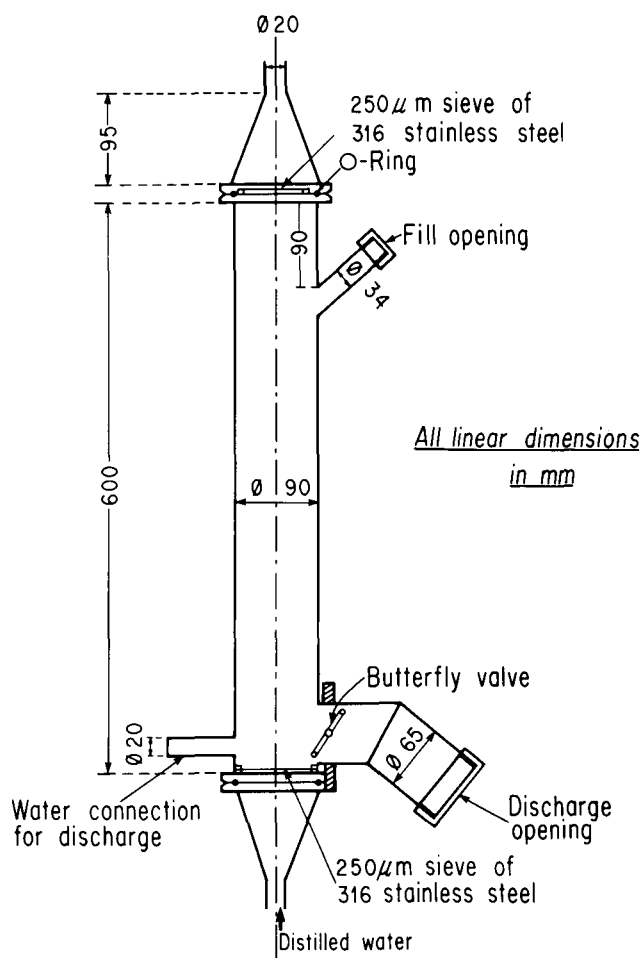

Figure 3
Wash column used for defining of carbon before and after testing

TABLE 1
OPERATING CONDITIONS FOR ABRASION RESISTANCE TESTING

Defining

Sieve apertures	:	0,25 mm
% Bed expansion	:	≃ 100%
Wash time	:	≃ 10 min
Drying	:	24 h at 110 °C
Wetting	:	24 h at 20 °C in distilled water

Abrasion testing

Suspension concentration	:	5 to 60 vol. %
Total suspension volume	:	1 285 cm³
Depth of suspension	:	80 mm (annular section)
Duration of experiment	:	12 h
Cycle time	:	60 s
Acceleration time	:	8,5 s
Deceleration time	:	8,5 s
Maximum rotation speed	:	1 200 r/min

Cycle time and rotation speed

Initial experiments with the abrasion resistance test unit had shown that to maintain visually turbulent flow in the container, the stirring direction had to be alternated at regular time intervals. If this is not done the particles will start moving in a laminar flow pattern, which is likely to result in a reduction in abrasion owing to the smaller degree of particle interaction. The short cycle time of 1 min (inclusive of the fixed acceleration and deceleration periods) was selected to satisfy this requirement.

The rotation speed of the plunger was increased while using a bituminous coal based activated carbon with a high wet particle density, and the speeds where the carbon particles became fully suspended as well as the subsequent point where excessive vortex formation occurred, were noted. The rotation speed of 1 200 r/min, interposed between these two limits, was selected as a practical operating level. The 1 min cycle time and 1 200 r/min rotation speed were used throughout the ensuing experimentation.

Results and discussion

Exploratory experiments

During the initial stages of experimentation, the carbons were used on an as-received basis, i.e. the initial hydraulic defining step had not yet been included. In addition, experiments were not yet done at constant temperature, but were subject to environmental temperature variations between about 15 to 25 °C. Two carbon types, carbon A (lignite based) and carbon B (bituminous coal based), were evaluated. The initial tests on carbon A, to explore the effects of solids concentration on abrasion losses, were done from 5 to 60 vol.%, at 5 vol.% intervals. A similar series of tests were carried out on carbon B, but each concentration was tested in triplicate to assess the reproducibility of the procedure as well. Each experiment was conducted for a period of 12 h. The results are presented in Fig. 4. Salient physical properties of all the carbons used in this study are presented in Table 2.

Up to about 15 vol.% the abrasion losses were essentially constant (approx. 2%) for both carbons. This is likely to be due to the fact that particle-metal interactions predominate here, the extent of which per unit volume of carbon, is largely independent of the carbon concentration. Between 15 to 45 vol.% particle-particle interactions predominate. Because these interactions are highly dependent on the carbon concentration, abrasion losses increase owing to a greater likelihood of particles colliding with one another. Between 45, and 50 to 55 vol.% there is a reduction in abrasion because the energy supplied remains constant while the number of particles in suspension increase progressively, and

because particle movement becomes severely restricted. At concentrations higher than 50 to 55 vol.% abrasion increases again, but this time because intense particle-metal interactions begin taking place when a tightly packed condition is approached.

The performance of both carbons is therefore comparable at a concentration level that could be expected during hydraulic transport ($\simeq 12$ vol.%). However, at a solids concentration of about 40 vol.% (which would be experienced in an adsorber during backwashing at 50% bed expansion), or during other operations that promote particle-particle interaction, the bituminous coal based carbon B outperforms the lignite based carbon A by a factor of more than two.

Standardized procedure

The method presented for determination of abrasion resistance appeared promising, based on the results for the first two carbons. Further refinements were therefore introduced with a view to more rigorous standardization. Temperature fluctuations were believed to have influenced data variability, insofar as viscosity, and therefore drag-force effects on particles in suspension, are temperature dependent. All subsequent experiments were conducted in a temperature controlled environment at 20 °C. The pre-test hydraulic defining procedure, as described in the *Materials and Methods* section, was also introduced at this stage. First attempts at the defining of large batches of carbon resulted in stratification according to particle size. Although the washed product was subsequently mixed manually, even a small degree of incomplete mixing was found to lead to abrasion-loss variability if batches of different particle sizes were taken for testing pur-
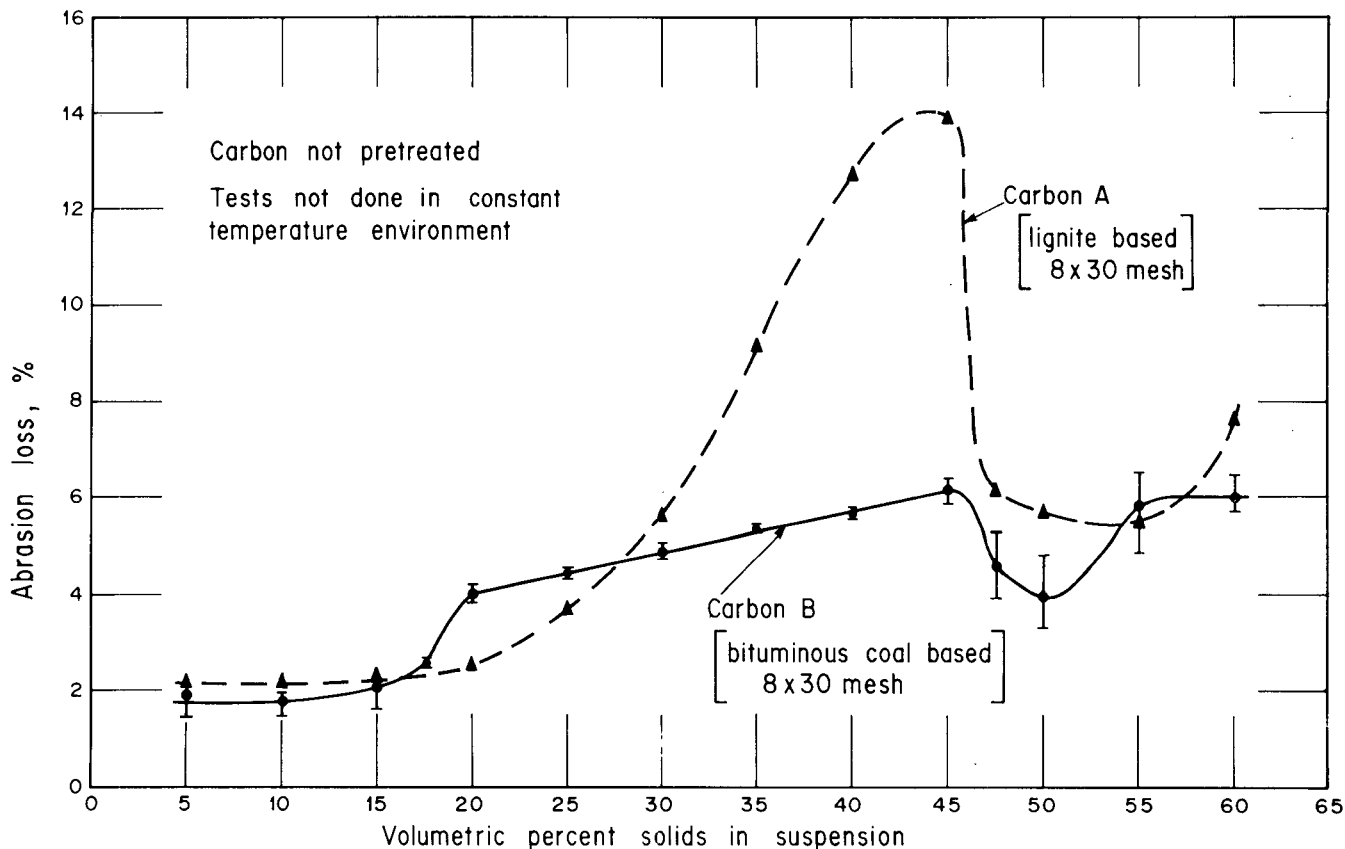

Figure 4
Effect of solids concentration on abrasion loss

poses. The important influence that particle size can have on abrasion loss was confirmed by the results depicted in Fig. 5, which were compiled for sieved particle size fractions of carbon G. In the case of carbon D, however, abrasion loss was insensitive to particle size (for the size range in question). The experimental

TABLE 2
SALIENT PHYSICAL PROPERTIES OF THE CARBONS TESTED

Carbon	Mesh size	Base material	Particle density (g/cm³)	Maximum volumetric concentration (%)	Corresponding packed density (g/cm³)
A	8 x 30	Lignite	0,703	61,0	0,429
B	8 x 30	Bituminous coal	0,855	62,6	0,535
C	Extruded 0,8 mm	Peat	0,616	61,4	0,378
D	1,00-2,50 mm	Lignite	0,673	60,0	0,404
	1,18-1,40 mm		0,660	57,0	0,376
	1,40-1,70 mm		0,644	59,6	0,384
	1,70-2,00 mm		0,654	54,6	0,357
	2,00-2,36 mm		0,607	55,4	0,336
E	0,42-1,40 mm	Anthracite	0,969	55,0	0,533
F	12 x 40	Bituminous coal	0,827	61,7	0,510
G	1,00-1,18 mm	Lignite	0,665	63,3	0,421
	1,18-1,40 mm		0,651	55,9	0,364
	1,40-1,70 mm		0,644	57,1	0,368
	2,00-2,36 mm		0,687	52,3	0,359

procedure was then conservatively fixed to prescribe the hydraulic defining of only slightly more carbon than that required for one abrasion resistance experiment.

Finally, the influence of time on abrasion loss was also investigated. The results, for the bituminous coal based carbon B (with pre-test defining, for 40 vol.% and at constant temperature), are shown in Fig. 6. The abrasion loss experienced for 12 h operation was 6%. Half of this was incurred during the first 3 h of operation, i.e. in 25% of the total time. This initial loss was probably due to the abrading of sharp edges, protrusions and perhaps a disproportionately highly activated and softer outer particle layer. Thereafter the rate of abrasion loss assumed a near constant value, which appears to reflect the characteristic structural resilience of the carbon particles themselves. Ultimately, the gradual reduction in particle size and increase in the concentration of fines will tend to further decrease the rate of abrasion loss, and a test duration of 12 h appears to be realistic and practical.

An extruded peat based activated carbon (carbon C) was tested according to the finalized procedure (as presented in the *Materials and Methods* section), for solids concentrations between 5 to 60 vol.%. The results are presented in Fig. 7. A pattern similar to those for carbon A and B emerged (Fig. 4), in that abrasion losses become greater with increasing solids concentration, reaching a peak around 45 to 50 vol.%. Whereas abrasion losses for the carbons A and B were relatively independent of solids concentrations up to about 15 vol.%, the values for the extruded carbon C gradually increased from the outset (i.e. from 5 vol.%). Nevertheless, the complete curve for the extruded peat based carbon is well below those for the granular bituminous coal and lignite based carbons.
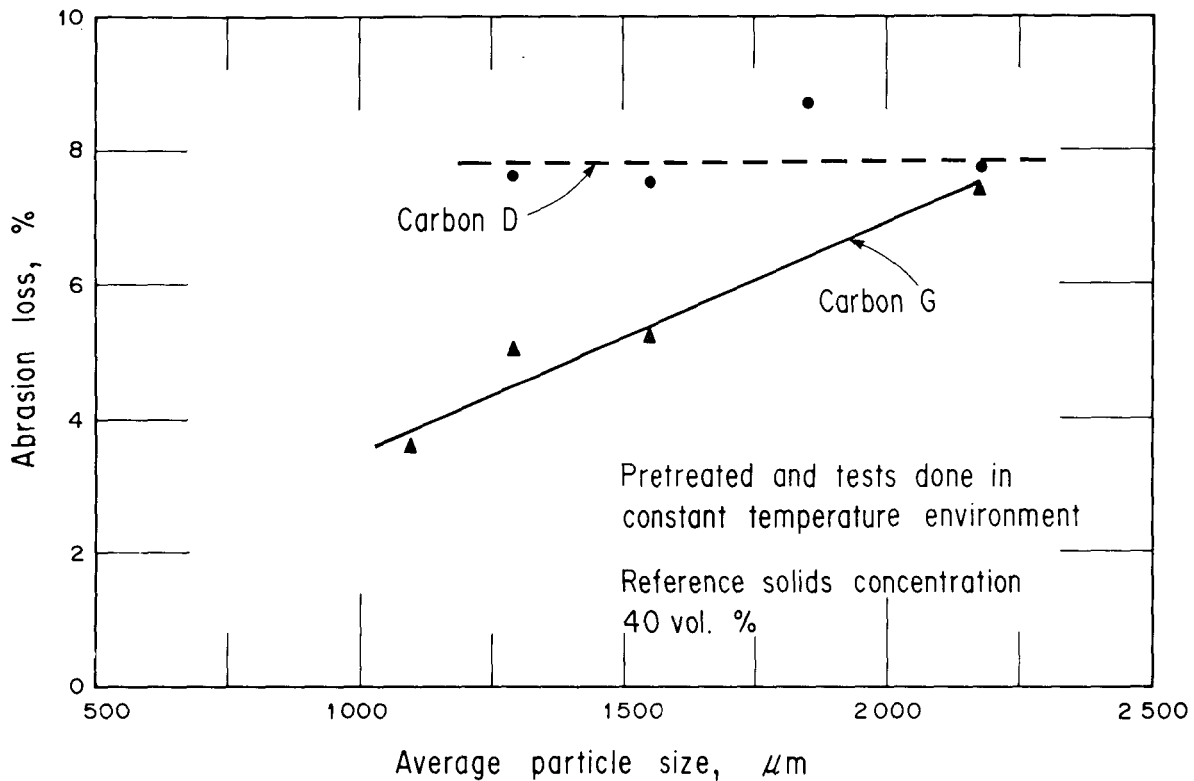

Figure 5
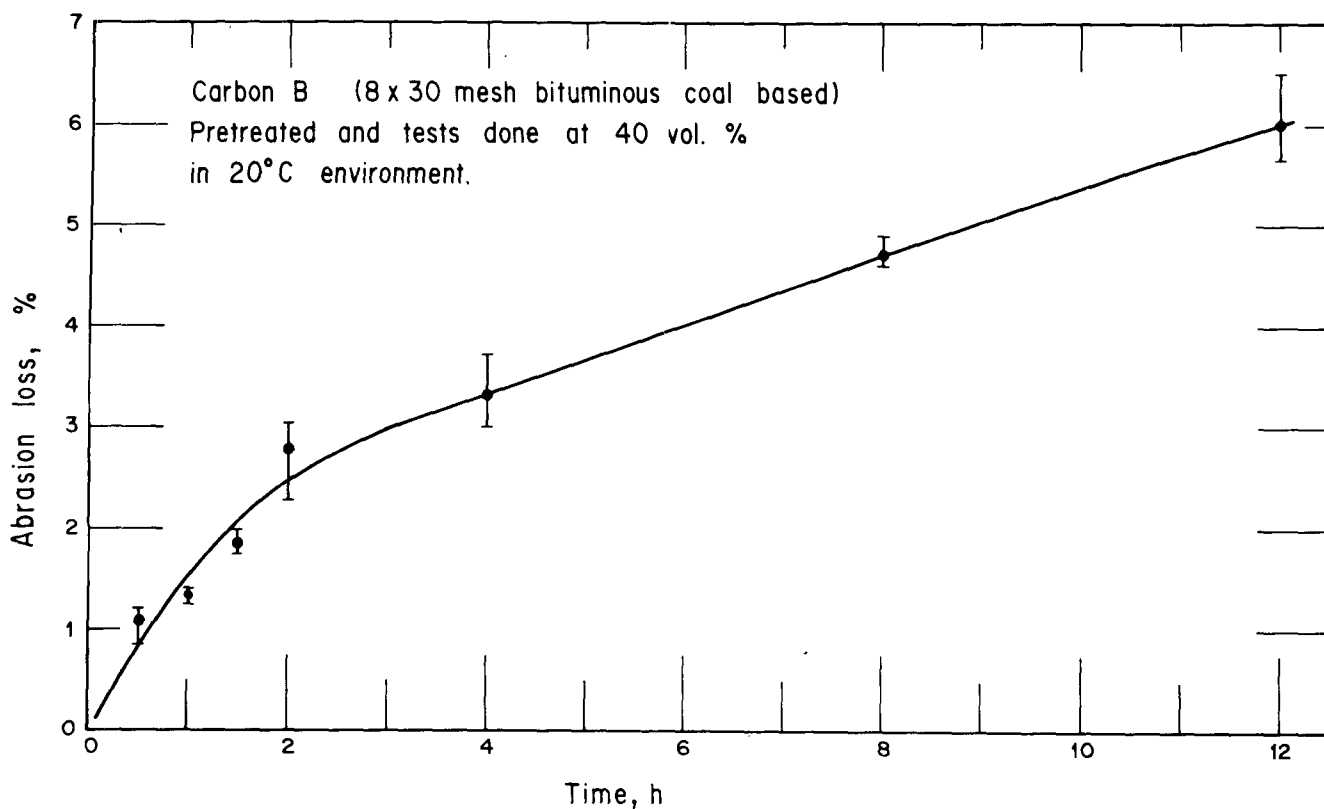*Effect of particle size on abrasion loss*

Figure 6
Abrasion loss as a function of time

Selection of conditions for rapid testing

A reference suspension concentration of 40 vol.% has been selected for relatively rapid comparison of different carbons. This is the concentration typically experienced during backwashing operations, and is also within a concentration regime where particle-particle interactions are considered to predominate during agitation.

A few additional carbons were evaluated under the selected conditions, *viz.* 0,42 to 1,40 mm anthracite based carbon E and 12 x 40 mesh bituminous coal based carbon F. The Ro-tap abrasion test (AWWA, 1974) was carried out on all the carbons considered in this study, except the extruded one. The results, which are listed in Table 3, represent the initiation of a comparative evaluation of these two methods, to include calibration, where possible, with available full-scale plant data. A rigorous comparison of the respective efficacies of the above methods is pending the intended extension of the type of data base illustrated in Table 3, its statistical analysis and correlation with available plant data.

Conclusions

A generalized technique for assessing abrasion resistance has been developed, which is applicable to all types of particulate activated carbons, including extruded and granular particle forms. The method is based on measuring the abrasion losses (i.e. particles < 0,25 mm) incurred when an aqueous suspension of activated carbon is agitated by a rotating plunger.

Abrasion losses are highly dependent on solids concentration, generally peaking at around 40 to 50 vol.%, which is the concentration range experienced during backwashing of an ad-

TABLE 3
COMPARATIVE ABRASION RESISTANCE VALUES FOR DIFFERENT ACTIVATED CARBONS

Carbon type	Mesh size	Base material	AWWA method, % retention of average particle size	Present method, % losses
			Abrasion resistance	
E	0,41-1,40 mm	Anthracite	94	0,3
F	12 x 40	Bituminous coal	91	3,1
C	0,8 mm extruded	Peat	—	3,8
B	8 x 30	Bituminous coal	87	5,7
D	1,0-2,5 mm	Lignite	72	7,4
A	8 x 30	Lignite	75	12,7

sorber. A reference concentration of 40 vol.% has been selected at which to conduct comparative evaluation of different carbons.

Abrasion losses can be insensitive to particle size, or increase with increasing carbon particle size. Care should be taken during sample preparation that representative batches are defined and tested.

During the intial stage of abrasion resistance testing a disproportionately high loss is experienced, probably due to the abrading of sharp edges, protrusions and a softer outer particle layer. Thereafter the rate of abrasion loss assumes a near constant value. A test duration of 12 h includes both the initial rapid and subsequent steady types of loss.
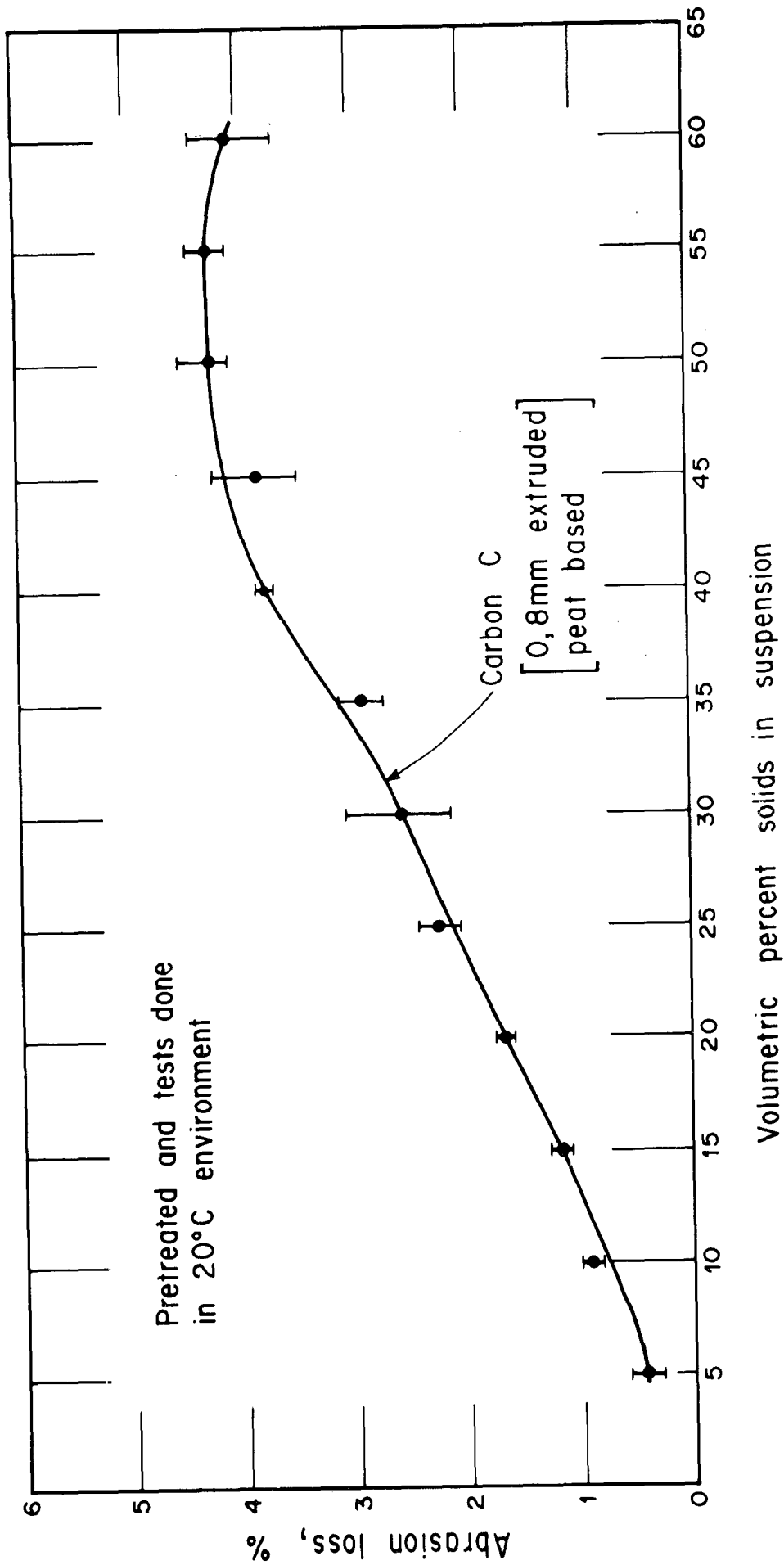
Figure 7
Effect of solids concentration on abrasion loss for an extruded carbon

An extruded peat based carbon was found to perform on par with a 12 x 40 mesh bituminous coal based carbon (in terms of abrasion resistance measured according to the method presented). The performance of a bituminous coal based carbon of larger mesh size (8 x 30) was not as good and two lignite based carbons recorded the highest losses. An anthracite based carbon's performance was unsurpassed with only 0,3% abrasion loss. (In the ultimate selection of a carbon, cost aspects must be taken into consideration, together with quality considerations.)

Ongoing work focuses on a comparison of the respective efficacies of the AWWA Ro-tap method and the present method, and the correlation of resulting data with plant results.

Acknowledgements

Mention of proprietory names does not constitute endorsement or recommendation.

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