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# Impact of Conversion to low-$NO_x$ Combustion on Fly Ash Quality: Investigation of a Unit Burning High-sulfur Coal

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ABSTRACT

The Center for Applied Energy Research has studied several conversions to low-$NO_x$ combustion, following the impact of the conversion on the fly ash petrology, in particular the amount and forms of carbon present before and after conversion, and on the fly ash chemistry and mineralogy. In this study, a large unit burning Western Kentucky high-sulfur coal produced a marketable fly ash prior to conversion. Fly ash carbon increased following $NO_x$ conversion, but not enough to push the fly ash to unmarketable levels.

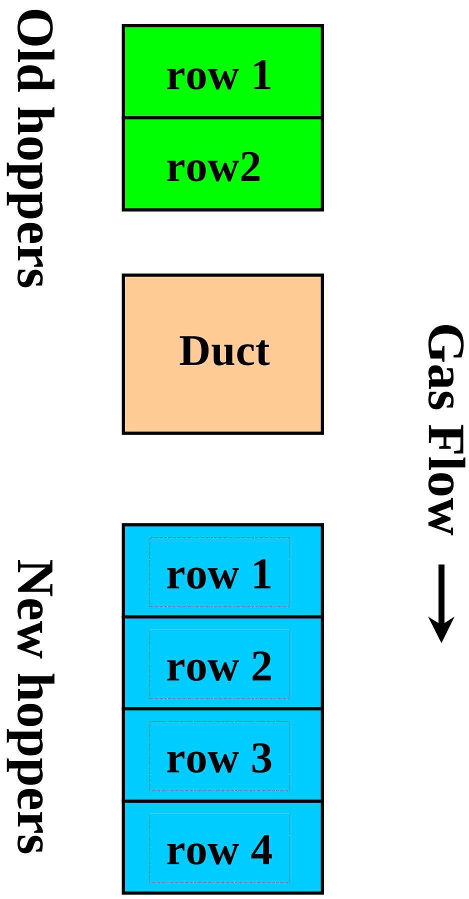
## INTRODUCTION

Previous studies at the CAER demonstrated that, in general, fly ash carbon will increase following the conversion to low-$NO_x$ combustion. These studies have included the investigations of a wall-fired unit burning low-S western US bituminous and subbituminous coal,[1] wall- fired[2] and tangentially-fired[3] units burning medium-S Central Appalachian high volatile A bituminous blends, and wall- and tangentially-fired units burning high-S Illinois Basin high volatile B/C bituminous blends.[4] Of these units, only the tangentially-fired unit burning Central Appalachian coal showed a decrease in fly ash carbon following conversion to low-$NO_x$ combustion.[3]

In this study, a large (>1000 MW), wall-fired unit burning high-S Western Kentucky coal produced fly ash with negligible carbon prior to conversion. The impact of the conversion to low-$NO_x$ combustion is of more concern in this case than in the previous studies where the fly ash was generally not marketed. Fly ash chemistry and petrology are used to describe the changes in the fly ash quality related to the $NO_x$ conversion.

## PROCEDURE

Fly ash and pulverized feed coal were collected at two different times: July 1998, prior to $NO_x$ conversion; and in March 1999, following stabilization of the burn after the conversion. Fly ash was collected from at least one ESP hopper per row from the two rows of the “old precipitators,” the duct hopper, and the four rows of “new precipitators.” The relative position of the ESP hoppers is shown on Figure 1.




Coal from pulverizer sampling, not coincident in time with the fly ash sampling; and fly ash from the first row of the old ESP hoppers, the duct hopper, and the first row of the new ESP hoppers were sized at 100, 200, 325, and 500 mesh. All of the primary and sized samples were analyzed at the CAER for carbon content (via ultimate analysis, using standard techniques for coal) and petrographic constituents. The latter were determined using polished, epoxy-mounted pellets with oil-immersion optics at a magnification of 500x. Fly ash categories are based on previous investigations at the CAER, as outlined by Hower et al. [5] (Table 1).

*Figure 1 (left). Relative position of the ESP hoppers. Fly ash samples subject to size analysis were taken from the first row of the old hoppers, the duct hopper, and the first row of the new hoppers.*

*Table 1 (below). Classification of microscopic constituents in coal-derived fly ash after references 1-5.*

*Microscopic Classification of Fly Ash Constituents*

- *Inorganic*
  *neoformed*
  - *glass*
    - *70 to >90% of most FA*
  - *mullite*
  - *spinel*
- *Inorganic*
  *coal derived*
  - *quartz*
- *Organic*
  *neoformed*
  - *isotropic coke*
  - *anisotropic coke*
- *Organic*
  *coal (or fuel) derived*
  - *inertinite*
  - *petroleum coke*

DISCUSSION

*Coal*. The pulverized coal is dominated by vitrinite and, consequently, vitrinite-rich microlithotypes (Table 2). This is particularly true in the finer fractions which dominate the size distribution of the coal feed. The post-conversion coal is finer than the pre-conversion feed, note the relative abundances of the 325 x 500 mesh and -500 mesh fractions (Figure 2). Coal rank is higher in the post-conversion feed coal, with a wider blend of high volatile C through A bituminous coal represented (Table 2). The total sulfur is lower in the post-conversion coal blend.

A.

| sample | size | % of total | mois. | ash | sulfur | Vit | Fus | Sfs | Mic | Mac | Exn | Res | Min |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 92566 | whole | | 4.14 | 9.93 | 3.13 | 85.9 | 5.4 | 2.4 | 0.6 | 0.0 | 2.8 | 0.0 | 2.6 |
| 1 July 98 | +100 | 4.61 | 3.37 | 7.96 | 2.83 | 82.4 | 3.0 | 4.0 | 0.4 | 0.0 | 7.6 | 0.8 | 1.8 |
| pre-NOx | 100x200 | 26.06 | 3.08 | 7.87 | 3.13 | 88.2 | 3.8 | 3.0 | 0.4 | 0.2 | 3.2 | 0.0 | 1.2 |
| | 200x325 | 23.71 | 2.96 | 9.06 | 3.55 | 84.8 | 4.0 | 3.8 | 0.4 | 0.0 | 3.6 | 0.2 | 3.2 |
| | 325x500 | 12.10 | 3.04 | 8.71 | 3.59 | 90.2 | 3.8 | 2.0 | 0.2 | 0.0 | 2.2 | 0.0 | 1.6 |
| | -500 | 33.52 | 3.93 | 13.60 | 3.19 | 90.2 | 5.0 | 3.2 | 0.0 | 0.0 | 1.0 | 0.0 | 0.6 |
| | | | | | | | | | | | | | |
| 92617 | whole | | 2.92 | 10.11 | 3.15 | 85.0 | 6.8 | 4.6 | 0.0 | 0.0 | 2.8 | 0.0 | 0.8 |
| 24 Mar 99 | +100 | 2.78 | 2.32 | 9.31 | 2.83 | 81.6 | 5.6 | 4.8 | 0.0 | 0.0 | 6.6 | 0.0 | 1.4 |
| post-NOx | 100x200 | 21.15 | 3.25 | 7.95 | 2.92 | 84.2 | 4.0 | 6.0 | 0.0 | 0.0 | 5.2 | 0.0 | 0.6 |
| | 200x325 | 21.53 | 2.98 | 8.37 | 3.25 | 88.4 | 3.2 | 3.2 | 0.2 | 0.0 | 3.4 | 0.0 | 1.6 |
| | 325x500 | 18.48 | 1.62 | 8.42 | 3.33 | 87.2 | 4.6 | 3.2 | 0.0 | 0.0 | 3.4 | 0.0 | 1.6 |
| | -500 | 36.06 | 2.49 | 13.84 | 2.75 | 91.2 | 3.4 | 3.6 | 0.0 | 0.0 | 0.4 | 0.0 | 1.4 |

B.

| sample | size | % of total | Vt | Lp | In | Cl | Du | Vi | Dc | Cd | Vl | Cm |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 92566 | whole | | 51.0 | 0.2 | 3.6 | 9.6 | 0.2 | 8.2 | 14.1 | 2.4 | 1.0 | 9.8 |
| 1 July 98 | +100 | 4.61 | 23.0 | 0.4 | 1.6 | 21.4 | 0.4 | 4.6 | 29.0 | 2.8 | 1.0 | 15.8 |
| pre-NOx | 100x200 | 26.06 | 35.2 | 0.0 | 1.2 | 16.0 | 0.6 | 5.6 | 26.0 | 1.8 | 0.2 | 13.4 |
| | 200x325 | 23.71 | 47.6 | 0.2 | 3.0 | 11.2 | 0.0 | 4.6 | 17.0 | 1.8 | 0.4 | 14.2 |
| | 325x500 | 12.10 | 55.4 | 0.0 | 2.6 | 13.4 | 0.4 | 8.2 | 11.0 | 1.0 | 0.0 | 8.0 |
| | -500 | 33.52 | 81.0 | 0.2 | 6.8 | 4.2 | 0.0 | 2.6 | 2.6 | 0.0 | 0.2 | 2.4 |
| | | | | | | | | | | | | |
| 92617 | whole | | 58.6 | 0.2 | 7.6 | 10.4 | 0.2 | 5.4 | 12.6 | 1.4 | 0.6 | 3.0 |
| 24 Mar 99 | +100 | 2.78 | 32.6 | 0.4 | 1.4 | 14.8 | 1.0 | 6.0 | 28.8 | 5.8 | 1.0 | 8.2 |
| post-NOx | 100x200 | 21.15 | 46.6 | 0.4 | 2.8 | 15.4 | 1.0 | 6.8 | 16.8 | 3.0 | 1.2 | 6.0 |
| | 200x325 | 21.53 | 55.4 | 0.0 | 2.4 | 10.2 | 0.4 | 5.6 | 19.2 | 1.2 | 0.0 | 5.6 |
| | 325x500 | 18.48 | 66.8 | 0.2 | 5.4 | 9.0 | 0.8 | 4.0 | 8.6 | 0.8 | 0.2 | 4.2 |
| | -500 | 36.06 | 86.2 | 0.0 | 5.8 | 1.8 | 0.4 | 2.0 | 2.0 | 0.0 | 0.0 | 1.8 |

C.

| Sample | Rmax | s.d. | v4 | v5 | v6 | v7 | v8 | v9 |
|---|---|---|---|---|---|---|---|---|
| 92566 | 0.57 | 0.04 | 2 | 70 | 26 | 2 | | |
| 92617 | 0.65 | 0.15 | 12 | 40 | 12 | 10 | 20 | 6 |

*Table 2. A/ Ash, sulfur, and maceral content of whole coal and size fractions, B/ Microlithotype content of whole coal and size fractions, and C/ vitrinite maximum reflectance and V-types of whole coal.*

*Macerals: Vit - vitrinite, Fus - fusinite, Sfs - semifusinite, Mic - micrinite, Mac - macrinite, Lip - liptinite, Res - resinite, Min - minerals*

*Microlithotypes: monomaceral: Vt - vitrite, Lp - liptite, In - inertite*

*bimaceral: Cl - clarite, Du - durite, Vi - vitrinertite*

*trimaceral: Dc - duroclarite, Cd - clarodurite, Vl - vitrinertoliptite, Cm - carbominerite*

*V-types (v4, etc,): v4 is* $0.40 \leq R_{max} \leq 0.49$*, etc.*

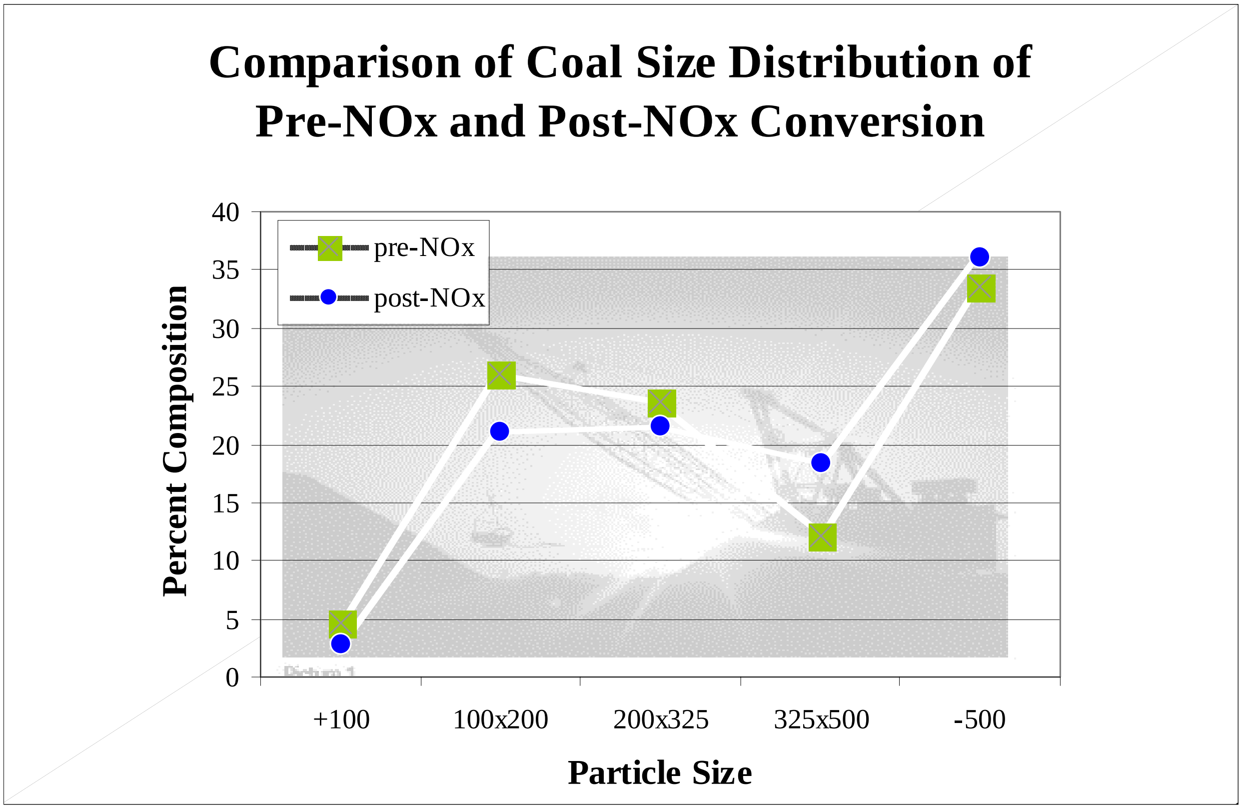



*Figure 2. Relative size distribution of pre- and post-conversion pulverized coal feed.*

*Fly ash*. As noted above, selected paths through the array of ESP hoppers were selected for sampling. With over 200 hoppers, it was not feasible to sample all bins, as can be done at smaller plants. Among the sampled bins, the glass content increases (Table 3) and the particle size decreases from the old precipitators to the new precipitators. In general, the latter trends also occur from the first through the last row of the new precipitators. Each row, removes a large percentage of the fly ash, about 80%, with the finer ash passing through to the next row. The duct hopper, between the old and new precipitators, capture a heavier, coarser fly ash than either set of ESP hoppers. The duct fly ash is particularly rich in spinel, particularly when compared to the new precipitators.

Fly ash from the first row of the old precipitators, from the duct hopper, and from the first row of the new hoppers was subjected to size analysis. Comparison of the relative amounts of the size fractions are shown on Figure 3. The ash, carbon, and fly ash petrography of the size fractions is given in Table 4. The post-$NO_x$ old precipitator ash is coarser than the pre-$NO_x$ fly ash. Some of the contrast is due to the increased carbon in the post-conversion fly ash. The post-conversion carbon in the +100 mesh fraction, 0.45% (ultimate analysis), is low, but still considerably higher than the 0.07% C in the equivalent pre-conversion fraction. The contrast is even more striking when the petrographic analysis are considered, as the pre-conversion fly ash has only trace quantities of carbon forms.

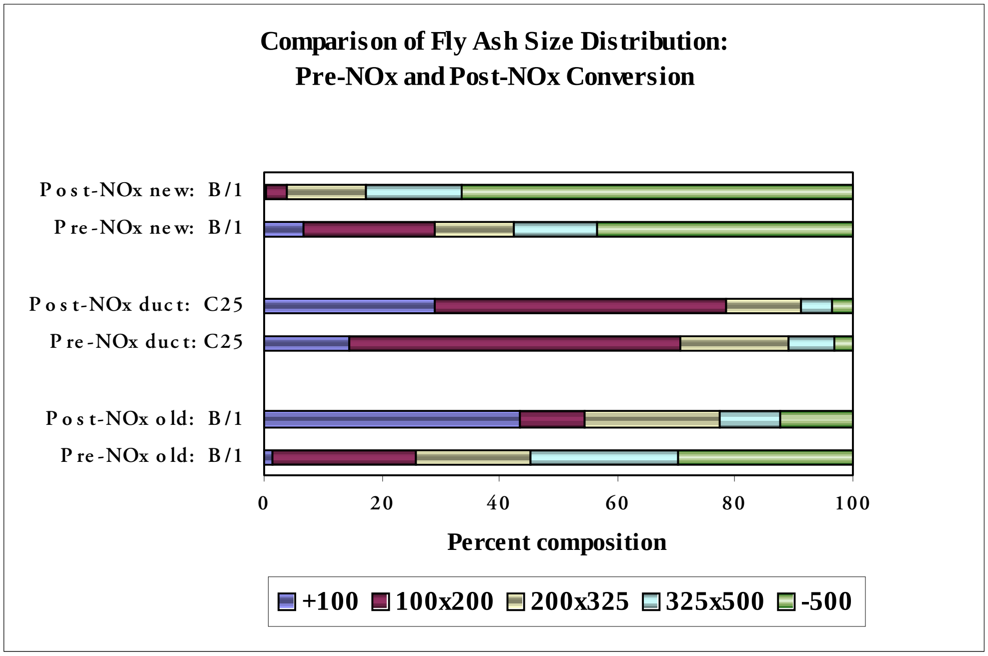



*Figure 3. Relative size distribution of selected pre- and post-$NO_x$ conversion fly ashes.*

.

| Date | location | field/row | sample | Ash | Carbon | glass | mullite | spinel | quartz | isotropic coke | anisotropic coke | inertinite |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 July 98 | comp. ALF-1 | | 92567 | 99.18 | <0.01 | 93.4 | 0.2 | 6.2 | 0.2 | 0.0 | 0.0 | 0.0 |
| pre-NOx | comp. ALF-2 | | 92568 | 99.06 | <0.01 | 95.2 | t | 4.8 | 0.0 | 0.0 | 0.0 | 0.0 |
| | old precip. | A/1 | 92569 | 99.73 | <0.01 | 88.2 | 0.2 | 11.2 | 0.4 | 0.0 | 0.0 | 0.0 |
| | old precip. | A/2 | 92570 | 99.20 | <0.01 | 84.0 | 0.4 | 14.6 | 1.0 | 0.0 | 0.0 | 0.0 |
| | old precip. | B/1 | 92571 | 99.77 | <0.01 | 85.6 | 0.8 | 12.4 | 1.2 | 0.0 | 0.0 | 0.0 |
| | old precip. | B/2 | 92572 | 99.23 | <0.01 | 85.0 | 0.2 | 13.8 | 0.8 | t | 0.0 | 0.2 |
| | duct | C25 | 92573 | 98.91 | <0.01 | 80.6 | 0.8 | 14.6 | 4.0 | t | 0.0 | t |
| | new precip. | B/1 | 92574 | 99.61 | <0.01 | 93.0 | 0.0 | 6.2 | 0.8 | 0.0 | 0.0 | t |
| | new precip. | B/2 | 92575 | 99.00 | <0.01 | 93.0 | 0.4 | 6.4 | 0.2 | 0.0 | 0.0 | 0.0 |
| | new precip. | B/3 | 92576 | 97.68 | <0.01 | 98.0 | 0.0 | 2.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| | new precip. | B/4 | 92577 | 97.31 | <0.01 | 99.5 | 0.0 | 0.5 | 0.0 | 0.0 | 0.0 | 0.0 |
| | new precip. | C/1 | 92578 | 99.32 | <0.01 | 90.6 | 0.0 | 8.0 | 1.2 | 0.0 | 0.0 | 0.2 |
| | new precip. | C/2 | 92579 | 98.88 | <0.01 | 96.0 | 0.0 | 3.6 | 0.4 | 0.0 | 0.0 | 0.0 |
| | new precip. | C/3 | 92580 | 98.73 | <0.01 | 95.4 | 0.0 | 4.2 | 0.4 | 0.0 | 0.0 | t |
| | new precip. | C/4 | 92581 | 97.64 | <0.01 | 98.8 | 0.0 | 1.2 | 0.0 | t | 0.0 | 0.0 |
| 24 Mar 99 | composite | | 92618 | 99.17 | 0.15 | 91.8 | 0.2 | 5.8 | 0.0 | 1.6 | 0.4 | 0.2 |
| post-NOx | old precip. | A/1 | 92619 | 99.78 | 0.07 | 87.0 | 0.8 | 10.2 | 0.0 | 1.2 | 0.6 | 0.2 |
| | old precip. | B/1 | 92620 | 99.96 | <0.01 | 88.0 | 0.4 | 10.0 | 0.0 | 1.2 | 0.4 | 0.0 |
| | old precip. | C/1 | 92621 | 99.65 | 0.14 | 83.6 | 1.0 | 11.4 | 0.0 | 3.0 | 0.6 | 0.4 |
| | duct | C25 | 92622 | 99.50 | 0.21 | 85.2 | 0.6 | 11.8 | 0.0 | 1.6 | 0.6 | 0.2 |
| | new precip. | B/1 | 92623 | 99.68 | 0.05 | 92.4 | 0.0 | 6.0 | 0.0 | 1.2 | 0.2 | 0.2 |
| | new precip. | B/2 | 92624 | 99.35 | 0.14 | 96.4 | 0.0 | 3.2 | 0.0 | 0.4 | 0.0 | 0.0 |
| | new precip. | B/3 | 92625 | 98.49 | 0.14 | 96.6 | 0.0 | 2.4 | 0.0 | 1.0 | 0.0 | 0.0 |
| | new precip. | B/4 | 92626 | 98.61 | 0.14 | 94.6 | 0.0 | 3.4 | 0.0 | 1.6 | 0.0 | 0.4 |
| | new precip. | C/1 | 92627 | 99.38 | 0.36 | 93.6 | 0.0 | 5.2 | 0.0 | 0.8 | 0.4 | 0.0 |
| | new precip. | C/2 | 92628 | 98.88 | 0.61 | 91.6 | 0.0 | 6.4 | 0.0 | 1.8 | 0.2 | 0.0 |
| | new precip. | C/3 | 92629 | 98.49 | 0.68 | 92.2 | 0.0 | 4.6 | 0.0 | 2.6 | 0.6 | 0.0 |
| | new precip. | C/4 | 92630 | 97.88 | 0.43 | 96.4 | 0.2 | 2.8 | 0.0 | 0.6 | 0.0 | 0.0 |

*Table 3. Ash, carbon, and fly ash petrographic constituents of whole fly ashes.*

| | bin | sample | | wt. % | Ash | Carbon | glass | mullite | spinel | quartz | isotropic coke | anisotropic coke | inertinite |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 Jul 98 pre-NOx | old: B/1 | 92571 | whole | | 99.77 | <0.01 | 85.6 | 0.8 | 12.4 | 1.2 | 0.0 | 0.0 | 0.0 |
| | | | +100 | 1.45 | 98.93 | 0.07 | 84.6 | 0.4 | 13.4 | 1.6 | t | 0.0 | 0.0 |
| | | | 100x200 | 24.23 | 98.56 | 0.14 | 89.4 | 0.0 | 9.4 | 1.2 | 0.0 | 0.0 | t |
| | | | 200x325 | 19.49 | 99.16 | 0.04 | 86.8 | 0.2 | 12.4 | 0.6 | 0.0 | 0.0 | 0.0 |
| | | | 325x500 | 25.15 | 99.00 | 0.11 | 84.4 | 0.4 | 14.6 | 0.6 | 0.0 | t | 0.0 |
| | | | -500 | 29.67 | 97.85 | 0.15 | 75.0 | 0.0 | 24.6 | 0.4 | 0.0 | 0.0 | 0.0 |
| | duct: C25 | 92573 | whole | | 98.91 | <0.01 | 80.6 | 0.8 | 14.6 | 4.0 | t | 0.0 | t |
| | | | +100 | 14.48 | 99.44 | 0.01 | 81.6 | 0.6 | 16.8 | 0.6 | t | 0.0 | 0.4 |
| | | | 100x200 | 56.34 | 98.41 | 0.07 | 87.8 | 0.4 | 11.0 | 0.6 | 0.0 | t | 0.2 |
| | | | 200x325 | 18.16 | 98.36 | 0.01 | 83.0 | 0.4 | 16.0 | 0.6 | 0.0 | 0.0 | t |
| | | | 325x500 | 7.80 | 99.19 | 0.01 | 66.0 | 0.2 | 33.2 | 0.6 | 0.0 | 0.0 | 0.0 |
| | | | -500 | 3.23 | 97.58 | 0.26 | 54.2 | 0.0 | 45.6 | 0.2 | 0.0 | 0.0 | 0.0 |
| | new: B/1 | 92574 | whole | | 99.61 | <0.01 | 93.0 | 0.0 | 6.2 | 0.8 | 0.0 | 0.0 | t |
| | | | +100 | 6.64 | 99.45 | 0.01 | 84.8 | 1.6 | 11.8 | 1.4 | 0.4 | 0.0 | 0.0 |
| | | | 100x200 | 22.43 | 98.76 | 0.01 | 79.0 | 0.6 | 18.2 | 2.4 | 0.0 | 0.0 | t |
| | | | 200x325 | 13.29 | 98.56 | 0.08 | 81.4 | 0.4 | 16.6 | 1.6 | 0.0 | 0.0 | t |
| | | | 325x500 | 14.01 | 98.72 | 0.14 | 82.4 | 0.0 | 17.2 | 0.4 | 0.0 | 0.0 | 0.0 |
| | | | -500 | 43.62 | 98.63 | 0.01 | 90.0 | 0.0 | 10.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 24 Mar 99 post-NOx | old: B/1 | 92621 | whole | | 99.65 | 0.14 | 83.6 | 1.0 | 11.4 | 0.0 | 3.0 | 0.6 | 0.4 |
| | | | +100 | 43.38 | 96.80 | 0.45 | 87.2 | 0.8 | 9.8 | 0.0 | 1.6 | 0.4 | 0.2 |
| | | | 100x200 | 11.16 | 98.46 | 0.48 | 85.6 | 0.4 | 7.8 | 0.0 | 4.6 | 1.2 | 0.4 |
| | | | 200x325 | 22.73 | 98.44 | 0.22 | 82.6 | 0.2 | 14.6 | 0.0 | 2.4 | 0.0 | 0.2 |
| | | | 325x500 | 10.48 | 99.12 | 0.15 | 83.4 | 0.4 | 14.2 | 0.0 | 1.8 | 0.2 | 0.0 |
| | | | -500 | 12.25 | 98.13 | 0.19 | 83.2 | 0.0 | 15.8 | 0.0 | 0.8 | 0.0 | 0.2 |
| | duct: C25 | 92622 | whole | | 99.50 | 0.21 | 85.2 | 0.6 | 11.8 | 0.0 | 1.6 | 0.6 | 0.2 |
| | | | +100 | 28.84 | 98.72 | 0.30 | 86.0 | 0.6 | 10.4 | 0.0 | 2.2 | 0.6 | 0.2 |
| | | | 100x200 | 49.64 | 98.53 | 0.30 | 81.2 | 0.2 | 16.0 | 0.0 | 2.0 | 0.2 | 0.4 |
| | | | 200x325 | 12.55 | 98.40 | 0.28 | 77.0 | 0.0 | 21.6 | 0.0 | 1.4 | 0.0 | 0.0 |
| | | | 325x500 | 5.43 | 98.77 | 0.28 | 72.8 | 0.0 | 26.2 | 0.0 | 0.8 | 0.2 | 0.0 |
| | | | -500 | 3.54 | 94.40 | 0.44 | 77.6 | 0.0 | 21.4 | 0.0 | 0.8 | 0.0 | 0.2 |
| | new: B/1 | 92623 | whole | | 99.68 | 0.50 | 92.4 | 0.0 | 6.0 | 0.0 | 1.2 | 0.2 | 0.2 |
| | | | +100 | 0.28 | 98.04 | 0.60 | 87.5 | 0.5 | 8.5 | 0.0 | 2.5 | 1.0 | 0.0 |
| | | | 100x200 | 3.78 | 97.94 | 0.46 | 90.8 | 0.4 | 6.2 | 0.0 | 1.6 | 0.8 | 0.2 |
| | | | 200x325 | 13.38 | 98.00 | 0.30 | 91.6 | 0.0 | 7.6 | 0.0 | 0.6 | 0.0 | 0.2 |
| | | | 325x500 | 15.99 | 98.42 | 0.22 | 89.6 | 0.0 | 9.8 | 0.0 | 0.6 | 0.0 | 0.0 |
| | | | -500 | 66.57 | 98.24 | 0.08 | 93.8 | 0.0 | 5.8 | 0.0 | 0.4 | 0.0 | 0.0 |

*Table 4. Ash, carbon, and petrographic constituents of size fractions of selected fly ashes.*

The pre-conversion duct fly ash had a higher spinel content than the post-conversion ash, as seen in the high spinel percentages in the finer fractions. Much of the spinel content of the coarser fractions is actually composed of welded -325 mesh spinels (Figure 4). With the duct fly ash, the coarser fractions actually dominate the size distribution.

In contrast to the fly ash from the old precipitators, the post-conversion ash from the new precipitators is finer than the equivalent pre-conversion ash. Much of the difference lies in the large amount of +200 mesh ash, 29% vs. 4%, in the pre-conversion ash vs. the post-conversion ash. In this case, the greater percentage of spinels in the pre-conversion ash may offset the increase in carbon in the post-conversion ash. The decrease in spinel content in all of the post-conversion fly ashes is likely a consequence of the decreased sulfur, and consequently $Fe_2O_3$ in the associated pyrite, content of the post-conversion feed coal.

*Figure 4. Welded spinels from the +100 mesh fraction of KCER-92573, the pre-conversion duct fly ash. The field of view is 200 microns on the long axis of the photo. Oil-immersion, reflected-light optics. Slide 412-14.*

Overall, the conversion to low-$NO_x$ combustion studied here did result in an increase in the carbon content of the fly ash. Starting from a base of negligible carbon, some increase could have been anticipated. The increased fineness of the post-conversion feed was likely a factor in preventing a greater increase in carbon than was actually noted. In the one previous study where we found a post-conversion decrease in fly ash carbon,[3] the increase in -500 mesh coal vs. the decrease in +100 mesh coal was one important factor identified as a contributor to the improved fly ash quality. In the present study, the increase in fly ash carbon was not severe enough to seriously impact the marketing of the fly ash.

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