

Considering switching to PRB coal? Don't let fuel system limitations stop you



COAL USERS' GROUP

After Michigan's Consumers Energy Co. decided to reduce the fuel costs and emissions of one of its units by switching to PRB coal, the utility realized that the change would require modifications to the unit's fuel-handling systems. Thanks to those changes—most notably, the upgrading of pulverizers—the unit has been able to maintain its capacity rating while firing PRB coal exclusively.

By **Stanley E. Kmiotek, PE**, Alstom Power Inc. and **Herbert A. Blue Jr., James P. Pomaranski, PE**, and **Richard I. Pellegrum**, Consumers Energy Co.

One of the largest engineering challenges of switching to Powder River Basin (PRB) coal is making changes to plant fuel-handling and conveying systems. There have been cases in which it was impossible to maintain a unit's maximum continuous rating (MCR) after a switch to PRB or a low-rank western coal because such a switch requires about a 20% increase in total coal flow.

Insufficient pulverizer capacity is usually one of the primary factors that prevent a unit from reaching its MCR after a fuel switch. The fuel flow constraints typically affect various parts of the system and manifest as inadequate airflow in exhausters, too-low primary air temperature, and/or insufficient power available for pulverizer system motors. In addition, the fineness of coal coming from existing pulverizers must be maintained to ensure that unburned carbon levels remain acceptable. The bottom line is this: Switching to PRB coal requires a very careful engineering analysis of a unit's entire fuel transport system; otherwise, some anticipated fuel-cost savings could be siphoned off in the form of capital equipment upgrades.

The 265-MW Unit 1 of Consumers Energy Co.'s (CEC) J.H. Campbell Generating Station on the shore of Lake Michigan (Figure 1) was designed and built by Combustion Engineering (now Alstom Power) and commissioned in 1962. The boiler is a controlled-circulation, balanced-draft, divided-furnace, radiant-reheat, tilt-

PRB Coal Users' Group

The PRB Coal Users' Group (www.lookingcube.com/prbcoals) promotes the safe, efficient, and economic use of Powder River Basin coals by generating companies that currently use, or are considering the use of, PRB coals. Alstom Power Inc. and Consumers Energy Co. (whose staff authored this article) are members of the group. The PRB Coal Users' Group's annual meeting will be held in conjunction with the Electric Power Expo (www.electricpowerexpo.com), April 5–7, 2005, in Chicago, Ill.



1. Upgraded for cost and environmental reasons. Consumers Energy Co.'s 265-MW J.H. Campbell Generating Station was originally designed and built by Combustion Engineering and commissioned in 1962. Unit 3 is on the left; Units 1 and 2 are on the right. *Courtesy: Alstom*

ing tangential burner-fired steam generator. Original MCR main steam flow for the boiler was 1,750,000 lb/hr with superheat outlet conditions of 2,450 psig and 1,050F. Reheat steam flow at MCR was designed to be 1,450,000 lb/hr at 1,000F. The boiler has been operating at approximately 1,900,000 lb/hr of main steam flow since the mid-1960s.

Unit 1's boiler was designed to burn Midwestern bituminous coal crushed by five pulverizers and pneumatically transported to five elevations in each of the eight corners of the divided furnace. The original design called for the raw coal to have a heat content of 10,700 Btu/lb, a Hardgrove Grindability Index (HGI) of 55, and a moisture content of 14%. To attain full load, four of the five pulverizers operated at 51,500 lb/hr during the early years of operation despite exhibiting coal spillage and fineness problems. Although many pulverizer modifications were made at the site, it was not until the installation of a vane wheel in the early 1980s that the unit's coal mills were able to operate at near design capacity. Prior to that, the mills were airflow-limited, due in part to higher-than-expected draft losses downstream of the pulverizer.

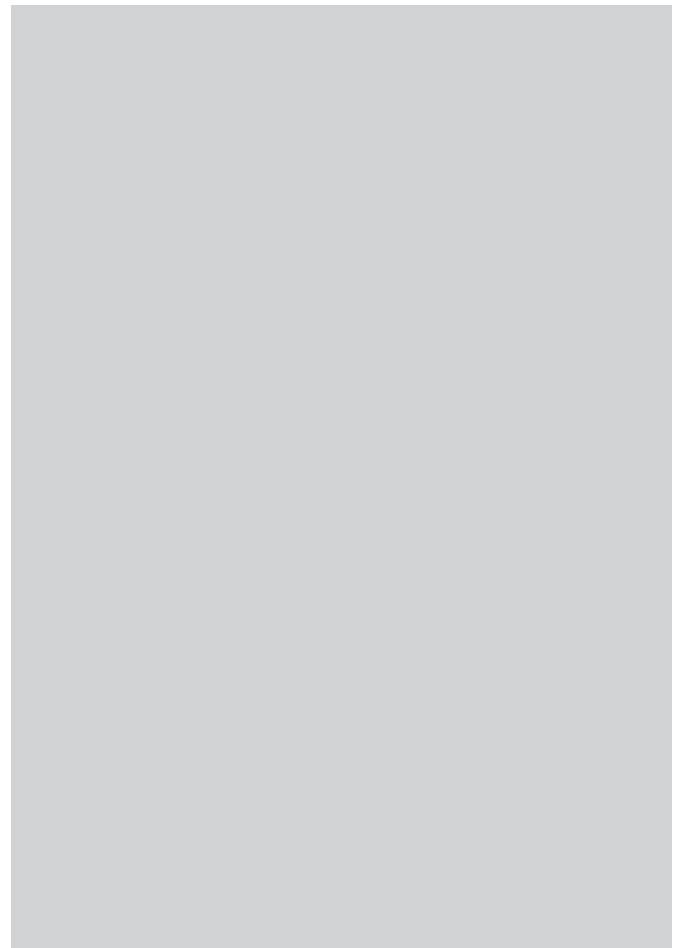
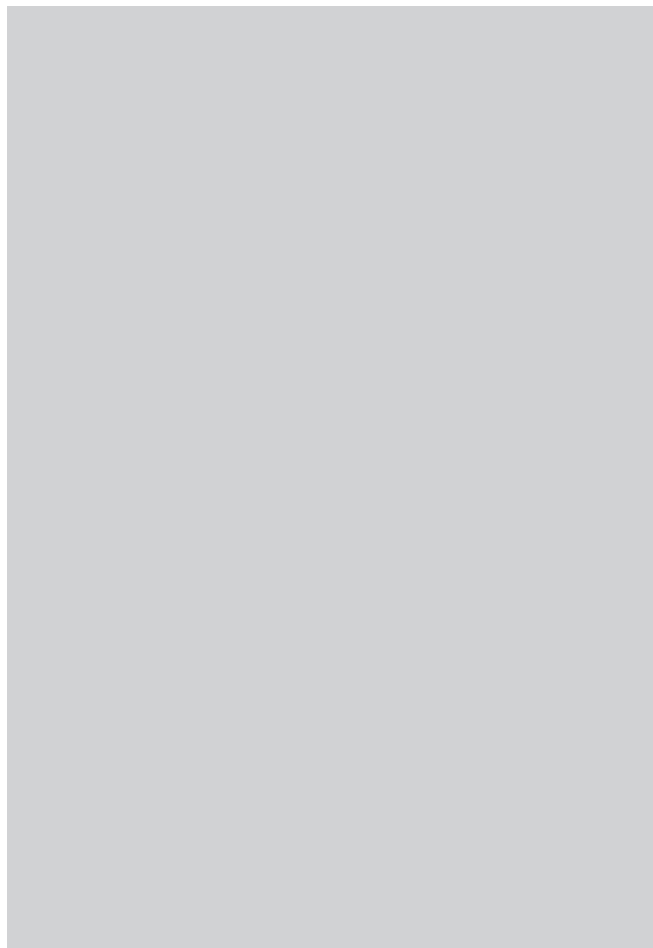
Blended coal to start

In the early 1990s CEC—a subsidiary of CMS Energy Corp.—began a fleetwide program to switch to a blend of 30% Western and 70% Eastern coal to reduce the cost of generation. As part of the switch, a non-OEM low-NO_x firing system was installed on Campbell Unit 1, but it increased fuel line pressure losses. Inadequate pulverizer capacity and reduced pulverizer airflow exacerbated the problem as the unit's total fuel demand increased.

To compensate for the higher pressure drop and to allow the higher required coal flow, a large-diameter, high-efficiency fan and an improved vane wheel assembly were installed on Unit 1 in 1995. The new equipment increased airflow and pulverizer capacity enough to satisfy the primary airflow requirements of the firing system's vendor. Along with the fan and vane wheel, the pulverizer motors were rewound and airflow measurement and control instruments were installed. These modifications, and operation with all five pulverizers, allowed continued operation of Unit 1's boiler at full load despite the increased pressure losses in the fuel transport piping and the higher required coal flow.

In the late 1990s, CEC hired Alstom Power to develop and implement an emissions-reduction strategy for several of the utility's Alstom-designed boilers, and the one at Campbell Unit 1 was among the first to be upgraded. For Unit 1, the upgrade included switching from the 70/30 Eastern/Western blend to firing 100% western coal and the installation of an Alstom TFS 2000R firing system. The first step of the effort was to perform a study to address the impact of firing 100% PRB coal on the pulverizer system and on the boiler's thermal performance and firing equipment. Another objective of the study was to gather data that would help in the selection of new fans and other components and systems. Designs were completed and equipment ordered to meet Unit 1's spring 2001 outage window.

A key result of the CEC initiative was a set of innovative designs by Alstom engineers that enabled the pulverizers of Campbell Unit 1 to be modified rather than replaced. The following summary of the design details and performance results of the pulverizer upgrade demonstrates that switching to PRB coal can be done without necessitating new pulverizers or major system upgrades.



Needs analysis first

Five different PRB coals were investigated during the analysis phase; their moisture content ranged from 25% to 31% and their heating value ranged from 8,500 Btu/lb to 9,350 Btu/lb. After a careful evaluation, a design coal was selected. Although the existing pulverizers had enough mechanical capacity to deliver the new, higher required flow of the design coal, there was essentially no margin. What's more, the existing pulverizers' thermal capacity was 15% below the new requirement.

In order to maintain Unit 1's MCR while firing 100% PRB coal and to maintain adequate thermal and mechanical pulverizer capacity margins, a design point of 70,000 lb/hr was selected. Both capacities would have to be increased to greater than 100% of the pulverizers' original design specs to minimize derates during pulverizer outages as well as during extreme weather conditions and when poor-quality coal was burned. The approach was twofold:

- Increase the primary mass flow and temperature to maximize the thermal capacity of the pulverizers. The result was an increase in the pulverizers' thermal capacity to 72,500 lb/hr, based on a maximum

allowable primary air temperature of 750F.

- Increase primary airflow capability and available motor power and install a dynamic classifier to increase the mechanical capacity of the pulverizers to 70,000 lb/hr.

Increasing airflow

To determine the magnitude of the proposed air delivery system modifications, flow and pressure requirements at the new coal flows had to be established. Required airflow was determined first by extrapolating standard Alstom airflow ramps and then verified using mathematical thermal modeling. System resistance curves were then developed using computational fluid dynamics (CFD) modeling and empirical data from Campbell Unit 1 as well as from other units with similar equipment arrangements and coal flows. The conclusions of this analysis indicated that the design should be based on a primary airflow entering the mill of 90,000 lb/hr and that the exhaustor should have a pressure rise capability of 41 to 42 inches wg. The flow through the exhaustor, with the addition of vapor load from the coal and air leakage, was expected to be approximately 27,500 acfm.

To achieve these performance levels, the speed of the exhaustor was increased by

adding a single motor driving both it and the pulverizer. To maintain the correct bowl speed, the worm and worm gear were replaced with units with a different reduction ratio to increase the operating speed from 900 to 1,200 rpm. Once the required exhaustor speed and equipment arrangement were determined, engineers performed a full mechanical analysis of the drive train. Several drive train mods were completed to ensure high reliability. One was the addition of direct-fired light oil primary air heaters to raise the inlet air temperature to 750F. The heaters were deemed necessary because the higher speed fan was not predicted to provide adequate drying heat input during all operating conditions.

Increasing mechanical capacity

As mentioned, the size of Campbell Unit 1's original pulverizers limited their mechanical capacity, rendering them unable of delivering the desired 70,000 lb/hr with the design coal at the required fineness. So engineers installed dynamic classifiers (Figure 2) to provide increased mechanical capacity and improve fineness.

Unlike Unit 1's original dual-cone/adjustable-blade static classifiers, the new

dynamic classifiers have a variable-speed conical rotor. The classifier rpm is ramped with feed rate to maintain fineness throughout the load range. Due to their higher efficiencies, the dynamic classifiers reduce the amount of coal recirculation for a given operating capacity and thus lower power consumption and mill pressure drop. The result is the ability to increase feed rates until maximum operating capacity is reached.

In addition to the upgrades already mentioned, the pulverizers also were "blue-printed" with new state-of-the-art vane wheels, new grinding elements, and rebuilt roller journal assemblies.



2. Not up to the task. Unit 1's original pulverizers were too small to deliver the higher required flow of PRB coal at the required fineness. Dynamic classifiers were installed to provide increased mechanical capacity and to improve fineness capability. *Courtesy: Alstom*

Baseline testing

Next, CEC engineers conducted a series of six performance tests at different flow rates to determine maximum pulverizer capacity and to identify the operating parameter(s) that limit system performance (Table 1). During the baseline testing, Unit 1 burned a 70/30 blend of Eastern bituminous coal and PRB coal. These tests would then be repeated following the pulverizer and boiler modifications to determine the capacity of the changed system. During baseline testing, coal spillage and positive underbowl pressure were the limiting factors. However, the ability to maintain desired fineness at higher coal flows also was observed.

To realize this increase in pulverizer capacity when burning 100% PRB coal, several modifications to the pulverizer system were deemed necessary. Among them were:

- Modifying the pulverizer exhauster to increase its pressure and flow.
- Increasing the horsepower of the pulverizer motors (beyond the 600 bhp achieved by their previous rewinding) to make them capable of grinding more coal per hour and driving the modified exhauster.
- Adding direct-fired auxiliary primary air heaters to supplement the existing air heater.
- Improving the classifier to lower internal recirculation loading (as a means for increasing grinding capacity).

During baseline testing, it became clear that underbowl pressure was very sensitive to coal flow. Increasing coal flow much beyond 49,000 lb/hr would increase the pulverizer inlet pressure to its operating maximum. At 49,000 lb/hr, the airflow is at its maximum for the required pressure rise and the exhauster fan cannot pump any additional fuel/air mixture due to system resistance. There was significant pressure

across the fan during all of the tests, including the clean airflow test.

The exhauster pressure rise is the sum of the pressure drops across the pulverizer and piping burner system. The original exhauster design used a predicted 10 inches wg pressure loss across the pulverizer and 15 inches wg pressure loss across the piping/burner system. During the pulverizer testing, the average pressure drop across the mill was approximately 7.5 inches wg and the average pressure loss across the piping/burner system was 21.4 inches wg. This increased load on the exhauster was reducing the volumetric flow and limiting the fan's ability to maintain pulverizer suction at high coal loads.

During baseline testing, the highest operating capacity measured (when corrected for grindability and fineness) was 90% of the rated value. The pulverizers were underperforming due to insufficient airflow, which was most likely caused by high fuel piping system resistance. Although it is very difficult to calculate the net effect on airflow of lowering the pressure loss through the piping system, basic fan laws suggest an increase in airflow of approximately 20%.

In addition to increasing the exhauster capacity, reduced piping losses will yield more available suction to maintain negative pulverizer pressures at high coal flows. With the reduction of fuel line pressure drops through burner modifications, the capacity should approach 100%. However, as previously discussed, pulverizer capacities in excess of 100% are required for 100% PRB operation at boiler MCR.

Post-mod tests

Unit 1's pulverizers were modified during a 15-week outage in the spring of 2001. Other significant work also was performed on the unit during this outage, including

Table 1. Baseline data. These performance data were collected during baseline testing, with the unit burning a 70/30 blend of Eastern bituminous coal and Powder River Basin coal. Entries in bold indicate feed rate from boiler/steam turbine-generator; italic entries indicate questionable HGI values. *Source: Alstom*

Performance test number	1	2	3	4	5	6
Coal flow (lb/hr)	53,000	49,600	47,400	46,200	60,000	49,600
Hardgrove Grindability Index (HGI)	52	43	55	54	54	52
Through 200-mesh fineness (%)	64.4	65.1	70	76.5	60.2	66.8
Expected throughput (lb/hr)	62,000	53,000	58,000	52,000	66,300	59,000
Operating capacity (%)	85%	94%	82%	89%	90%	84%
Coal spillage (lb/hr)	210	50	55	60	50	10
Underbowl pressure (inches wg)	-0.5	-0.7	-0.8	-0.9	-1	-0.6
Pulverizer current (amps)	61	61	62	63	54	59
Mill outlet temperature (F)	140	139	140	139	140	139
Coal moisture content (%)	4.58	5.13	4.47	6.98	6.28	5.39

installation of the TFS 2000R low-NO_x firing system. The pulverizer modification went as expected and was complicated only by typical issues related to the overhaul of 40-year-old equipment. The unit was restarted in June 2001 and pulverizer post-modification testing took place two months later.

A series of tests similar to those conducted at the baseline stage were performed with the modified pulverizers handling

100% PRB coal. Performance data were recorded at various coal loads and classifier rpm. Data collected were used to develop the classifier speed vs. fineness curves and to establish classifier ramps.

Coal flow goal met

Table 2 lists the performance measurements taken during post-modification testing. To generate MCR steam flows with four of five pulverizers operating, each

pulverizer would have to grind approximately 73,000 lb/hr. Performance test #6 illustrates a maximum operating condition that exceeds this requirement, so a pulverizer can be kept as a spare to improve system reliability. Although no attempt was made to maximize fineness and therefore capacity at lower coal flows, the data are presented to show performance trends as a function of pulverizer loading while maintaining fineness levels of approximately

Table 2. PRB data. These were the post-modification test results, with the unit burning 100% PRB coal. Entries in bold indicate feed rates calculated from Btu; italic entries indicate maximum operating condition. *Source: Alstom*

Performance test number	1	2	3	4	5	6
Coal flow (lb/hr)	36,750	52,500	63,000	73,500	78,750	84,000
Hardgrove Grindability Index (HGI)	60	60	60	60	60	<i>60</i>
Through 200-mesh fineness (%)	73.8	71.96	74.7	67.9	71.6	<i>76.3</i>
Plus 50-mesh fineness (%)	0.46	1.15	0.48	0.14	0.14	<i>0.1</i>
Expected throughput (lb/hr)	58,025	58,020	58,016	58,012	58,008	<i>58,004</i>
Operating capacity (%)	63%	90%	109%	127%	136%	<i>145%</i>
Coal spillage (lb/hr)	0	0	0	0	0	<i>0</i>
Underbowl pressure (inches wg)	-18.4	-12.6	-10.2	-5.45	-3.37	<i>-1.88</i>
Pulverizer current (amps)	78	89	99	105	112	<i>121</i>
Mill outlet temperature (F)	128	133	129	129	130	<i>127</i>
Coal moisture content (%)	26	26	26	26	26	<i>26</i>

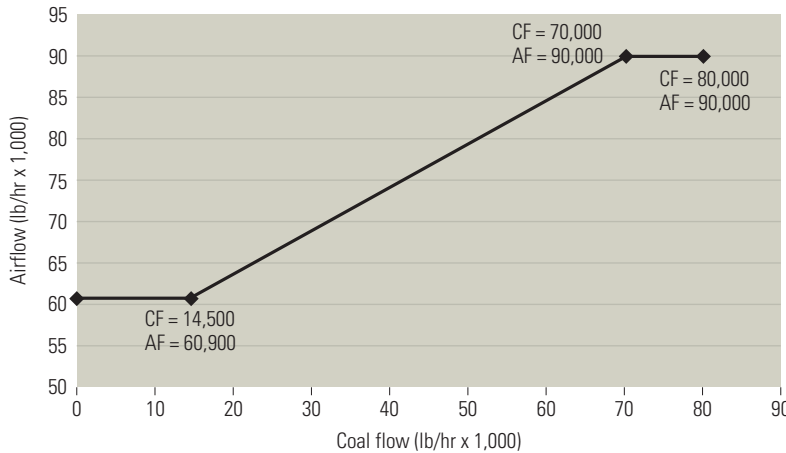
70% smaller than 200 mesh. By analysis, the coal being processed at the time of the testing had a grindability index (HGI) of approximately 45. However, based on the authors' experience, PRB fuels behave as

if they have a higher grindability value. For this analysis, therefore, an HGI of 60 was used to calculate operating capacities.

As mentioned, during baseline testing underbowl pressure and spillage were

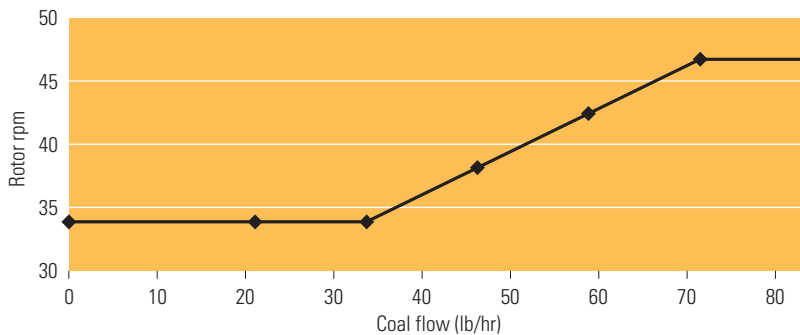
found to be the limiting factors. During post-modification testing, however, the pulverizers were able to run at operating capacities far in excess of baseline values without being limited either by underbowl pressure or spillage. None of the pulverizers have had any significant spillage under any operating condition since being returned to service after the modification.

3. Linking airflow to coal flow. Currently, online airflow is measured and controlled on a ramp with coal flow. This optimizes the primary airflow into the boiler throughout the load range and minimizes wear due to excessive velocities at low feed rates. The airflow is controlled using the hot air damper and an electrically driven cold air damper. *Source: Alstom*

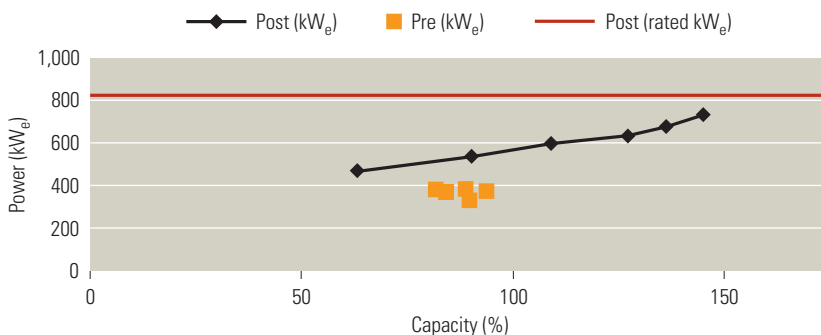


Notes: CF = coal flow
AF = airflow

4. Classifier speed curve. The dynamic classifiers' rpm vs. feed rate ramp was programmed into the plant's distributed control system. *Source: Alstom*



5. Well worth the cost. The pulverizer system's power consumption measured during baseline and post-modification testing. Although the mods increased the system load, power consumption remained below design predictions and well below the motor's nameplate rating. Note that the post-modification measurements included the consumption of the motor driving the new, dynamic classifier. *Source: Alstom*



Airflow and pressure increase

As expected, a very significant increase in airflow capacity was the result of increasing the speed of the exhauster. Clean airflow increased from the maximum premodification state of 126% of design airflow to 180% of design airflow. With the exhauster modification, the full predicted airflow of 90,000 lb/hr entering the pulverizer could be maintained at higher coal flows (Figure 3).

Not only was coal throughput increased, but the quality of the product also improved, even at the highest coal flows. Fineness requirements of 70% smaller than 200 mesh were desired to support good combustion. Testing showed that the pulverizers could maintain fineness levels of about 75% smaller than 200 mesh, with larger than 50-mesh levels of less than 0.5% even at coal flows in excess of those required to generate full load on four of five mills (Figure 4).

The pulverizer motors were sized using Alstom standard practices and extrapolated using fan laws. The composite pulverizer/dynamic classifier/exhauster specific power that resulted from this analysis was 20 kW/ton. Actual measured power consumption was lower than expected. Specific power at the maximum operating capacity was about 18 kW/ton. For comparison purposes, the specific power during the baseline testing was about 15 kW/ton (Figure 5).

Floating-pin problems

New vane wheel segments were included as part of the mill blueprinting materials that were to be attached to the existing bowls. Alstom had developed a new floating-pin attachment method specifically intended to fasten vane wheel segments to older bowls. The original bowl design did not easily accept the vane wheel segments; historically, there have been many failures in this connection, and Campbell Unit 1 was no exception. After several design changes, Alstom and CEC decided to replace the original, worn bowls with new bowls designed to be compatible with the new vane wheel segments. Since the bowls were replaced, none has failed. ■