Energy, Mines and Resources Canada
Énergie, Mines et Ressources Canada

CANMET
Canada Centre for Mineral and Energy Technology
Centre canadien de la technologie des minéraux et de l'énergie

CONTROL OF ACID RAIN EMISSIONS FROM CANADA'S FIRST FLUIDIZED BED HEATING PLANT

G.K. Lee, V.V. Razbin and F.D. Friedrich
Combustion and Carbonization Research Laboratory

April 1987

For presentation to the International Symposium on Coal Combustion, Tsinghua University, Beijung, China, September 10-14, 1987.

ENERGY RESEARCH PROGRAM
ENERGY RESEARCH LABORATORIES
DIVISION REPORT ERP/ERL 87-31 (OPJ)

CONTROL OF ACID RAIN EMISSIONS FROM CANADA'S FIRST FLUIDIZED BED HEATING PLANT

G.K. Lee*, V.V. Razbin** and F.D. Friedrich***
*Manager, **Research Engineer and ***Research Scientist, Combustion and Carbonization Research Laboratory, Energy Research Laboratories, CANMET, Energy, Mines and Resources, Canada. K1A 0G1.

INTRODUCTION

Canada's first bubbling fluidized bed heating plant was successfully commissioned during the 1984/85 heating season. It has exceeded all performance specifications and has met all national guidelines for acid rain and fly ash emissions while burning an Eastern Canadian high-volatile bituminous coal containing 4.5% sulphur, 13% ash and a higher heating value of 25.9 MJ/kg. Fluidized bed technology was selected for this plant because of its potential to burn local high-sulphur low ash fusion coals with minimal pollution and to reduce the region's heavy dependence on imported oil. The plant is located in Summerside, Prince Edward Island, on the Gulf of St. Lawrence where daily mean temperatures are below 0°C and wind speeds average over 25 km/h for five months of the year.

HEATING PLANT SPECIFICATIONS

The heating plant has two identical natural circulation boilers each rated at 18000 kg/h of steam. The furnace gases pass through an economizer and a baghouse before entering the stack at 175°C maximum. The furnace in each boiler, shown schematically in FIGURE 1, is divided by a membrane-tube wall which separates the fluidized combustor into two beds designated preferential and secondary. The preferential bed has no in-bed tubes and is used for startup, for boiler loads up to 50% and for burn-up of char recycled from the boiler and cyclone collector hoppers. The secondary bed, which has 18 in-bed tubes, is ignited by circulating hot material from the preferential bed through an opening in the membrane dividing wall, and is used for boiler loads above 50%. A turn-down of up to 8:1 is achievable for sustained operating periods using both beds.

Coal, 32 mm x 0, is fed to each bed by spreader stokers and limestone, 2.4 mm x 0.8 mm, is fed into the opposite end of each bed by a drop pipe. Drain pipes, one per bed for controlling bed level, are located at the stroker end thus ensuring maximum time for sulphation of the limestone. Material from the bed drain and from the baghouse collector is not recycled.

Normally the depth of the expanded bed varies from 1.2 to 1.4 m with fluidization velocities from 2.4 to 3.0 m/s. The depth of the slumped bed is about 0.7 m. Bed temperatures are controlled between 830°C and 885°C to optimize both sulphur capture and carbon burnout with the specified Ca/S mol ratios of less than 3:1. TABLE 1 gives the analyses of the design coal and limestone.

BOILER ACCEPTANCE TESTS

During acceptance tests at full load and a Ca/S mol ratio of less than 2.5:1 with the design coal, all performance guarantees were easily met. ASME boiler efficiencies exceeded the 80% minimum and SO_2 and particulate emissions were less than the maximum specified limits of 705 mg/MJ and 86 mg/MJ respectively. Carbon combustion and sulphur capture efficiencies, which were over 96% and 80% respectively, both decreased as the boiler load decreased owing to a gradual drop in bed temperatures as the coal rate decreased. The exceptionally steady load and combustion conditions illustrated in FIGURE 2, the size distributions of the coal, limestone and ash streams shown in FIGURE 3, and the mass balance shown in FIGURE 4, were typical of all the tests.

Although designed to operate with 3.6% O_2 in the flue gas, the combustors typically required about 10% O_2 to prevent bed overheating and ash clinkering. The preferential bed particularly required a high level of excess air because bed temperatures tended to increase above 875°C with continuous char injection. However, this higher than specified excess air requirement did not adversely affect boiler performance because the tower-type furnace had sufficient heat adsorption surface to maintain furnace exit temperatures below the design maximum of about 600°C.

Samples of the spent bed ash were sectioned and examined by scanning electron microscopy to study the extent of the sorbent reaction layer. Generally, the particles had a porous inner core of unreacted CaO, a thick intermediate layer of low porosity $CaSO_4$ and an impervious outer shell of a calcium-iron complex (1). Although the low porosity $CaSO_4$ layer probably retarded the diffusion of SO_2 to the unreacted core, surface fractures increased noticeably the degree of sulphation. The outer skin, which varied from 5 to 15μm thick and was sulphur free, may also retard both the diffusion of SO_2 to the unreacted core and attrition of the sulphate layer during combustion.

PERFORMANCE WITH ALTERNATE COALS

On completion of the acceptance tests, a series of demonstration trials was conducted to evaluate the capability of the fluidized bed boiler to perform at different loads and within the environmental guidelines using four other locally available coals. These coals, on an as-fired basis, contained from 4.1 to 11.4% sulphur, 8.7 to 23.1% ash, 30.5 to 34.8% volatile matter and higher heating values of

22.0 to 28.0 MJ/kg. TABLE 2 summarizes the results of the boiler performance tests using both the design and the alternate coals.

MAXIMUM SULPHUR CAPTURE

In the demonstration trials stepwise decreases in boiler load from 100 to 65% and from 65 to 22% had no apparent effect on sulphur capture which appeared to depend only on the Ca/S mol ratios, although bed and freeboard temperatures decreased progressively from a high of about 880°C and 580°C respectively to a low of about 800°C and 350°C. Boiler efficiencies and CO_2 levels both decreased with load, but NO levels remained consistently below 250 mg/MJ at all loads.

Early in 1986, the US Environmental Protection Agency collaborated with Energy, Mines and Resources Canada in a study at Summerside to maximize sulphur capture at boiler loads of 70% or more (2). This study, which comprised three tests run sequentially over one month consisted of:

a) a 30-d continuous test to establish the Ca/S mol ratios required for a minimum sulphur capture of 90% during long term operation;
b) a 20-h test to compare the effect of a coarser limestone, 6 mm x 0 on sulphur capture;
c) an 8-h test to assess the maximum possible sulphur capture without seriously affecting combustion performance or steam output.

Operating data averaged over the 30-day test yielded a boiler load of 70.6% while burning a 5.9% sulphur coal with a higher heating value of 27.2 MJ/kg on an "as-fired" basis. Average flue gas analyses were 10.7% O_2, 485 ppm CO, 258 mg/MJ SO_2 and 267 mg/MJ NO_x. Sulphur capture and carbon combustion efficiencies were 92% and 93% respectively at Ca/S mol ratio of 4:1 and an ash recycle ratio of above 6. The recycle ratio, defined as the flowrate of recycled solids divided by the coal firing rate, was estimated at about 4 for the cyclone hopper ash and above 2 for the continuously injected solids from the boiler hopper.

In the test with coarser limestone from the same source as the finer material used in both the 30-d test and the acceptance tests, the SO_2 capture decreased to 91% with a Ca/S mol ratio of 4.5:1 and a coal sulphur content of 6.5%. This test confirmed the results of the electron microscopy evaluation performed on spent bed ash from the acceptance tests, which showed that the formation of a thick sulphate shell around each particle tended to inhibit further sulphur capture unless surface attrition occurred.

The short term test to maximize sulphur capture resulted in a sulphur capture efficiency of 99.4% at a Ca/S mol ratio of 7.2:1 using a 5.7% sulphur coal. Average emission readings during the test, which was conducted at 56.2% load, were 26 mg/MJ SO_2, 301 mg/MJ NO_x and 114 ppm CO. This test demonstrated that SO_2 emissions from the unit can be maintained below 40 ppm while burning coals with 2% sulphur or less.

An analysis of the data from the three tests of this study indicated that at Ca/S mol ratios from 1 to 6 the SO_2 capture efficiency increased in accordance with the equation:

$$\% \text{ S capture} = 1 - \text{Exp}\ [(0.049\ \text{Ca/S} - 0.987)\ \text{Ca/S}]$$

but was unaffected by bed temperatures between 770°C and 880°C and boiler loads between 60 and 100%. In all tests the baghouse ash contained about 10% combustible.

COMBUSTION SYSTEM MODIFICATIONS

Following the acceptance and demonstration trials, three problems were identified and resolved. The main problem of combustor tube erosion, which resulted in catastrophic tube failures after 5600 h of operation, was arrested by welding studs to the membrane wall tubes and longitudinal rods to the in-bed tubes. The second problem, which involved severe erosion of the double lock hopper system for reinjecting fly ash from the cyclone collectors, was corrected by replacing it with a modified "L-valve" arrangement to eliminate moving parts. The third problem of warping of the slide gate, which prevented ignition of the secondary bed with hot bed material from the preferential bed, was eliminated by removing the gate and leaving a smaller permanent opening. Air jets were installed to assist the flow of hot material from the preferential bed when required.

A modification was also made to improve significantly the cold start up of the preferential bed which was designed with 70% fewer bubble caps than the secondary bed. By increasing the number of bubble caps in the preferential bed by 75%, it is now possible to fluidize the cold preferential bed with a full depth of 6 mm x 0 limestone. Previously, a full depth of the more expensive 2.4 mm x 0.8 mm limestone could not be fluidized during cold starts.

CONCLUSIONS

The Summerside boilers are now considered proved for operation on automatic control. However, the operating reliability of the in-bed tubes installed in the fall of 1986 will be evaluated at the end of each of the next two heating seasons by comparing the wear rates of the studded and rodded in-bed tubes with 6 bare, T-9 alloy tubes.

REFERENCES

1. Kalmanovitch, D.P. et al, Microstructural Characteristics of AFBC Limestone Sorbent Particles, Proc Eighth Inter. Conf. on Fluidized Bed Combustion, Houston, pp 53-64, 1985.

2. Radian Corporation, Statistical Analysis of Emission Data from the Fluidized Bed Combustion Boiler at Prince Edward Island, Canada, US Environmental Protection Agency Contract No. 68-02-3816, October 1986.

TABLE 1. Coal and limestone analysis.

DESIGN COAL

PROXIMATE, DRY WT %	
ASH	19.3
VOLATILE MATTER	33.5
FIXED CARBON	47.2

ASH FUSION TEMP. °C (REDUCING)	
INITIAL	1175
SPHERICAL	1305
HEMISPHERICAL	1355
FLUID	1375

ULTIMATE, DRY WT %	
CARBON	64.2
HYDROGEN	4.0
SULPHUR	5.5
NITROGEN	1.0
ASH	19.3
OXYGEN (diff.)	6.0

ASH ANALYSIS, WT %			
SiO_2	39.7	K_2O	2.3
Al_2O_3	25.5	Na_2O	2.7
Fe_2O_3	27.0	TiO_2	1.2
CaO	1.0	P_2O_5	0.7
MgO	0.5	SO_3	0.7

MOISTURE, as rec'd   0–10%

GROSS CALORIFIC VALUE, dry   26.7 MJ/kg

LIMESTONE

	wt %
LOSS on IGNITION (975°C)	42.6
Ca	39.5 *
Mg	0.4
Si	0.6
Al + S	< 0.2

* CALCULATED $CaCO_3$ = 98%

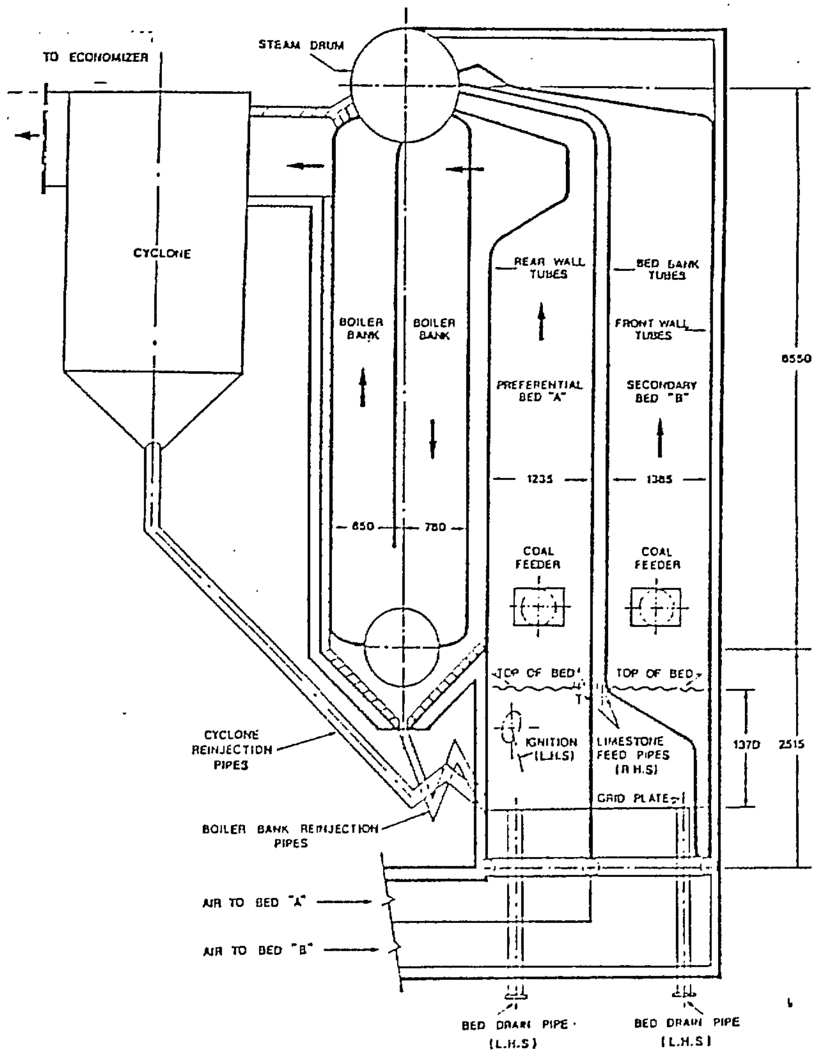

FIGURE 1. Section view of fluidized-bed boiler.

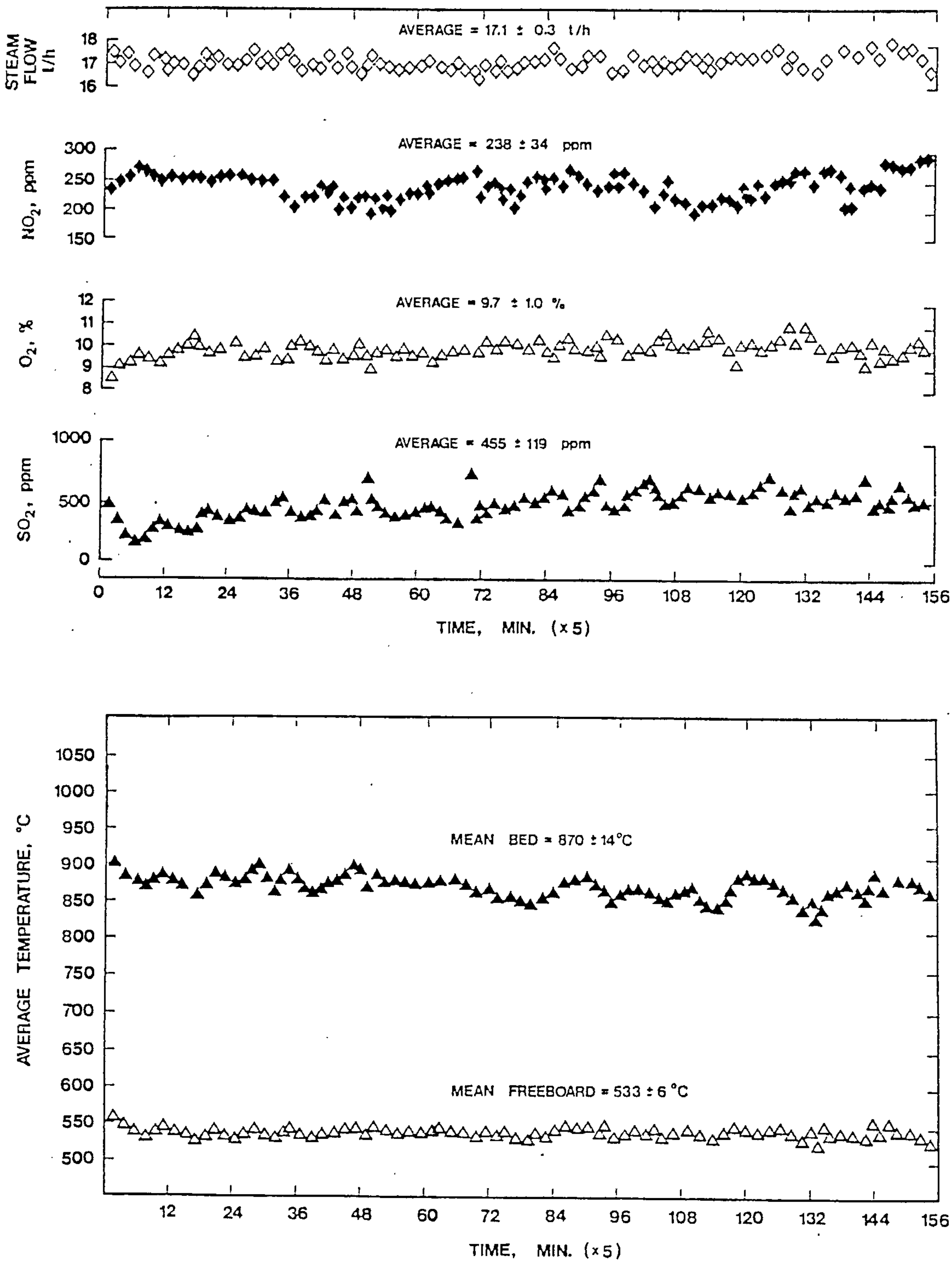

FIGURE 2. Boiler conditions at full load.

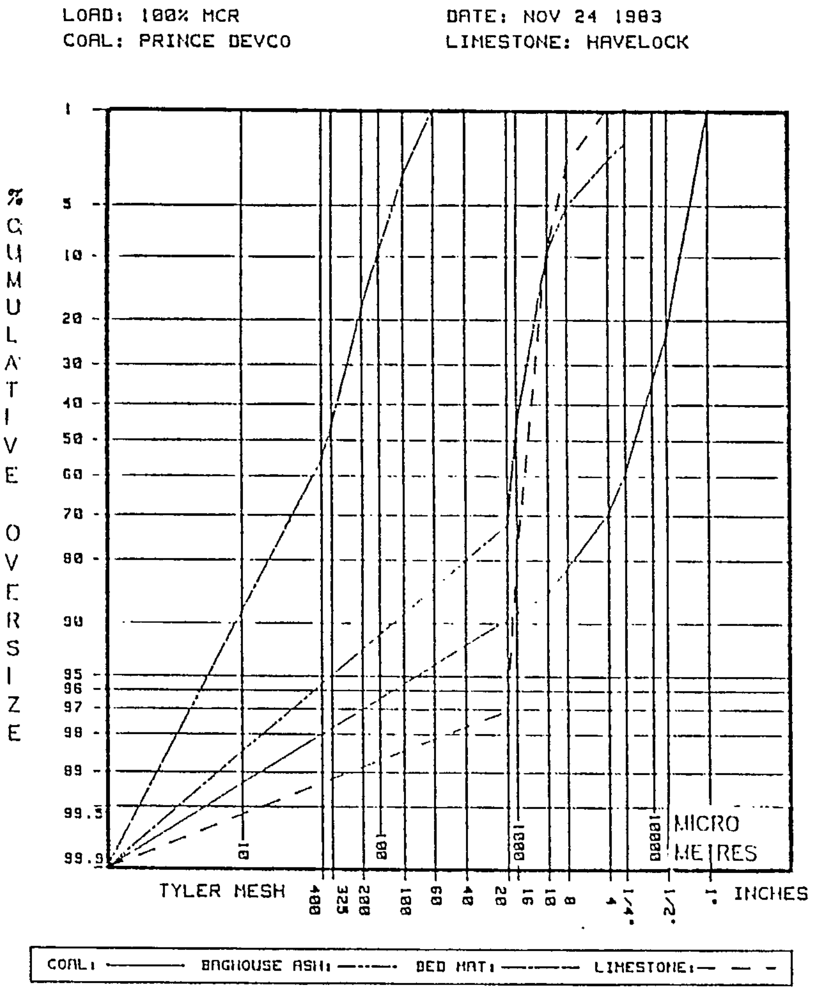

FIGURE 3. Sieve analysis of boiler solid streams.

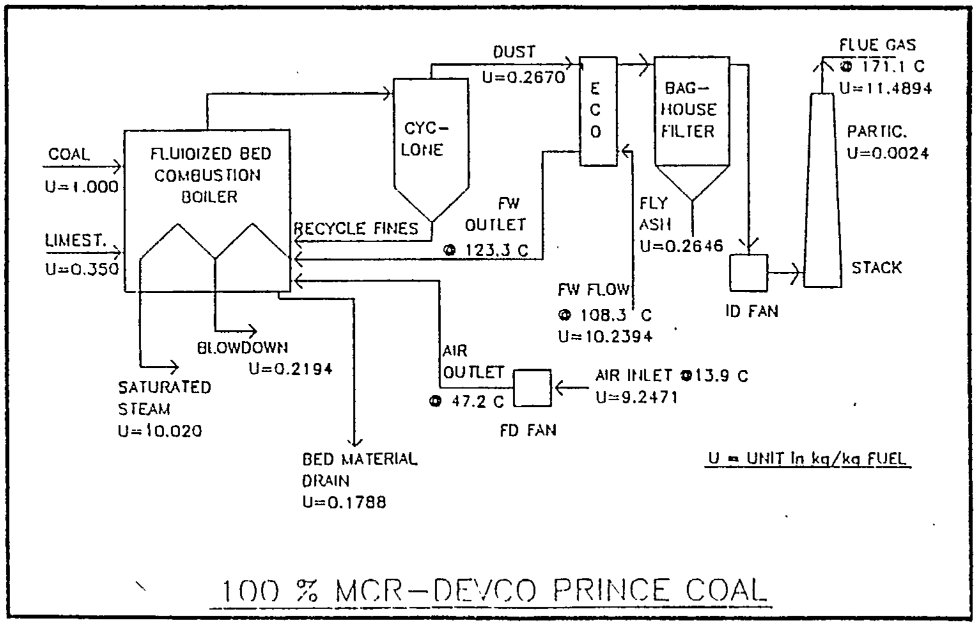

FIGURE 4. Boiler mass balance at full load.

TABLE 2. Summary of results with alternate coals.

COAL	S %	HHV MJ/kg	BOILER LOAD %	FEED kg/h	S INPUT g/MJ	Ca/S RATIO	S CAPTURE %	CARBON LOSS, %	BOILER EFFY.,%
DEVCO	4.4	26.0	100	1755	1.7	2.1	80.8	3.6	81.2
DEVCO	4.6	25.4	65	1180	1.8	3.0	83.6	5.2	80.5
BROGAN	4.8	27.2	100	1690	1.9	2.5	72.3	3.9	80.9
BROGAN	5.2	26.8	65	1090	1.8	2.6	73.5	1.6	83.4
EVANS	6.1	26.7	100	2030	2.3	3.1	80.7	5.6	77.1
EVANS	5.6	25.9	65	1455	2.1	2.6	70.6	7.2	76.5
MINTO	7.4	27.7	100	1700	2.7	2.4	83.4	8.3	76.7
MINTO	6.8	26.3	65	1105	2.6	2.0	82.5	5.6	81.4
NOVACO	4.6	22.5	100	1780	2.0	1.9	79.4	5.4	79.2
NOVACO	4.2	24.0	65	1130	1.8	1.4	74.6	2.6	83.9
MINTO	8.3	25.5	22.5	440	3.3	1.6	76.0	6.5	78.6
NOVACO	4.1	27.4	22.5	410	1.5	0.7	58.8	3.3	83.3
BROGAN	11.3	22.0	22.5	470	5.1	1.9	80.4	6.1	76.0