Pilot Plant Experience Using Stamped Charging of Peruvian and Imported Coal Blends

Yoni Abrigo[1], José Martínez[1], Mariano de Córdova[2], Jorge Madias[2]

[1]Corporación Aceros Arequipa
297, Enrique Meiggs Avenue, Callao 1, Lima, Peru
Emails: yabrigo@aasa.com.pe; josemart@aasa.com.pe

[2]metallon
432, 9 de Julio street, San Nicolas B2900HGJ, Buenos Aires Province, Argentina
Emails: mariano.decordova@metallon.com.ar; jorge.madias@metallon.com.ar

INTRODUCTION

Corporación Aceros Arequipa is the largest Peruvian steelmaker. The company operates a facility in Pisco, 241 km South from Lima, on the Pacific Ocean, a facility including a meltshop with a capacity of 850.000 tpa of liquid steel, and rolling mills with a capacity of 1.250.000 tpa of long rolled products: bar, rebar, wire rod and shapes. An upstream integration project has been considered, including mini blast furnace, sinter plant and non-recovery coke plant. As part of this project a pilot coke oven was installed and operated. The aim was to test domestic and foreign coals to obtain blends with maximum participation of local coals. The coke quality aimed for the mini blast furnace was defined elsewhere [1] and is summarized in table 1.

Table 1. Aimed coke quality

Variable	Unit	Value
Micum 40	%	≥ 80
Micum 10	%	≤ 9
Ash	%	≤ 12
Sulphur	%	≤1

Usually, industrial coke quality lies below the pilot coke oven quality [2]. Nevertheless, in this case the tests were carried out as for a conventional, slot oven byproduct recovery plant, with relatively short coking time. It is expected with the much longer coking time typical of non-recovery coke ovens, a coke quality similar or better than that of the pilot coke oven will be obtained.

This paper includes a short review of Peruvian coal resources, the main features of the domestic and imported coal, a shot description of the equipment used for coal preparation, coking, quenching and testing, as well as a summary of the pilot coke experiences with domestic and imported coals.

PERUVIAN COAL RESOURCES

In table 2, main coal basins in Peru are mentioned, including coal type, reflectivity, FSI and total reserves, according to [3]. Low- and high-volatile coals of Oyon and Jatunhuasi basins are the more interesting for cokemaking. Anthracite may eventually be included in coking blends to adjust coke properties and increase coal to coke yield. In Oyon basin, low-volatile bituminous coals are located in Pampahuay, and have reflectivities of 1.5-2.0. In Jatunhuasi, the thicker seams are present in Celica, Negro Bueno, Cosmos, Isolina, Cachi-Cachi, Llacta and Chaucha [3]. These seams belong to Corporacion Aceros Arequipa.

Previous studies on coking with domestic coals were surveyed [4-9]. They were carried out mostly with 100% domestic coals, individually or in blends, and in conventional facilities, not using stamped charging or other methods to improve coke quality.

Table 2. Main coal basins in Peru and their characteristics.

Basin	Coal type	Reflectivity	FSI	Total reserves (t)
Alto Chicama /Santa	Anthracite, Meta-anthracite	4.11 – 5.71	0	554.474.000
Oyon	Anthracite, Semi-anthracite, Low-volatile bituminous	1.52 – 5.50	N/D	190.050.000
Jatunhuasi	Low-volatile and High-volatile bituminous	0.57 – 2.51	1 a 7	62.362.150
Goyllarisquisga	Semi-anthracite, Sub-bituminous	N/D	<2.5 - 3	9.512.500
Others	Sub-bituminous, Lignite	0.27 - 0.63	N/D	287.723.000
Total				1.103.634.035

COAL SELECTION FOR PILOT OVEN TESTING

Domestic coals

Six coals were selected on the base of their FSI, plus anthracite. Five of them belong to Jatunhuasi basin: Negro Bueno, Celica, Cachi-Cachi, Cosmos and Ayhuin; and one to the Oyon basin (Pampahuay). In table 3, their main properties are summarized.

Table 3. Main features of the domestic coals selected.

Code	P1	P2	P3	P4	P5	P6	AN
Name	Negro Bueno	Celica	Cachi-Cachi	Pampahuay	Cosmos	Ayhuin	Anthracite
Volatile matter (%)	33.82	35.93	31.5	21.9	30.7	30.2	4.23
Ash (%)	7.86	16.76	13.8	9.5	9.3	20.7	9.12
Fixed carbon (%)	58.32	47.29	54.8	68.6	60.0	49.1	86.66
Sulphur (%)	2.73	4.50	5.9	0.59	1.96	2.56	0.17
FSI	6.5	6.5	0	0.5	2.5	1 to 6	0
Max fluidity (ddpm)	63	14336	0				0
Petrography							
V4 %			4				
V5 %			32				
V6 %	2.7	10.0	58				
V7 %	24.2	22.6	8				
V8 %	28.3	24.6					
V9 %	12.1	9.3					
Ro %	0.82	0.8	0.61				
ASTM Stability (%)	33	34					
M40 (%)	43.5	66.9	Not aggl.	Not aggl.	57.0		
M10 (%)	8.4	11.7	Not aggl.	Not aggl.	23.7		

Imported coals

Three Colombian and four American coals were selected to add agglomeration capacity to the blend and mechanical strength to the coke, see table 4.

TESTING FACILITIES

Taking into account the poor coking properties of the selected domestic coals, in order to maximize their participation in the blends, the stamped charging system was selected. As is widely known, this process makes possible to obtain a coal cake with high density (up to 1080 kg/dm^3, dry base), as long as an optimum moisture content is present in the blend (around 10%). The strength of the coke obtained is higher, as coke porosity decreases and mean thickness of the coke cell walls increases, due to more contact between coal particles [10]. As a result, this technique allows for a higher percentage of poorly coking coals in the blend, in comparison with usual low-density charge. A pilot oven scale of 40 kg was chosen, taken into account the easy of use of this size, and the coke needed for testing.

Table 4. Main features of the imported coals selected.

Code	C1[1]	C2[2]	C3[3]	U1[5]	U2[5]	U3[5]	U4[5]
Origin	Colombia	Colombia	Colombia	USA	USA	USA	USA
Volatile matter (%)	23.86	25.67	20.49	28.78	21.27	27.31	31.35
Ash (%)	9.55	6.55	8.15	10.29	8.88	7.75	6.04
Fixed carbon (%)	66.59	67.78	71.36		69.85		62.61
Sulphur (%)	0.99	0.97	0.60	0.76	0.70	0.93	1.01
FSI	8.5	8	8.5	7.5	9	8	8.5
Max. fluidity (ddpm)	268		59	10502	917	1630	29880
Petrography							
V8 %	0.6						
V9 %	1.8			2.2		1.8	11.4
V10 %	10.9			33.3		14.7	23.4
V11 %	8.5			30.1		19.6	20.2
V12 %	16.3			3.5	10.2	15.3	8.2
V13 %	12.1		14.1	1.4	21.9	7.3	
V14 %	6.6		31.8		17.8	2.4	
V15 %	3.0		20.7		11.6		
V16 %	0.6		7.4		4.8		
V17 %					2.0		
Ro %	1.25		1.48			1.18	1.09
ASTM stability (%)	53.5		61	59	60	61.0	59
M40 %	78.1	85.3	87.9	87.7	87.4	83.7	78.4
M10 %	7.2	6.1	6	5.1	5.9	5.4	6.7

Domestic coals were washed to reduce ash and sulphur. To this purpose, concentration by dense media according to washability ASTM D 43771 standard, floatation cell Denver D12, Humphrey spiral and column cell were used, after design and built by CAASA.

All coals were ground to 90 % < 2.8 mm in a lab mill. Anthracite, instead, was ground to 100% <1 mm. Coals dosing was carried out with a 100 kg scale. Mixing was manual. The required water was incorporated with manual spray, to increase moisture from 2% (due to the particularly dry conditions at the plant) to 10 - 11 %. The 43-50 kg coal cake was prepared in the stamp equipment, introducing the coal in a steel charging box (350 mm wide, 460 mm length, 460 mm high) and compacting in four steps (10 strokes in 15 s each), figure 1.

Figure 1. Stamping equipment.

Oven inner dimensions are 400 mm wide, 500 mm length and 660 mm high. Charging is through the bottom, by means of a hydraulic lifting car, see figure 2.

Figure 2. Left: General aspect of the pilot coke oven. Right: Charging of the coal cake in a box through the bottom of the oven, using a hydraulic lifting car.

The oven has two heating walls, each one with six silicon carbide bars, the temperature being measured with a thermocouple in each wall. Coking time may be varied between 14 and 24 hours, but the standard chosen was 18 h. Programmed heating curve is shown in figure 3.

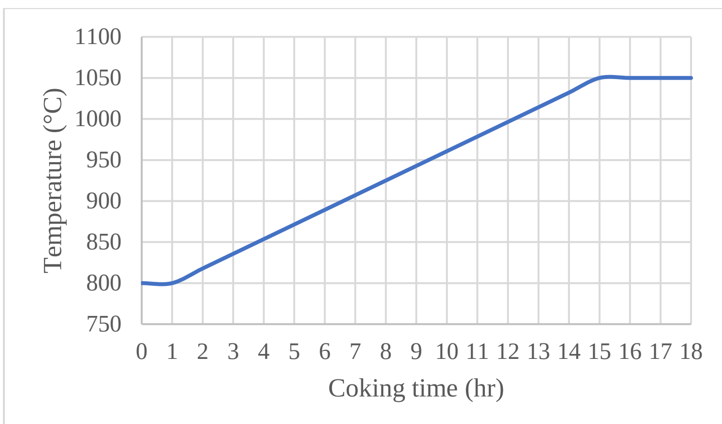

Figure 3. Programmed heating curve for the walls of the pilot coke oven.

Temperature in the center of the charge is taken with a thermocouple, too. It is inserted in the cake after charging, then removed before discharging. The error margin for wall temperature is ± 80°C and the difference between both walls must be less than 10°C. The incandescent **coke**, still within the steel box, is quenched in a quenching tower with water sprays during two minutes, then dumped into a pan and quenched again (figure 4).

Figure 4. Steel box with incandescent coke after discharge from the oven. Right: quenching tower.

The mechanical testing of the coke was carried out with a shatter test as a first step, for drop strength and coke stabilization. The coke produced, charged in a pan, is let to fall twice from 1.83 m high. Then it is classified in fractions of +80 mm Ø, +60mm Φ, +40 mm Ø, +25 mm Ø, +10 mm Ø and -10 mm Ø, see figure 5 (left). A ¼ MICUM tumbler test was implemented for resistance to fissuring (M40) and to abrasion (M10), according to Chinese GB2006-80 standard: 1000 mm diameter 250 mm length. 12.5 kg of coke of >80 mm and 80 - 60mm are charged and the tumbler rotates 100 turns to 25 rpm (figure 5, right).

Figure 5. Equipment for shatter test (left) and ¼ MICUM test (right).

COKING TESTS AND RESULTS

Taking into account the above mentioned characterization data and coke quality requirements, different blends were formulated, for extensive testing. The blends included domestic coals washed and not washed, disaggregating coals P1 and P2 in seams A, B, and C with Colombian coals C2 and C3 and American coal U1. Priority was given to tests of coals P1 and P2, seam B, because of their high FSI compared with other local coals. Anthracite was then included in blends with domestic coals P1 and P2, Colombian coal C2 and American coal U2. As pressure on oven walls is not a concern for non-recovery horizontal coke ovens, there was no limits to the participation in the blends of low-volatile Colombian coal C3. In table **5** the main blends tested are presented.

Table 5. Blends tested in the pilot coke oven.

Test Number	Domestic coals									Imported coals			
	P1	P2	P1W	P2W	P5	P5W	P6	P6W	Anthracite	C2	C3	U1	U2
5	0										100		
8	B50										50		
9	B30										70		
11	B100										0		
13	B70										30		
14		B100									0		
15		B90									10		
16		B80									20		
17		B70									30		
18		B60									40		
19		B50									50		
20		B40									60		
21		B30									70		
29			B100								0		
30			B90								10		
31			B80								20		
32			B70								30		
33				B100							0		
34				B90							10		
35				B80							20		
36				B70							30		
40						100					0		
41					50						50		
42					30						70		
43						50					50		
44						30					70		
45							50				50		
46							30				70		
47								50			50		
48								30			70		
54	C70										30		
55		A70									30		
56			C80									20	
57			A80									20	
58			B80									20	
59				A80								20	
61				B80								20	
62				C80								20	
63				C80						20			
64			C80							20			
65			B80									20	
66				B80								20	
67			A55	B25						20			
68			A50	B20						30			
73				A60					10	30			
74				A60					20	20			
78			B50						20				30

P1, P2, P5 and P6: not washed domestic coals. P2W, P5W and P6W: washed domestic coals. A, B, C: different seams of coals P1 and P2.

In the following, the results of the tests are discussed ordered by domestic coal type. M40, M10, average coke size and fraction below 25 mm (nut coke plus coke fines) are included.

<u>Negro Bueno coal</u> (P1). With 30% of not-washed seam B (P1B), and 70 % of Colombian C3 coal aimed quality was achieved (test 9). After washing, the share of P1BW could be increase to 80% without missing the aim (test 31), see table 6. The washing not only decreased ash and sulphur but was also helpful in improving M40 and M10.

Table 6. Tests with Negro Bueno coal, non-washed (top) and washed (bottom).

Test No.	P1B %	P1B/C3 blend				Coke						
		Moisture	VM	Ash	Sulphur	VM	Ash	Sulphur	M40	M10	Size (ave.)	<25 mm
11	100	10.4	31.9	7.6	2.65	2.0	15.6	2.26	50.4	9.0	60	13.4
13	70	9.6	27.9	8.6	1.78	1.9	17.6	1.45	78.1	11.0	68	15.9
8	50	10.3	25.6	7.5	1.35	1.3	13.6	1.04	88.9	6.6	70	8.4
9	**30**	**9.8**	**22.3**	**6.8**	**1.10**	**1.3**	**12.2**	**0.86**	**85.4**	**6.7**	**75**	**5.9**
5	0	10.2	18.4	8.8	0.55	2.1	13.4	0.4	88.2	5.3	74	7.4

Test No.	P1BW %	P1BW/C3 blend				Coke						
		Moisture	VM	Ash	Sulphur	VM	Ash	Sulphur	M40	M10	Size (ave.)	<25 mm
29	100	11.0	33.4	4.3	1.04	1.4	7.3	0.93	49.4	8.3	62	6.8
30	90	10.4	31.5	6.9	1.05	1.2	10.7	0.91	64.3	7.4	68	5.2
31	**80**	**10.6**	**30.4**	**6.6**	**1.11**	**1.3**	**9.5**	**0.92**	**82.2**	**6.2**	**71**	**5.2**
32	70	11.0	28.3	9.2	0.98	1.7	12	0.98	89.0	5.6	74	6.3

Celica coal (P2). Blends of non-washed coal (P2B) and Colombian coal C3 did not reach the aim. Washed coal was successful: the aim is obtained even with 80% of P2BW and 20% of C3 (test 35), see table 7. Again, washing added cost but made feasible a blend with high proportion of domestic coal.

Table 7. Tests with Celica coal, non-washed (top) and washed (bottom).

Test No.	P2B %	P2B/C3 blend				Coke						
		Moisture	VM	Ash	Sulphur	VM	Ash	Sulphur	M40	M10	Size (ave.)	<25 mm
14	100	10.0	35.4	12.5	4.41	2.4	20.9	3.67	66.9	11.7	70	8.3
15	90	10.4	33.3	12.4	4.40	2.3	20.4	3.78	73.0	10.9	73	9.4
16	80	10.2	32.1	11.5	4.00	1.8	16.4	3.33	78.7	8.8	70	4.4
17	70	10.2	29.7	11.0	3.35	2.0	16.7	2.48	83.5	7.5	76	5.0
18	60	10.8	28.5	10.6	3.06	2.0	16.9	2.30	86.7	6.1	73	5.2
19	50	10.2	26.7	14.0	1.71	0.7	20.0	1.32	85.8	6.9	79	4.1
20	40	9.7	25.0	12.3	1.97	1.4	16.9	1.51	89.4	5.9	78	4.0
21	30	10.5	23.3	11.7	1.44	0.9	17.4	1.11	87.7	6.4	80	4.5
5	0	10.2	18.4	8.8	0.55	2.1	13.4	0.40	88.2	5.3	74	7,4

Test No.	P2BW %	P2BW/C3 blend				Coke						
		Moisture	VM	Ash	Sulphur	VM	Ash	Sulphur	M40	M10	Size (ave.)	<25 mm
33	100	11.6	32.5	5.2	1.51	1.5	10.2	1.22	66.6	7.7	66	5.8
34	90	11.1	32.0	8.0	1.47	1.6	12.5	1.10	74.7	6.6	73	4.9
35	**80**	**10.2**	**30.6**	**6.0**	**1.27**	**1.5**	**9.8**	**1.02**	**82.4**	**7.2**	**72**	**5.0**
36	70	11.3	29.0	7.6	1.29	1.4	11	1.02	85.6	6.6	72	9.9

Cosmos coal (P5). With non-washed coal the quality aim was not achieved. Tests with washed coal were successful. Maximum acceptable was a blend of 30% washed coal (P5W) and 70% Colombian coal C3 (test 44), see table 8.

Table 8. Tests with washed Cosmos coal.

Test No.	P5W %	P5W/C3 blend				Coke						
		Moisture	VM	Ash	Sulphur	VM	Ash	Sulphur	M40	M10	Size (ave.)	<25 mm
40	100	10.8	30.7	9.3	1.97	2.5	15.4	1.71	57.0	23.7	72	39.4
43	50	10.0	24.9	8.2	1.19	1.9	16.3	0.90	68.8	19.8	65	33.8
44	**30**	**11.0**	**22.7**	**7.5**	**0.90**	**1.0**	**11.4**	**0.71**	**82.7**	**7.2**	**69**	**11.1**

Ayhuin coal (P6). Neither non-washed nor washed blends with this coal, in blends with Colombian coal C3, reached the proposed quality level, due to the high ash content, even in the washed condition, see table 9.

Table 9. Tests with washed and non-washed Ayhuin coal.

Test No.	P6 %	P6-P6W/C3 blends				Coke						
		Moisture	VM	Ash	Sulphur	VM	Ash	Sulphur	M40	M10	Size (ave.)	<25 mm
45	50P6	9.5	23.9	17.4	1.65	1.0	23.5	1.25	81.3	11.5	80	9.7
46	30P6	10.5	22.3	13.0	1.08	1.0	19.0	0.85	88.2	6.6	68	14.7
47	50P6L	13.7	25.4	11.2	1.05	1.3	16.4	0.8	83.5	7.0	71	8.8
48	30P6L	10.5	22.8	9.4	0.87	1.3	13.6	0.72	87.2	5.8	70	12.0

Anthracite. Interestingly enough, with washed 60% Celica coal, seam B (P2BL), 30% Colombian coal C2 and 10% anthracite (test 73), the aimed quality is achieved, see table 10. Colombian coal C3 was not used due to lack of stock; may be with it results would be even better, see table 10.

Table 10. Tests of blends including anthracite.

Test N°	Anthracite %	Blend				Coke						
		Moisture (%)	VM (%)	Ash (%)	Sulphur (%)	VM (%)	Ash (%)	Sulphur (%)	M40 (%)	M10	Mean Ø (mm)	< 25 mm
72[1]	10	10.5	26.7	9.8	1.27	1.5	16.3	0.97	73.0	17.0	81	8.4
73[2]	**10**	**9.7**	**26.1**	**9.1**	**1.22**	**0.9**	**11.5**	**0.98**	**86.0**	**8.0**	**80**	**3.3**
74[3]	20	9.3	24.4	10.0	1.31	2.0	12.8	1.04	70.0	27.0	82	25.9
78[4]	20	10.5	22.3	7.6	1.13	1.6	10.4	0.94	72.3	25.8	87	12.0

[1]P2A coal 60 %, C2 coal 30%, anthracite (100 % <2 mm)
[2] P2B coal 60 %, C2 coal 30% (100 % < 2 mmm), anthracite (100 % < 1mm)
[3]P2B coal 60%, C2 coal 20% (100 %< 2 mm), anthracite (100 % < 1 mm)
[4]P1B 50%, U2 coal 30%; anthracite (100 % < 1 mm)

DISCUSSION OF RESULTS

For this analysis, the model developed at CRM, Liege, Belgium, is applied. This model predicts M40 and M10 based on the Reactive Caking Index (RCI), the Total Inerts Content (TIC) and the maximum fluidity of the blend. Details are presented elsewhere [11]. The results obtained are shown in figures 6 for blends of washed Negro Bueno coal (seam B) and Colombian coal C3, and in figure 7 for washed Celica coal (seam B) and Colombian coal C3. For Negro Bueno coal, the calculation is less sensitive to the addition of Colombian coal than the test results.

The average coke size for blends of washed Negro Bueno (seam B) and washed Celica coal (seam B) with 20% of Colombian coal C3 is 71 and 72 mm, respectively. This value is high but adjustable to normal values by means of coke crushing, as usual. The fraction of less than 25 mm is 5%, which is good. A higher value is to be expected in case of crushing.

It is worth to mention that the addition of 10% anthracite to the blend with 60% washed Negro Bueno coal and 30% Colombian coal C2, allows for an increase in total coke yield from 72% to 74%, taking test 36 in table 7 as a reference. Sulphur in coke decreases from 1.02% to 0.98%. Average coke size increases from 72 to 80 mm, as is normal with the addition of inerts to the blend. Besides, fraction with less than 25 mm is kept low (3.3 %).

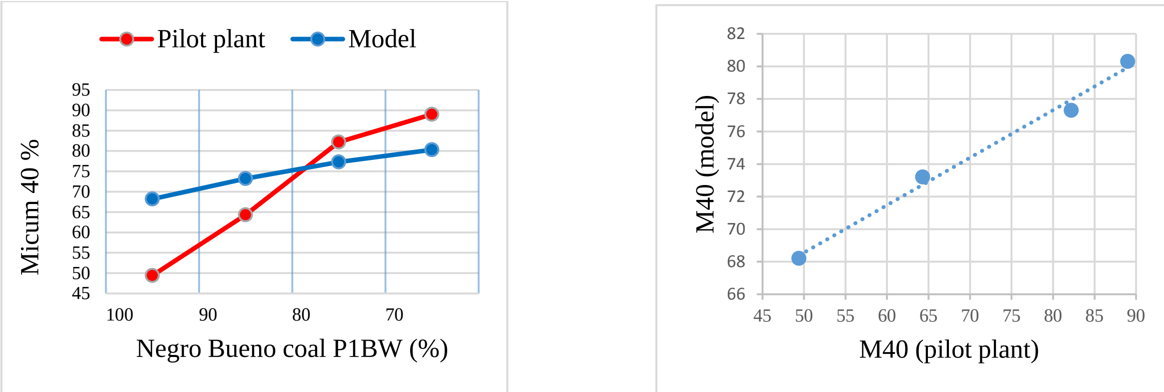

Figure 6. Blends of washed Negro Bueno coal (seam B) and Colombian C3 coal. Left: calculated and tested Micum 40 results. Right: correlation between calculation and test results.

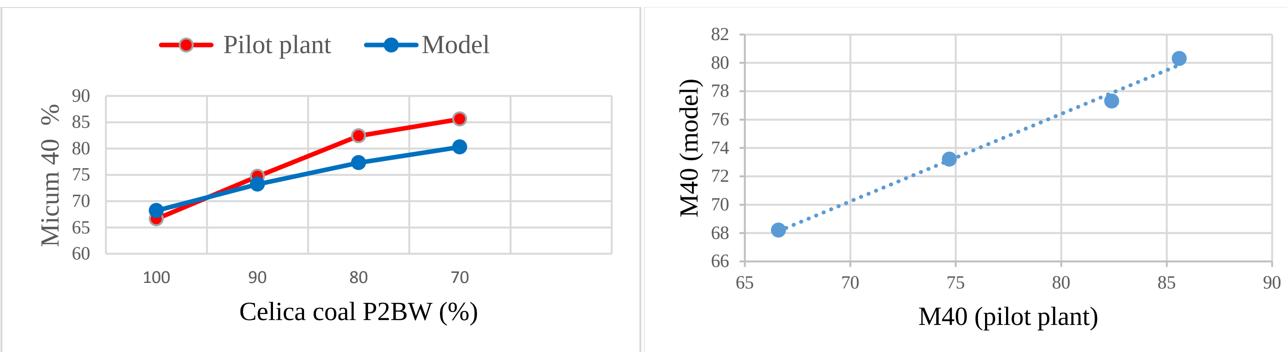

Figure 7. Blends of washed Celica coal (seam B) and Colombian C3 coal. Left: calculated and tested Micum 40 results. Right: correlation between calculation and test results.

ACKNOWLEDGMENTS

The authors are grateful to the management of Corporación Aceros Arequipa for permission to publish this paper. They appreciate the efforts of Engineers and Technicians that move forward the installation and start-up of the pilot plant, as well as those participating in the tests.

CONCLUSIONS

The use of non-washed domestic coals must be discarded, as well as the use Oyon and Cachi-Cachi coals. Blends with large share of domestic coals, fulfilling the predefined quality aims, were obtained.

The blends with largest share of washed domestic coal that achieved the quality aim had 80% Negro Bueno coal (seam B, washed) or Celica coal, seam B, washed), and 20 % of Colombian coal C3.

The required coke quality was also obtained for a blend with 30% of washed Cosmos coal, from Jatunhuasi basin, and 70% of Colombian coal C3. This result may improve with another imported coal and/or use of additives.

Anthracite could be used up to 10% in blend with 60% washed Celica coal of seam B and 30% of Colombian coal C2, increasing total coke yield and decreasing sulphur content. This result may be improved, too.

REFERENCES

1. de Cordova, M.; Madias, J. “Coke quality for a mini blast furnace”. metallon report, June 2010 (in Spanish)
2. Madias, J.; Colombo, L.; Ruiz, O.; “Correlation between a pilot oven and industrial coking batteries”. Siderurgia No. 42, June 1986, pp. 34-42 (in Spanish).

3. Carrascal, R.; Matos, C.; Silva, O.; "Coal in Peru". National Engineering University, Geological, Mining and Metallurgy Institute INGMMET, Bulletin N° 7, Series B, Lima, Peru, October 2000, pp. 1-150 (in Spanish).
4. Curran, M.D.; "Report on coke elaborated with Oyon coal". INGMMET Technical Archive, Code A2282, July 1999 (in Spanish).
5. Ampuero, L.; "The coal industry in Peru, historic evolution and development perspectives", December 1969 (in Spanish).
6. The Peruvian, Official Journal, Lima, Peru, September 28, 1971 (in Spanish).
7. Paredes, R.; Baca, M.; "Pre-feasibility of the installation of a power station with anthracite gasification in La Libertad department - Peru" (in Spanish).
8. León, E.; "The importance of mineral coal in the development". Journal of the Research Institute of FIGMMG at UNMSM, Vol. 9 N° 16, 2006, pp. 91-97 (in Spanish).
9. Vander T., "Negro Bueno Report Coal Analysis – Phase 1" Document N° C0096/01, November 14, 2008, Revision A, IJmuiden, The Netherlands.
10. Madias, J.; de Cordova, M.; "A review on stamped charging of coals". AIST 2013 Proceedings, pp. 253-262.
11. de Córdova, M.; Madias, J.; "Review on modeling of coal blends for prediction of coke quality". AISTech 2016 Proceedings, pp. 297-309.