Experimental research on the behavior of the pneumatic transport of fine-grained iron

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Abstract. Mixed injection of fine–grained iron ore and pulverized coal in the furnace, involves determining the behavior of these materials during pneumatic transport in a dense state through the pipe and setting possibilities for adjusting the flow rate of material transported with the corresponding values of the process. Parameters of the pneumatic transport were determined for the main types of iron ore and chalk used in Arcelor Mittal Galati. Outside the intended purpose of injecting iron ore and flux, it was considered also the experimental check of the possibility for injecting ilmenite in the furnace for crucible protection purpose. The possibility of injecting cinder mill into the furnace was also considered. Injecting cinder could be taken into account for the recycling of ferrous waste in the furnace, also as additive for intensifying the combustion process around the tuyeres.

1. Introduction

All experimental research had the following deployment: preparing the research materials, mounting the installation, checking the installation for starting operations, achieving actual experiments, data processing.

During the experiments the following materials were considered:

- ore from India
- concentrate from Brazil
- ore from Australia (Robe River)
- 80% ore from India and 20% dolomite
- ilmenite concentrate
- rolling mill cinder

The ore from India and Robe River, the concentrate from Brazil and the dolomite are the materials that are being presently used in Arcelor Mittal Galati.

The ilmenite concentrate was obtained from Preparation Facility in Merisani, Arges County, as part of Rare Metals Autonomous Regia Bucharest. The rolling mill cinder came from the Pipe Factory in Roman.

The chemical composition of the used materials is presented in Figure 1.

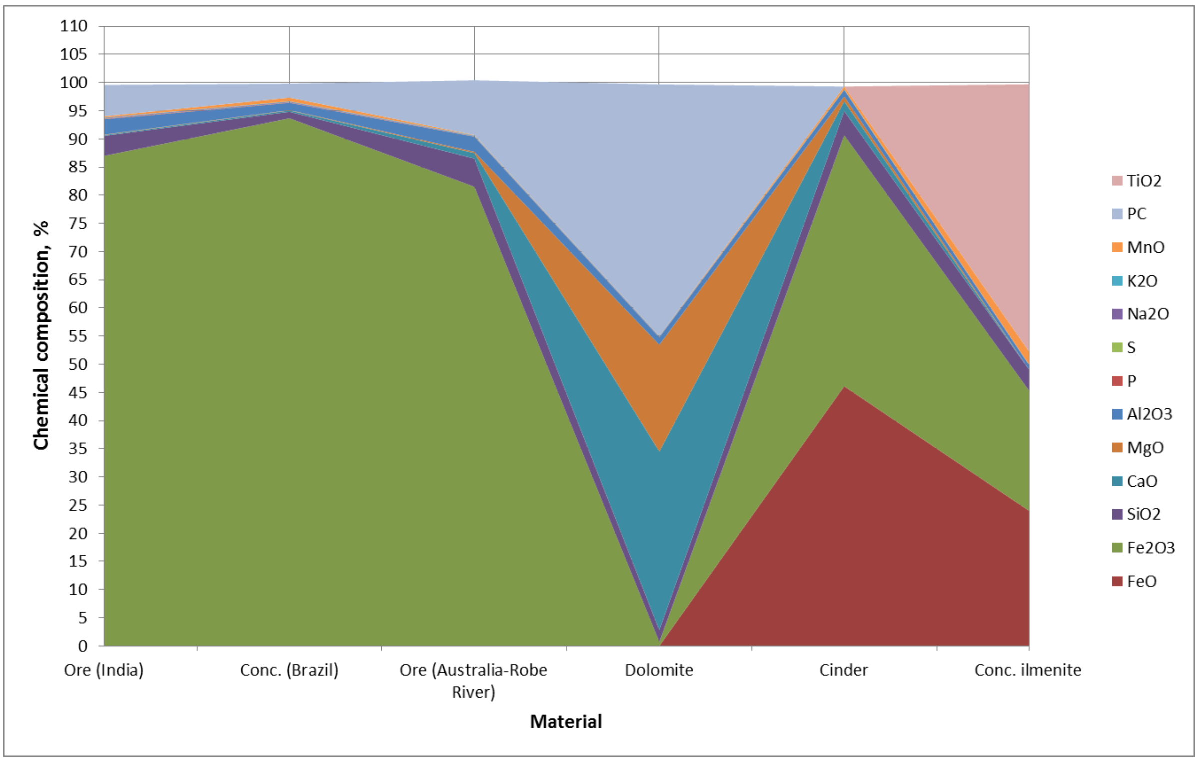
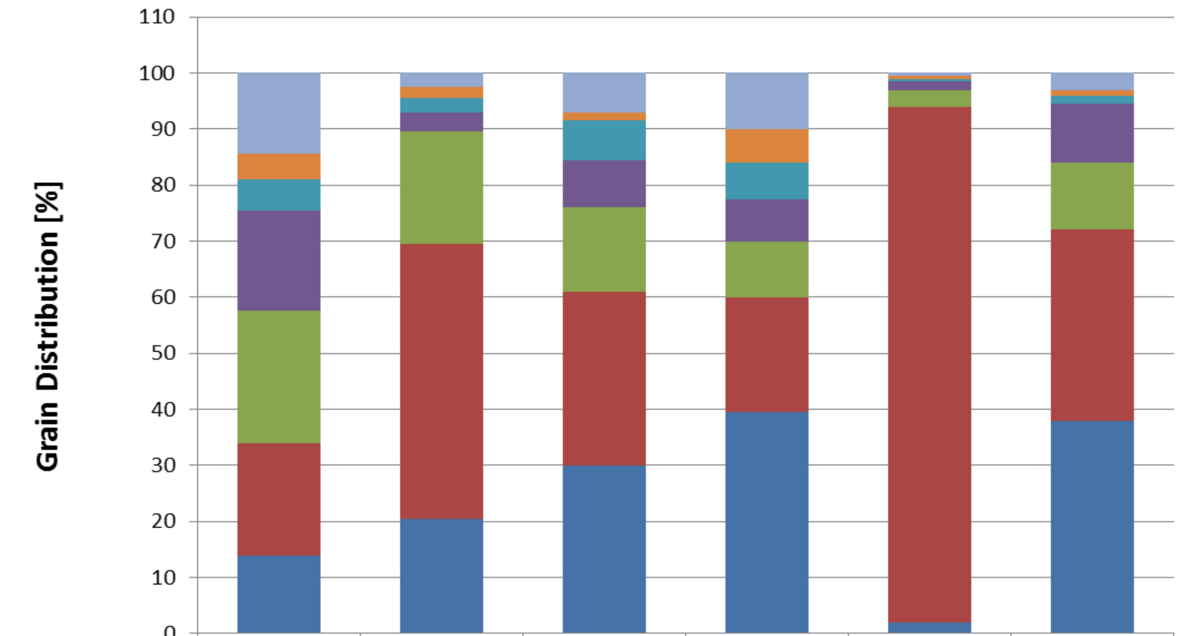


Figure 1. Chemical composition of the materials used

In terms of physical characteristics, the corresponding requirements for experimental materials required previous preparation [1], [2], [3]. The preparation process covered the following operations: grinding in order to bring the grains to a 1 mm dimension; grain classification for removing the grains larger than 1 mm and drying to eliminate the humidity.

It is worth mentioning that from a chemical point of view all materials are suitable for use in the furnace [4].

The grain distribution and the density of the materials are presented in Figure 2 and Table 1.



	Ore India	Ore Brazil	Ore Robe River	Dolomite	Ilmenite Concentrate	Cinder
< 0.063	14.5	2.5	7	10	0.5	3
0.071 - 0.063	4.5	2	1.5	6	0.5	1
0.09 - 0.071	5.5	2.5	7	6.5	0.5	1.5
0.1 - 0.09	18	3.5	8.5	7.5	1.5	10.5
0.2 - 0.1	23.5	20	15	10	3	12
0.5 - 0.2	20	49	31	20.5	92	34
1.0 - 0.5	14	20.5	30	39.5	2	38

Figure 2. Grain characteristics of the used materials

Table 1. The density of used materials

Material	Density kg/m^3	Bulk density kg/m^3		Gap fractions	
		uncompact	compacted	uncompact	compacted
Ore India	3504	1780	2136	0.492	0.390
Concentrate Brazil	4625	2381	3030	0.485	0.345
Ore Robe River	3688	1923	2222	0.479	0.397
Ore Venezuela	3892	2020	2424	0.481	0.377
Dolomite	2901	1299	1786	0.552	0.384
Ilmenite concentrate	4660	2160	-	0.536	-
Cinder	3640	1800	-	0.505	-

2. Experimental approach

2.1. Experimental facility

The facility consists of the following component parts: compressed air supply circuit, powder distributor, a circuit for pneumatic transport of the material.

The operating principle was the following: the compressed air brought in the distributor through the supply chain was streamlining the material and created a certain pressure due to which the fluid flows through the pipeline to the tuyeres. The flow rate is determined by the difference between the pressure and the resistance on the transport path of the streamlined mixture.

2.2. Experimental procedure

Prior to the experiment the preparation steps were established: checking the outside of the facility for any faults, placing the pipes for transport of the compressed air and of the streamlined mixture at ground level, checking if the valves are closed, connecting the pipe for the compressed air to the compressor, checking the pressure in the compressed air circuit by turning the valve on and reading the manometer at the reducers, purging the installation for 10 minutes with compressed air in order to eliminate the condensate or other impurities that could disturb the experiment (for this the valves are opened at the entrance to the distributor and at the entrance in the transport circuit).

In case of a required TiO_2 of 10-20 kg/t iron results a quantity of TiO_2 of 57-114 kg/h.g.v [5], [6], [7], [8].

2.3. Experimental results

Two groups of experiments were made:

- Group A: with material evacuated directly from the distributor through the connector, Φ_{int}=6 mm.

A set of tests were performed during the A experiments, A_0, with material evacuated through the pipe with overflow, Φ_{int} = 15 mm, using Robe River ore to verify the ability of the device to evacuate the overflow.

- Group B: with pneumatic transport and evacuation through a rubber pipe, Φ_{int}=8 mm and 12 m length, in horizontal position and with the evacuation end lifted up to approximately 1.6 m to simulate the placement on the furnace platform.

All experiments were done with pressures in the distributor of 0.2 up to 4 bar with evacuation at atmospheric pressure. During the experiments it was noticed that all materials studied had good behavior and were transported pneumatically even at low pressure of 0.2 bar in the distributor.
In the situation of material evacuation directly from the distributor with small pressures, up to 1 bar, the streamlined mixture flowed still, being maintained in a laminar domain; at higher pressures, over 1.5 bar, the mixture jet becomes increasingly strong and the flow had a turbulent character with intense dust releases.

In the case of material transport through the pipe, in general, the flow of streamlined mixture, material / air, is stable. A flow with fewer beats and dusty exhaust is observed at pressures above 1.5 bar for ore from India, from Robe River and the mixture 80% ore from India and 20% dolomite, with a grain showing a high content of disperse and ultrafine fractions below 0.063 mm. It was noticed that the flow was resumed easily after the temporary interruption of the transport process.

Throughout the experiments no blocking phenomena occurred besides accidental situations because of moisture or contaminants with the size greater than 1 mm entered in the distributor. Based on experimental data obtained, mass flow of material discharged at different pressures and the parameters of pneumatic transport through the pipeline were calculated, also actual transmission velocities and the velocities at the exit of the pipe of the mixture and the mass loading coefficients m.

Figure 3 and Figure 4 present the mass flow at different pressures. It was observed also the equipment ability to operate in a wide range of flow rates and its sensitivity to changes in pressure.

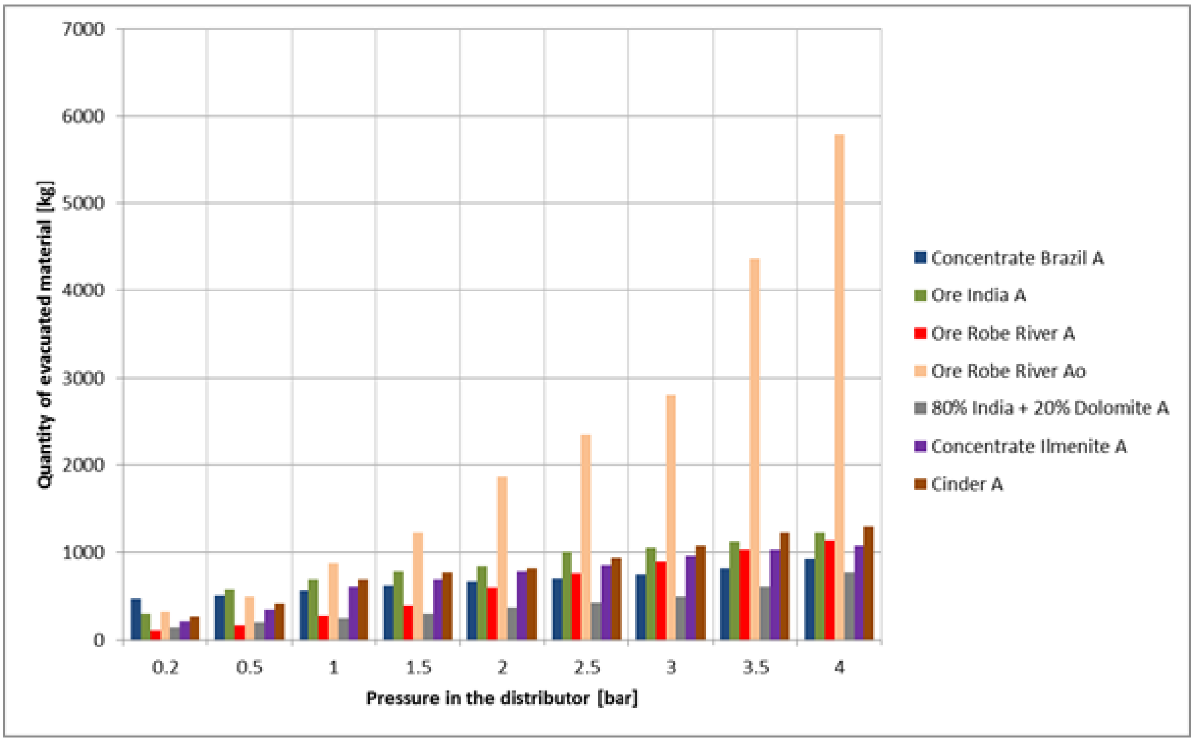


Figure 3. Material mass flow evacuated at different pressures directly from the distributor through the connection Φ 6 mm (A) and through the overflow pipe Φ 15 mm (A_0)

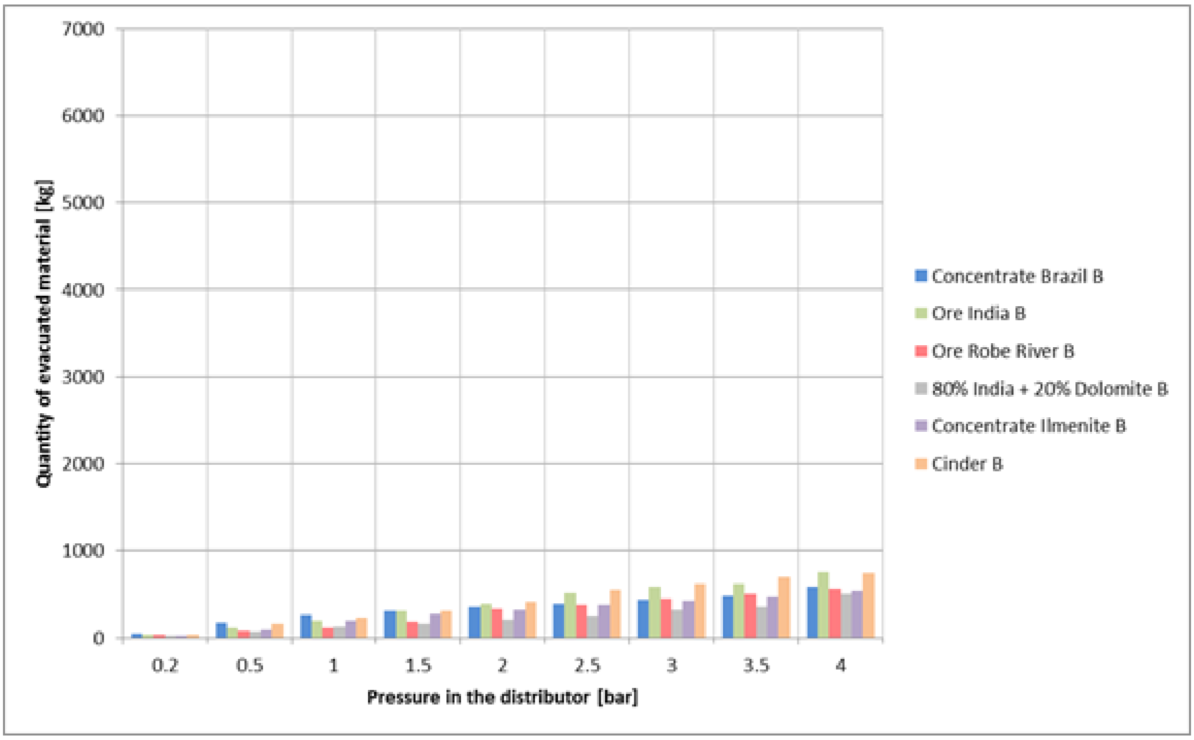


Figure 4. Material mass flow evacuated at different pressures through the rubber pipe Φ = 8 mm x 12m (B)

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The mass flow rates obtained by evacuating Robe River ore directly from the distributor through the pipe with overflow $\Phi_{int.}$ = 15 mm at pressures between 0.2 - 4 bar is between 324 - 5784 kg / h. By fitting a bottleneck connection $\Phi_{int.}$ = 6 mm it was obtained a mass flow reduction by 70-80%. Minimum flows are between 108 kg / h (ore from Robe River) and 468 kg / h (ore from Brazil) and the maximum between 768 kg / h (80% ore India and 20% dolomite) and 1296 kg / h (cinder).

In case of pneumatic transport by pipeline F_{int} 8 mm x 12 m due to pressure loss a reduction in the minimum flow to between 24-48 kg / h and a maximum of between 504-756 kg / h is observed. Flow ranges of 45-340 kg / h can be achieved at low pressure in the distributor at maximum 2.4 bar, except mixture 80% India ore and 20% dolomite requiring max pressure 3.2 bar.

The possibility of injecting the ilmenite in the ranges 125-260 kg/h for pressures in the distributor of 0.6-1.4 bar. These results show that the resistance on the transport path is lower and it is possible to accomplish the pneumatic transport in the flow ranges at a pressure in the distributor of 0-4 bar. Adjusting the flows at a value required by the process could be done by choosing the working overpressure in the distributor. Tables 2-8 transport process parameters for all materials studied.

Table 2. Transport process parameters for each material

Material	Evacuated flow, [kg/h]	Overpressure distributor, [bar]	Maximum required air flow, [Nm^3/h]	Maximum transport velocity, [m/s]	Maximum pipe output velocity, [m/s]	Maximum mass loading coefficient, [kg mat/ kg air]
Concentrate Brazil	-	0.2 - 1.8	4.6	10	25.8	57
Ore India	45-340	0.2 - 1.65	4.5	10	25.4	58
Ore Robe River	-	0.2 - 2.2	4.8	10	27	55
80% ore India + 20% dolomite	-	0.2 - 3.2	5.4	10	30.4	49
Ilmenite	125-260	0.6 -1.4	2.7-4.2	10	23.5	63
Cinder	36-744	0.2 - 4	5.7	10	32.6	101

Table 3. Pneumatic transport parameters through the pipeline of the concentrate from Brazil

No.	Pressure in the distributor, [bar]	Air flow, [m^3/h]	Mass flow evacuated material, [kg/h]	Transport velocity [m/s]	Pipeline output velocity, [m/s]	Mass loading coefficient, μ [kg mat./kg air]
1.	0.2	1.80	48	8.3	9.96	20
2.	0.5	2.60	168	9.57	14.36	51
3.	1.0	3.60	264	10.06	20.11	57
4.	1.5	4.20	312	9.48	23.71	57
5.	2.0	4.80	360	8.99	26.97	58
6.	2.5	5.20	396	8.32	29.12	59
7.	3.0	5.30	432	7.46	29.83	63
8.	3.5	5.50	480	6.9	30.98	68
9.	4.0	5.70	588	6.4	32.2	80

Table 4. Pneumatic transport parameters through the pipeline of the ore from India

No	Pressure in the distributor, [bar]	Air flow, [m^3/h]	Mass flow ejected material [kg/h]	Transport velocity, [m/s]	Pipeline output velocity, [m/s]	Mass loading coefficient, μ [kg mat./kg air]
1	0.2	1.8	36	8.3	9.95	15
2	0.5	2.66	120	9.56	14.35	36
3	1	3.6	192	10.05	20.1	42
4	1.5	4.2	312	9.53	23.83	57
5	2	4.8	396	9.06	27.17	64
6	2.5	5.2	516	8.42	29.45	77
7	3	5.3	588	7.6	30.24	86
8	3.5	5.5	624	6.98	31.4	88
9	4	5.7	756	6.54	32.7	103

Table 5. Pneumatic transport parameters through the pipeline of the ore from Robe River

No.	Pressure in the distributor, [bar]	Air flow, [m^3/h]	Mass flow ejected material [kg/h]	Transport velocity, [m/s]	Pipeline output velocity, [m/s]	Mass loading coefficient, μ [kg mat./kg air]
1	0.2	1.8	36	8.29	9.95	16
2	0.5	2.6	84	9.52	14.28	25
3	1	3.6	120	9.98	19.97	26
4	1.5	4.2	180	9.4	23.6	33
5	2	4.8	336	9	27.04	54
6	2.5	5.2	384	8.35	29.22	57
7	3	5.3	444	7.5	29.98	65
8	3.5	5.5	504	6.93	31.2	71
9	4	5.7	564	6.47	32.37	77

Table 6. Pneumatic transport parameters through the pipeline of the mixture 80% ore India + 20% dolomite

No.	Pressure in the distributor, [bar]	Air flow, [m^3/h]	Mass flow ejected material [kg/h]	Transport velocity, [m/s]	Pipeline output velocity, [m/s]	Mass loading coefficient, μ [kg mat./kg air]
1	0.2	1.8	24	8.28	9.93	10
2	0.5	2.6	72	9.52	14.27	22
3	1	3.6	132	10	20	29
4	1.5	4.2	156	9.4	23.6	29
5	2	4.8	204	8.9	26.9	33
6	2.5	5.2	252	8.3	29.06	38
7	3	5.3	324	7.46	29.83	47
8	3.5	5.5	360	6.9	31	51
9	4	5.7	504	6.47	32.3	69

Table 7. Pneumatic transport parameters through the pipeline of the ilmenite concentrate

No.	Pressure in the distributor, [bar]	Air flow, [m^3/h]	Mass flow ejected material [kg/h]	Transport velocity, [m/s]	Pipeline output velocity, [m/s]	Mass loading coefficient, μ [kg mat./kg air]
1	0.2	1.8	24	8.27	9.93	10
2	0.5	2.6	96	9.51	14.27	29
3	1	3.6	192	10.01	20.03	42
4	1.5	4.2	276	9.47	23.66	51
5	2	4.8	324	8.98	26.93	52
6	2.5	5.2	384	8.31	29.1	57
7	3	5.3	420	7.45	29.8	62
8	3.5	5.5	468	6.88	30.97	66
9	4	5.7	540	6.43	32.16	74

Table 8. Pneumatic transport parameters through the pipeline of cinder

No.	Pressure in the distributor, [bar]	Air flow, [m^3/h]	Mass flow ejected material [kg/h]	Transport velocity, [m/s]	Pipeline output velocity, [m/s]	Mass loading coefficient, μ [kg mat./kg air]
1	0.2	1.8	36	8.29	9.95	16
2	0.5	2.6	156	9.6	14.39	47
3	1	3.6	228	10.07	20.14	50
4	1.5	4.2	312	9.5	23.8	57
5	2	4.8	408	9.05	27.16	66
6	2.5	5.2	552	8.42	29.48	83
7	3	5.3	624	7.56	30.26	91
8	3.5	5.5	696	6.99	31.47	98
9	4	5.7	744	6.53	32.65	101

By analyzing the process parameters for each material from the Tables 3-8, it was observed, in general, that they are maintained in the transport ranges in a dense state ($\nu_{transport} \leq 10$ m/s, m>20). The maximum air flow that was necessary for a productivity of the installation of 340 kg/h is, in general, 4.2-4.8 Nm^3/h, exception is the mixture 80% ore India and 20% dolomite, which requires a flow of approximately 5.4 Nm^3/h. The velocities at the outlet of the transport pipe (injection velocity) are similar with the ones at the outlet of the transport pipe for pulverized coal (18-25 m/s). This is a necessary condition for not disturbing the injection of the pulverized coal in the furnace.

The results presented in Tables 3-8, regarding cinder, like the observation made during the experiments demonstrated its capacity for being transported pneumatic in dense state. At overpressures of 0-4 bar, in the distributor, flows of 36-744 kg/h can be injected in the furnace. The checks that were done on the installation after assembly have shown that the installation has the capacity of operating in safety condition at pressures of maximum 7 bar.

Experimental results with evacuation through the pipe with overflow Φ_{int} = 15 mm, indicated that at pressures of 0-4 bar in the distributor and 1 bar at the evacuation, the evacuation capacity of the dispensing device with overflow is situated in the ranges 324-5784 kg/h. The evacuation capacity with connection Φ_{int} = 6 mm is reduced by 70-80%, the mass flow was 108-1296 kg/h.

The experimental results for the injection process simulation show that the studied materials had a good behavior and can be pneumatic transported even at low pressures of 0.2 bar in the distributor and 1 bar at evacuation, the evacuation capacity through the rubber pipe Φ_{int} = 8mm x 12 m is situated between the ranges 24-756 kg/h. this demonstrates the applicability of the process when injecting ore and flux in the furnace with the flows 45-340 kg/h, also when injecting ilmenite with the flows 125-260 kg/h.

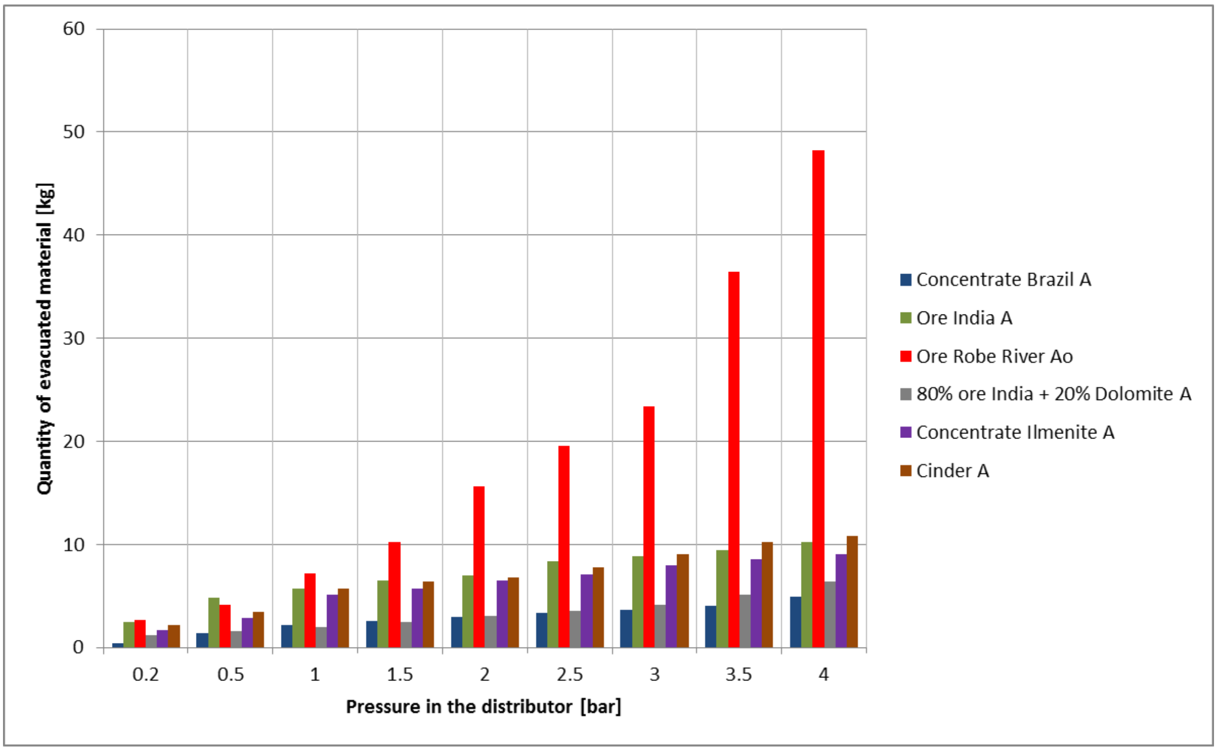

Figure 5. The obtained parameters in the pilot injection experiments with the evacuation directly from the distributor through the connection Φ = 6 mm (A) and through the overflow pipe Φ = 15 mm (A_0)

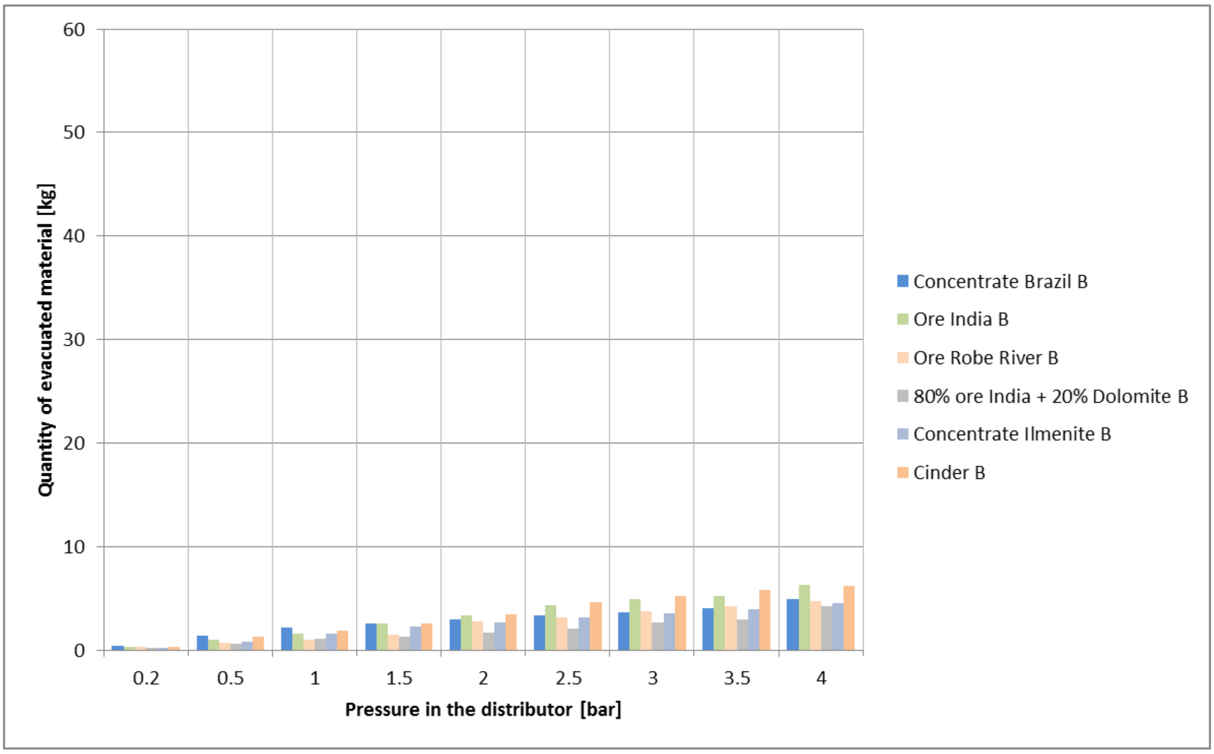

Figure 6. The obtained parameters in the pilot injection experiments with evacuation through the rubber pipe Φ = 8 mm x 12 m

3. Conclusions

The presented results demonstrate the installations capacity to operate in a regime of transport in a dense state ($\nu_{transport} \leq 10$ m/s, m>20).

Pneumatic transport of the materials in the flow ranges 45-340 kg/h and 125-260 kg/h is accomplished at low overpressures in the distributor which indicates that the resistance on the transport path is small.

The velocity at the outlet transport pipe and the mass loading coefficient is situated in the injection parameter ranges of injecting pulverized coal in the furnace (y_i = 18-25 m/s, m = 40 – 50).

Experimental results also show the cinders capacity of being transported pneumatic in a dense state and as a result we can consider recycling it in the furnace by injection through the tuyeres. The experiments have also allowed us to establish a correlation between the evacuated material mass flow and the pressure in the distributor. On this basis, in the injection technology is now possible to determine a working overpressure in the distributor and adjusting the flow at a value required by the process.

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