Stiff Extrusion Agglomeration of Arc Furnace Dust and Ore Fines for Recovery at a Ferro Alloy Smelter

By

Richard B. Steele
&
Aitber Bizhanov

Since 1889

J.C. Steele & Sons
710 S. Mulberry Street
Statesville, NC 28677
www.jcsteele.com

Prepared for

Institute for Briquetting and Agglomeration

September, 2011. New Orleans, Louisiana

ABSTRACT

The objective of this study was to evaluate the viability of auger extrusion as a method for agglomerating fine manganese ore and arc furnace dust for recovery in a MnSi metal alloy smelting process. This comprehensive project proceeded from concept through lab trials, hot strength evaluations, to a full scale 2000 ton production run and successful recovery in the smelting furnaces.

KEY WORDS: cold bonded agglomerates, arc furnace dust, Mn ore, stiff extrusion, vacuum de-airing, extruded briquettes (BREX).

INTRODUCTION

In 2010 JC Steel and Sons, Inc. teamed up with a manganese-based ferro alloys producer in order to investigate the feasibility of using auger extrusion for agglomeration of their waste dust and off-spec ore. Their process is carried out in submerged arc furnaces. Typical of such operations one of their main wastes is a bag house dust which has a significant Mn content and represents a loss of resource and poses an environmental cost. In addition their feedstock ores contain a certain amount of fines. Recovery of the dust and fine ore is highly desirable but not really possible if these materials remain in the fine state. Therefore agglomeration of these materials is very beneficial provided that it can be done economically.

Previous attempts were made to make cold bonded agglomerates out of their furnace dusts via pelletizing disc, vibro-pressing and roll briquetting but these processes did not produce acceptable results either physically or economically. This lack of success eventually led them to approach JC Steele and Son's, Inc. in order to investigate the feasibility of our proprietary "Stiff Extrusion" process for agglomerating their furnace dust, and fine ore, and coke breeze into cold bonded briquettes suitable for direct recovery in their furnaces. I should note that "cold bonding" basically refers to an agglomerate product that has not been sintered but develops strength either by virtue of the agglomeration process or the use of binders or a combination of both.

The theoretical advantages that stiff extrusion offers in the production of cold bonded briquettes are as follows:

1. Low capital cost for a given level of productivity.
2. Flexibility in sizes and shapes of agglomerates
3. High strength of green pellets (+100 Kg/cm^2)

4. Process tolerates fines and coarse particles
5. Can accommodate wet or dry feed stocks without the need for preprocessing; drying, grinding, etc.
6. Low binder requirements (Usually <1% Bentonite, <6% Portland cement)
7. Rapid curing of green agglomerates (due to application of high pressures and vacuum in process)
8. Simple, rugged, reliable equipment.

LABORATORY EXTRUSION TRIALS

In the JC Steele extrusion lab we evaluated the materials for suitability for the extrusion process through a Steele laboratory extruder with a three inch (80mm) diameter auger. Except for the furnace dust it was necessary to grind the samples in order to run through the Steele lab extruder. The feed stocks of Mn ore and coke breeze were ground through at laboratory roll crusher to minus 8 mesh. Sample mixes were blended with water and binder through an Eirich laboratory mixer. Note that we refer to extruded briquettes as “BREX”.

Suffice it to say that the lab trials led to a focus on three basic compositions which were selected for further evaluation as promising cold bonded briquette mixtures. The following sample compositions were prepared with 5% Portland cement (PC) as the sole binder:

1. Mn ore fines-50%, furnace dust -50%, Stiff extrusion moisture-11%*
2. Mn ore fines-60%, furnace dust-25%, coke breeze-15%, Stiff extrusion moisture-9.8%*
3. Mn ore fines-70%, Furnace dust-30%, Moisture required for stiff extrusion-10.2%*

   *Moistures are calculated on the wet basis

Figure 1: Laboratory Extrusion Testing

It should be noted that the main objective of the extrusion trials is to evaluate material suitability for extrusion. The BREX samples were evaluated for mechanical and thermal strengths sufficient for them to be handled and transported to the arc furnaces and to withstand the thermal stresses of the smelting process. We did not investigate the exact chemical compositions of the feed stock materials nor that of the final agglomerates.

Cold Strength Evaluation of BREX

It was possible to drop the green BREX from a height of 20ft(~6M) onto a concrete floor with the result being that they would only flatten on one side but would otherwise maintain their integrity. Three day old cured pellets were subjected to drop tests with the following procedure: 10 similarly sized BREX were put into a container, then simultaneously dumped onto a thick steel plate from a height of one meter. The samples would be collected back into the container and the process repeated nine more times. After the 10^{th} drop the sample was screened through a Tyler #4 mesh screen (net opening 4.75mm). The amount of material passing through the screen was recorded as % passing. The drop test results for the three selected samples were all in the range of 4%.

Cold strength crush tests were performed at the Walter Bai Ag Equipment at the time of the thermal testing. The crushing strengths are roughly representative of 21 day cured strengths. See results in Table 1.

TABLE 1: Cold Strength Tests

Sample	Crushing Strength, N/cm2	Comments
1	1528 4400	Longitudinal Split Compressive Crush
2	690 455	Longitudinal Split Compressive Crush
3	4800 4600	Longitudinal Split Compressive Crush

The cold strengths of compositions 1&3 must be considered very good. The generally recognized benchmark for strength of Mn briquettes is 800:1200 N/briquette. The relatively low strengths exhibited by composition 2 BREX are conjectured to be due to the weak aggregate strength of the coke breeze. The strength of this composition could be improved by the addition of more Portland cement binder.

Thermal Properties

Samples for thermal strength testing were sent to the Moscow Institute for Steel and Alloys (MISA). There thermal analysis was performed with a NETZCH Thermical STA 499C in an argon gas atmosphere, with a heating rate of 20 grad/min over a temperature range of 20-1400°C. The thermal results are given in Figures 1-3:

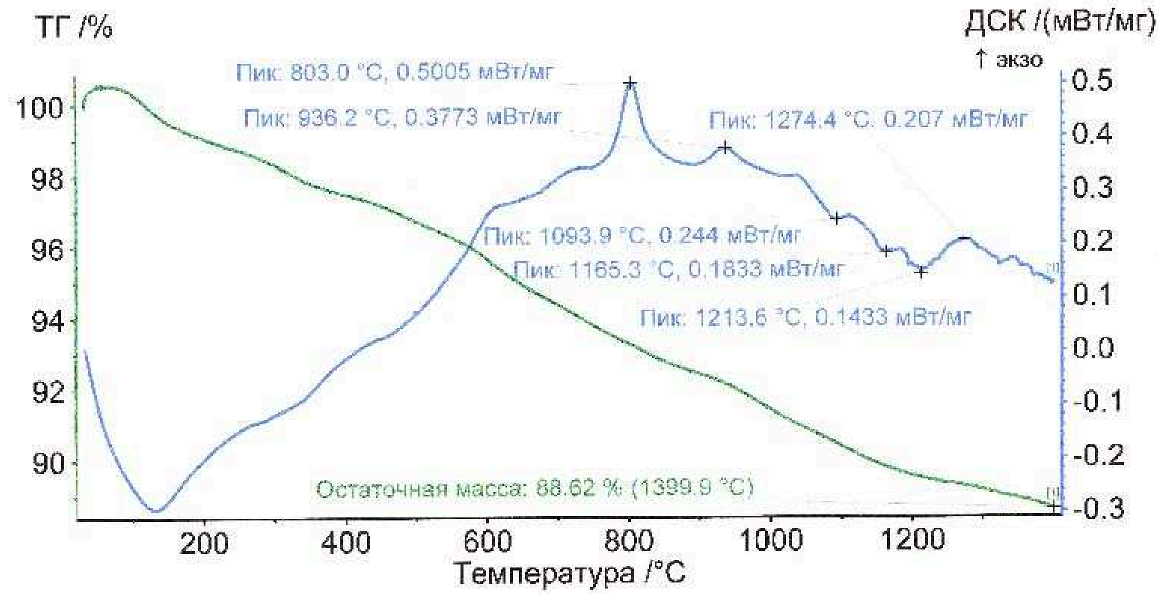

Fig.1.

Figure 2: Thermograph of BREX № 1 Constituents.

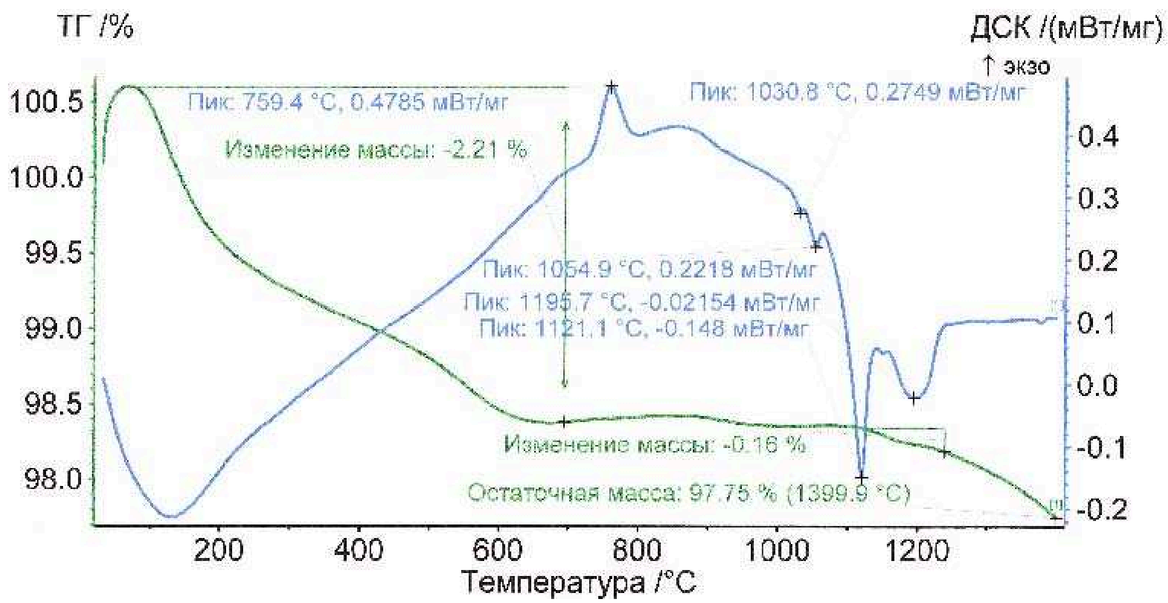

Figure 3: Thermograph of BREX № 2 Constituents.

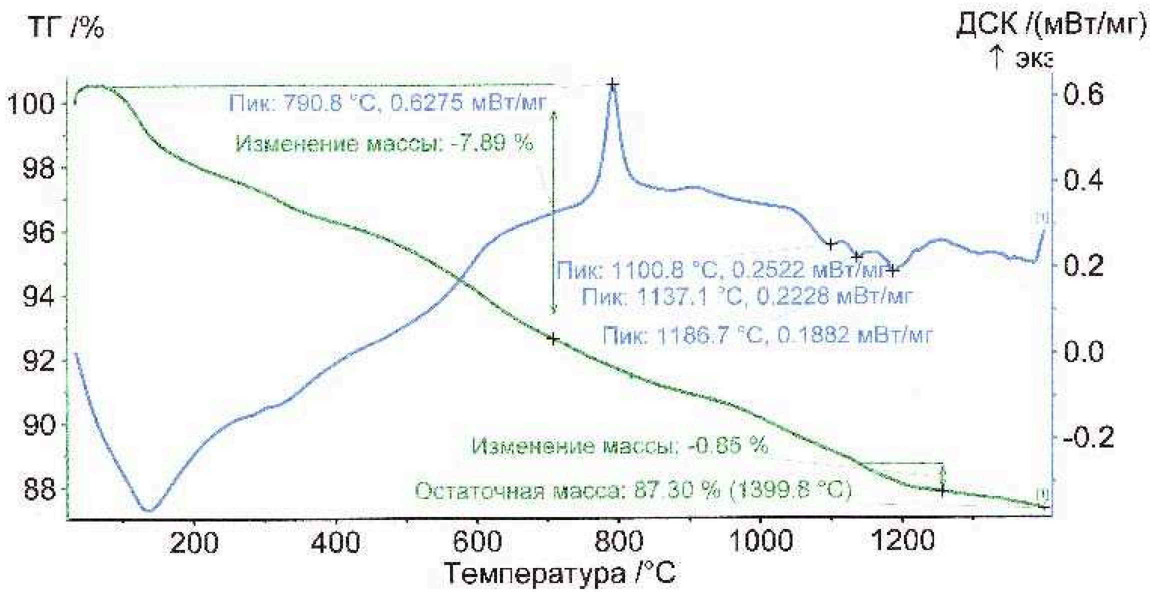

Figure 4: Thermograph of BREX № 3 Constituents.

It is apparent that the compositions of BREX 1 and 3 are similar. Mass loss of compositions 1 & 3 were 11.38% and 12.7% respectively. These mass losses can be attributed to the elimination of the surface and chemically combined moisture and the decay of carbonates. In general the surface moistures of the BREX at the time of testing was in the range of 6-8%. Starting at about 1000°C the decay of carbonates begins and then ends at about 1400°C. Beginning about 800°C we can observe the exothermal effect related to the beginning of the solid state reaction involving FeO-SiO_2-CaO.

Sample 2 contains sufficiently lower surface moisture (around 1%). In general the mass loss of this sample are at the level of 2.25%. At 1120-1196°C we observe the endothermic effects related to the decay of carbonates and higher Mn oxides.

The substances in all the BREX samples formed fusible eutectics at temperatures higher than 1000°C and by 1400°C all substances are melted.

Thermal Stability

One of the most important metallurgical properties of briquettes is their thermal stability. The property determines the behavior of a briquette under conditions similar to those found in the metallurgical process (smelting, reduction). High thermal stability is a good indicator of the performance of the briquettes in the smelting process.

In this case the thermal stability of the briquettes was evaluated by exposing them for 5 minutes to 1200°C temperature in the inner part of the furnace. This approach differed from the normal procedure as the BREX were not put inside of a graphite container before being exposed to this high temperature. Therefore the obtained results are exceptional. The procedure was as follows: 50mm samples were cut from the standard 25mm diameter BREX. The samples were placed inside tungsten wire baskets and suspended inside a Tamman furnace. The samples were weighed before and after the test. A normal air atmosphere was maintained inside the furnace. Photos of the samples before and after the tests are given in Figures 4-6.

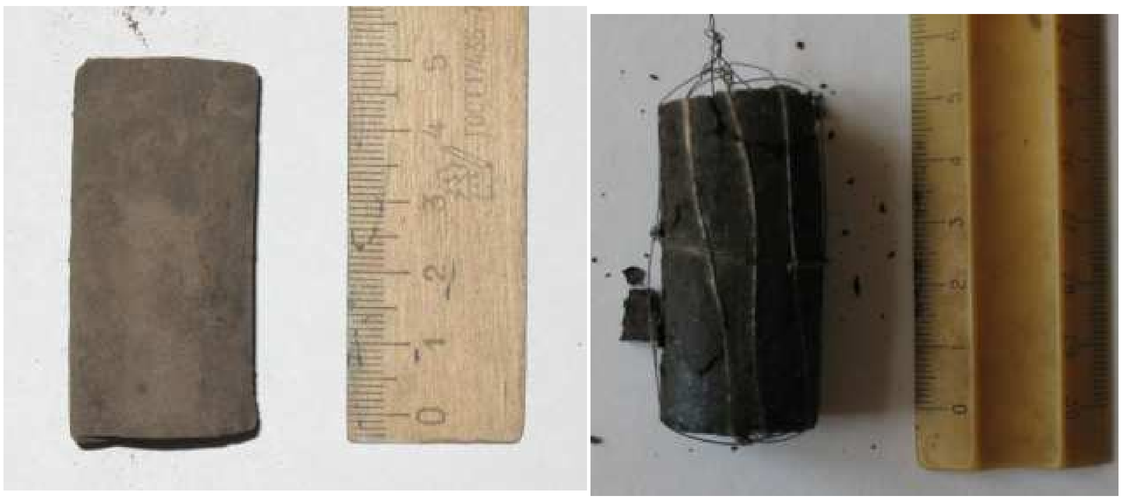

Fig 5: Sample №3 before and after thermal shock at t = 1200°C.

Fig. 6: Sample №2 before and after thermal shock at T = 1200°C.

Fig. 7: Sample №1 before and after thermal shock at T = 1500^{o}C.

The results of thermal tests demonstrated high thermal stability of the samples №1 & №2 after five minutes exposure at 1200 ^{o}C. There was practically no mechanical degradation. Only the beginning of the smelting was observed with sample N^{O}1. Sample №2 melted sufficiently. Part of the substance melted out of the basket.

Sample №3 being exposed in a furnace heated up to 1500 ^{o}C melted out within 1 minute. As a result of melting and crumbling a few smaller pieces were produced with sizes 10 – 35 mm.

As a result of these tests the following general conclusions were reached:

1. Samples of the briquettes demonstrated sufficiently high cold strength such that they can be expected to withstand reasonable handling, transportation and storage.
2. Mineral composition of the briquettes favors formation of fusible eutectics which leads to high smelting rate.
3. The samples demonstrated high thermal stability.

2000 TON PRODUCTION TRIAL

Due to the success of this testing it was concluded that further investigation was warranted. Based on the thermal and cold strength testing results the mix composition of 70% Mn ore fines and 30% arc furnace dust was selected as the best composition for further evaluation. It was also determined that since such high strengths were achieved with an addition of 5% PC, lesser amounts of cement binder could be used in future testing.

Based on the positive results achieved through the laboratory extrusion trials and the cold and hot strength testing, there was justification for organizing a full scale production trial. The MnSi alloy producer is a subsidiary of a company that is headquartered in the Ukraine and has multiple Mn alloy production facilities worldwide. In order to fully evaluate the behavior of the BREX in the furnaces it was decided that 2000 tons would permit them to evaluate different loading scenarios under actual production conditions.

A plan was put into effect in which required considerable coordination was required. Arrangements were made to land 1400 tons of a fine, wet Mn ore from a company owned mine in the Republic of Georgia. This material was landed in the port of New Orleans and then transshipped via barge and truck to a brick plant in Ragland, Alabama. 600 tons of arc furnace dust was sent from the MnSi smelter in West Virginia. These materials were blended at the brick plant site and run through their JC Steele Extruder. The extruder was equipped with multi-hole extrusion plate dies which formed the material into noodle shaped extrusions. From this point the BREX were handled and transferred numerous times and eventually shipped by barge to the smelter in WV.

Extrusion Trial

The production process in the brick plant consisted of blending the dust and ore volumetrically via front end loader into blending stockpiles. Because the ore came in coarser than was desirable, the material blend was fed into the plant through the grinding facility where the material was reduced to minus 8 mesh (2.25mm). The blended and ground material was transferred into the feed tanks in the extrusion plant. The blend was fed into a JC Steele model 75ADC De-airing (vacuum) Extruder where it was mixed with water and 3-5% of PC. The extruder and its vacuum mixer had a combined HP of 450 (338 KW). The extruder was equipped with multi-hole extrusion plates with round openings of 25 & 30mm diameter.

Figure 8: Blending Mn Ore and Furnace Dust On Site

Typical production parameters:

1. Production rate: 50 metric tons per hour.
2. Binder addition: Portland cement, 3-5%
3. Moisture content of brex: 10.5%
4. Vacuum level: -26 in Hg (-660 mm Hg)

Figure 9: Stiff Extrusion-50 mtph

Figure 10: Dumping Green Brex within 2-20 min. after Extrusion

Furnace Trials

The whole production run of 2000 tons was delivered to the smelter dock in WV by barge where they were transported to open air stockpiles. The company selected one of their furnaces in which to conduct their trials. This unit is a 27 MVA submerged arc furnace. It was selected in part because it had operated in a stable regime before the trial.

Suffice it to say that in order to properly understand the results, it is necessary to understand the factors that influence furnace operations and the resulting recovery from the smelting process. Some of these factors include; thermal inertia of the furnace, furnace stoppages and upset conditions, and charge proportions and the content of metalized components. For the sake of correct comparison, efforts were made to hold the total Mn content in the furnace charges at a more or less constant level which was in the range of 29-31%.

Baseline data was collected from the furnace operating without briquettes for the period of Oct 11, 2010 through Oct 19, 2010. Briquettes were campaigned through the furnace for the period of Oct 22, 2010 through November 16, 2010. The starting proportion of briquettes included in the charge was 5% calculated on the basis of total Mn content. This content was increased during the trial up to the level of 40%. See Figures 11 & 12.

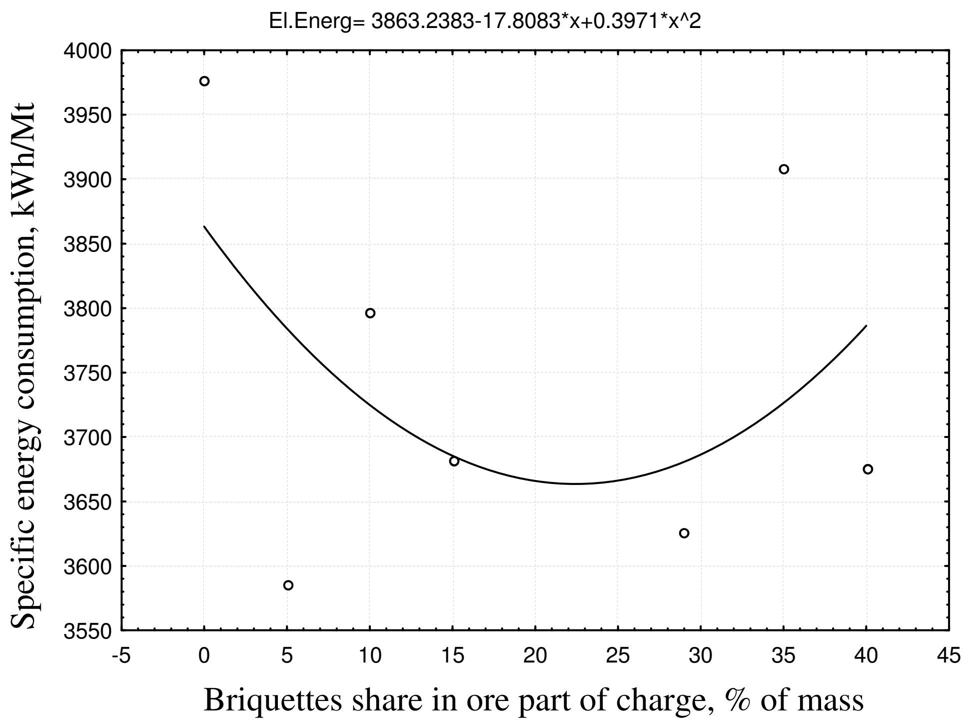

Figure. 11

Relationship between specific energy consumption & percent of briquettes in the charge.

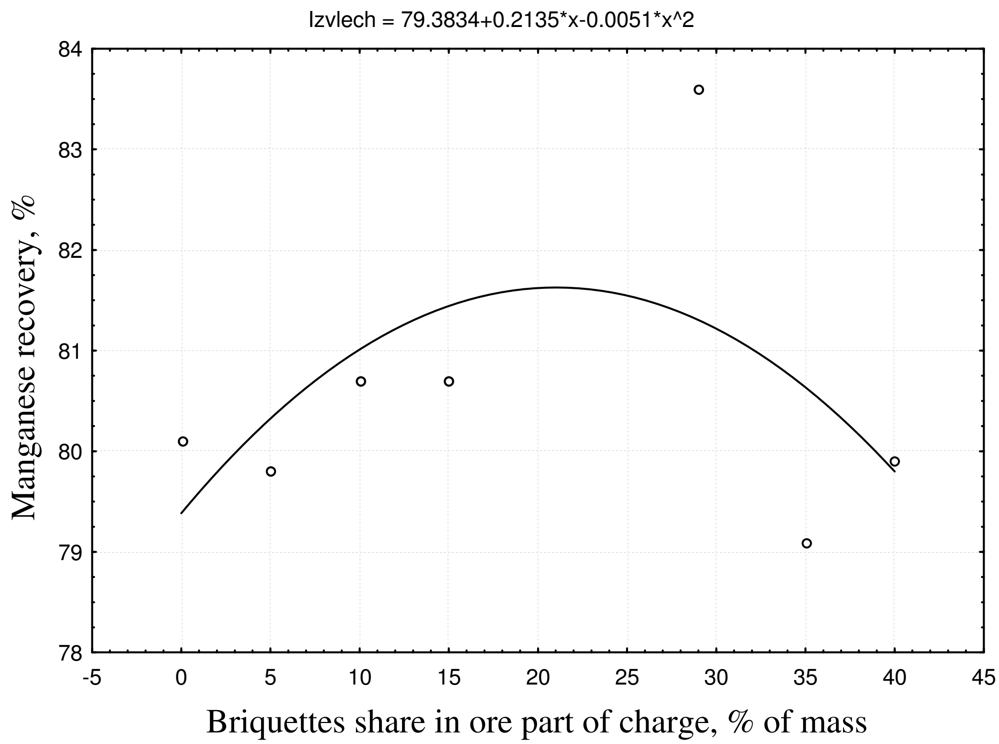

Figure 12
Relationship between Mn recovery & percent of briquettes in the charge.

CONCLUSIONS

The full-scale test based on the Mn-containing briquettes made of the Mn-ore fines (70%) and the aspiration dusts (30%) of the SiMn production by J.C.Steele&Sons, Inc stiff-extrusion technology demonstrated the efficiency of these briquettes introduction to the charge for the Manganese Alloys production. This introduction leads in general to the improvement of the overall technical-economical results of the process.

The full-scale testing campaign passed without any evident changes in technological parameters: furnace operated smoothly, under constant current load, tapping took place according to schedule, chemical compositions of the metal and slag did not change sufficiently, gas permeability of the furnace top improved.

It is worth mentioning that the briquettes demonstrated sufficiently high mechanical strength. No degradation of briquettes was observed from the top surface of the furnace charge. This indicates that the briquettes did indeed have a high level of the thermal stability and were able to withstand the thermal shock. These circumstances confirm the validity of the preliminary lab-scale test held in Statesville and Moscow in 2010.

The results of the full-scale tests show that with the increase of the briquettes share in the ore part of the charge up to the 30% level, Mn recovery increased by 3,5%, and the specific energy consumption decreased from 3977 to 3627 kWh (almost 9%).

Comparing the results of the furnace operation during the trial with and without briquettes in the charge, we can conclude that some of the essential furnace parameters were improved.

The J.C.Steele&Sons' stiff-extrusion based technology proved itself as an exceptionally efficient method for producing cold bonded agglomerates for recycling of fine Mn ore and furnace dust. The binder consumption for the production of these briquettes appeared to be at the lowest achievable level compared to other cold-bonding agglomeration technologies (3%).

These tests and production trial results, in addition to previous experience with agglomeration of steel mill wastes, further confirms the applicability of stiff extrusion as a desirable agglomeration technology for many metallurgical recycling processes. The hallmarks of stiff extrusion are high productivity, low binder requirements, tolerance for fines and wet materials and process simplicity. All of this makes for a very cost effective agglomeration method.