PHASE II CALDERON PROCESS TO PRODUCE
DIRECT REDUCED IRON
RESEARCH AND DEVELOPMENT PROJECT

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QUARTERLY TECHNICAL PROGRESS REPORT
PHASE II CALDERON PROCESS TO PRODUCE DIRECT REDUCED IRON
RESEARCH AND DEVELOPMENT PROJECT

CALDERON ENERGY COMPANY
COOPERATIVE AGREEMENT NO. DE-FC22-95PC92638

Reporting Period: 10-01-01 to 12-31-01

Date of Report: 1-22-02;

Phase II Award Date: 6-23-00; Anticipated Completion Date: 12-03-03

Total Project: \$ 25,814,000.00 Budget II Total DOE Share This Action: \$6,457,000.00

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Project Director: Albert Calderon

Assistant Project Director: Reina Calderon

Abstract

This project was initially targeted to the making of coke for blast furnaces by using proprietary technology of Calderon in a phased approach, and Phase I was completed. The project was then re-directed to the making of iron units. U.S. Steel teamed up with Calderon for a joint effort which will last 30 months to produce directly reduced iron with the potential of converting it into molten iron (hot metal) consistent with the Roadmap recommendations of 1998 prepared by the Steel Industry in cooperation with the Department of Energy. The work which is labeled as Phase II will take place at two levels; namely, the bench scale level and the process development unit (PDU) level.

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Introduction

The commercialization path of the Calderon technology for making a feedstock for steelmaking with assistance from DOE initially focused on making coke and work was done which proved that the Calderon technology is capable of making good coke for hard driving blast furnaces. U.S. Steel which participated in such demonstration felt that the Calderon technology would be more meaningful in lowering the costs of making steel by adapting it to the making of iron - thus obviating the need for coke.

U.S. Steel and Calderon teamed up to jointly work together to demonstrate that the Calderon technology can produce iron units from iron concentrate (ore) and coal quite competitively by eliminating pelletizing, sintering, coking and blast furnace operation. Such demonstration would also prove that, potentially, a significant reduction in pollution would occur including the minimization of greenhouse gases and specifically CO₂ by virtue of Calderon's technology being efficient and closed.

Accomplishments and Discussion

During the past quarter additional progress was made in the following areas:

- Developing feed rates.
- Mechanical Changes and Additions.
- Testing of various approaches relating to the ore and coal introduction into the reactor.
- Work towards reaching steady state
- Melting of iron/carbon product by induction at the foundry

As mentioned in the previous report, in making molten metal from a mixture of ore concentrate and coal, there are three challenges.

The first challenge is in the feeding of the solids; the second is in the heating of these solids in order to bring them to condition to react, and the third is the reacting of the materials under such conditions as to obtain an acceptable percentage (75%-80%) of metallization. Once such degree of metallic iron is obtained then there is need to homogenize it in order to convert the metallized iron into pig iron which contains around 4% carbon or into steel which contains various percentages of carbon--from .03% C for lowest carbon steel to 1.07%C for highest carbon steel.

Developing Feed Rates

In developing feed rates, it was obvious that steady feed rates needed to be developed. Changes were made to the hydraulic control system wherein the charging of the ore and coal into the cavity ahead of the reactor would be rapid and the feed into the reactor proper would be slow and steady, in order to keep the processing of the materials uniform. In so doing it was found that the existing pushing mechanism was too complex to accomplish this approach because of problems encountered in the raising and lowering of engagement pins by means of solenoids. A new pusher was designed.

Mechanical Changes and Additions

The new pusher was designed devoid of pins and solenoids; its detailed engineering was completed and an order was placed with the fabricator. The delivery of this new pusher was set for the third week of January 2002 (photograph #1).

Since the ore and some of the coal is delivered wet, the feeding of wet material into the reactor has been detrimental to the operation as reactions are retarded and steam

generated tends to revert reduced material back to iron oxide. A dual purpose drier/mixer was built in house in order to dry the ore as well as mix the ore and coal (photograph #2).

Another change to the equipment was the injection of oxygen at different levels of the product collector which is located below the elbow to further reduce material discharged from the reactor. It was also found that the ends of the injection tuyeres were melting due to the oxygen short-circuiting at the injection points. The shell and the lining of the collector was modified to provide for the two levels of injectors and while this was done, the high temperature refractory was changed at the injection points to overcome the melting of the tuyeres by reducing the diameter of ports and by extending the refractory for the ports all the way to the shell of the collector. Since this change was made no melting of tuyeres has occurred.

Approaches Relating to the Introduction of Feed Materials into Reactor

To find out as to which is the best approach to feed the ore and coal into the reactor to maximize efficiency, three approaches were tried. The feed with a core, the feed as slices, and the feed as a uniform mix. Of these approaches, the most efficient proved to be the core approach as it makes possible the formation of reducing gases early in the reactor thus subjecting the ore to a longer residence time as its movement progresses towards the discharging end of the reactor. Longer residence time means higher degree of metallization.

Working Toward Reaching Steady State

During the past quarter, 22 runs were made and reaching steady state has been relatively consistent depending upon as to whether the runs are carried out during consecutive days or during days with the weekend in between. It has been found that runs

that were conducted in consecutive days, it takes about 4 hours to bring the unit to steady state; whereas, with a weekend interruption the time required to reach steady state is extended to about 6 hours because the unit cools off between Friday and Monday. At the end of each run, the unit would be sealed for the night. Next morning the collector would be unbolted and withdrawn from under the reactor. Frequently the product would reglow (photograph #3) by virtue of re-oxidation which in continuous operation will be avoided in since the system is closed. Random samples of the iron/carbon product would be taken and be subjected to a grindability test to determine whether the product is an iron or a steel (photograph #4).

Melting of Iron/Carbon Product at the Foundry

Arrangements were made with Castmasters (a specialty foundry) in Bowling Green, Ohio to melt the Iron/Carbon product produced by the Bench Scale in an induction furnace (photograph #5) in order to homogenize the product and produce an iron or a steel. Initially there were trials to determine the coupling properties of the product in the induction furnace. Having found that coupling does occur, the next step was to melt the product. To Calderon's surprise the product melted made a low carbon steel.

On the 21st of December, a melting test was conducted in the presence of NETL's personnel and the heat was cast (photograph #6) into squares. The analysis of the samples taken from this heat showed that the product was low carbon steel which was directly made from iron ore and coal, a major breakthrough. The squares were sawed-off from the sprues, (photograph #7).

Conclusion

The past quarter was constructive as important information was accumulated from the Calderon process. The next quarter will be focused on a continuous run of several days and produce material that is on average 80% metallized. All the material produced during this period of operation will be transported to the U.S. Steel Research and Technology Center for evaluation. An overall mass balance for the process will be performed. In order to accomplish this extended continuous test, the new pusher will be installed and de-bugged and sealed containers will have to be provided in order to prevent the material from re-oxidation.

Submitted by:

Albert Calderon
Project Director

PHOTOGRAPH #1

PHOTOGRAPH #2

PHOTOGRAPH #3

PHOTOGRAPH #4

PHOTOGRAPH #5

PHOTOGRAPH #6

PHOTOGRAPH #7