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

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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 successfully completed. The project was then re-directed to the making of iron units. In 2000, U.S. Steel teamed up with Calderon for a joint effort which will last 42 months to produce directly reduced iron with the potential of converting it into molten iron or steel consistent with the Roadmap recommendations of 1998 prepared by the Steel Industry in cooperation with the Department of Energy by using iron ore concentrate and coal as raw materials, both materials being appreciably lower in cost than using iron pellets and coke.
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Executive Summary

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.

The fact that U.S. Steel and Calderon teamed up to jointly work together to demonstrate that the Calderon technology will produce in a closed system iron units from iron concentrate (ore) and coal competitively by eliminating pelletizing, sintering, coking, blast furnace operation and possibly doing away with the BOF and the EAF by making steel directly, a huge reduction in CO₂ generation relating to steelmaking would ensue. Such reduction will restructure the steel industry away from the very energy-intensive steelmaking steps currently practiced and drastically reduce costs.

The development of a technology to lower U.S. steelmaking costs and become globally competitive is a priority of major importance. Therefore, the development work which Calderon is conducting presently under this Agreement with the U.S. Department of Energy becomes more crucial than ever. To demonstrate feasibility of the Calderon process U.S. Steel set a target for metallization of 80%. Calderon met 90% of the 80% target (72.3% metallization). Steps were taken during the past quarter to make changes to the equipment to overcome the impediment which prevent the attainment of 80% or better metallization of the iron ore concentrate. Work is proceeding to attain this objective.
Experimental

During the quarter which this report covers three experiments were conducted; Tests Runs #136, #137, and #138. Runs #136 and #137 were carried out with the conveyor and Run #138 with a modified construction which incorporated a slide gate replacing the conveyor.

Test Run #136 was started at 4:50 a.m. on January 5 and ended at 5:00 a.m. on January 8. A period of 72 hours and 10 minutes. The total number of pushes were 755. High pushing pressures were observed 12 times during the Run which necessitated poking from the eastern side port to dislodge frozen material stuck at the discharge of the elbow. Pushing was completely stalled at push 34 and push 275. The stalling at push 34 was overcome by poking whereas the stalling at push 275 necessitated the moving of the conveyor away from the drop point and the cleaning of the discharge apron of the elbow. At push 534 the skirt making connection between the bottom of the elbow and the conveyor caught fire; the conveyor was moved out of the way and a drum was installed below the elbow in order to continue with the 72 hour test.

Test Run #137 was started at 5:53 a.m. on January 12 and ended at 5:00 p.m. on January 15; a period of 83 hours and 7 minutes. The total number of pushes were 904. High pushing pressures were observed 11 times during the run, the 11th of which was at shut-down (1400 psi). To relieve these high pressure pushes, it was resorted to poking from the eastern side port to dislodge frozen material stuck at the discharge of the elbow. Pushing was completely stalled at push 812. The conveyor was dropped and a large stalagmite rested on the drop point of the conveyor and extended upwardly into the elbow. Effort was expended to break the hot stalagmite in order to remove it; there was enough of it broken and removed
which enabled the continuation of the Run. Because of the problems experienced with the conveyor especially with the material sticking at the drop point and building up into the elbow (see photographs #1 and #2) it was decided to cease testing with the conveyor and make changes to the equipment in order to have a means at the drop point which will force the material to move rather than stay stuck and build-up. This will be discussed in detail in the Discussion section of this report.

Test Run #138 was started on March 29 after making the modifications to the equipment which included a slide gate to be described in detail in the Discussion section which follows. The test began at 5:00 a.m. with the normal preheat and was ended on the morning of April 1 at 7:00 a.m., a period of 74 hours. The total number of pushes were 822. High pushing pressures were experienced two times during the Run at push 452 and push 626. Instead of poking, the horizontal lance was completely withdrawn and parked for five minutes (one push), the pressure dropped from 1000 psi to 255 psi. With respect to the high pressure experienced during push 626 the horizontal lance was reversed and the pressure dropped to 366 psi. The pusher stalled completely at push 674, the horizontal lance was parked for 10 minutes (2 pushes), the pressure dropped to 253 psi; normal horizontal lance practice was resumed. At push 578 a large build-up of material at the apron (discharge of elbow) was observed; that material was pried loose with bars. At push 813 the slide gate would not open, after several attempts it finally opened. It is surmised that some solid material must have lodged in the clearance between the gate and its track.

Results and Discussion

The experience with the vibrating conveyor proved that it was not suited for this application. Vibrating conveyors are quite efficient in moving solid materials but it has been
found that as the iron ore undergoes through the metallization phase, it becomes “mushy” and sticky, this being the property that iron takes as it turns ductile. From one standpoint it is an excellent property since it converts to metal but the side effects of this property would have to be dealt with. When the metallized “lacey” material is produced in the reactor and discharges from the elbow it must be coaxed to move and not stick to the apron (discharge of elbow) where it loses temperature becoming a solid build-up. This solid build-up at the discharge which is immobile, prevents the advancement of material within the reactor, such advancement being caused by the pushing forces applied by the ram at the charging end. Therefore keeping the apron at the discharge hot without causing the material to melt is of primary importance while at the same time preventing the solidification of the mushy/sticky material in order as not create negative forces at the discharge which negate the pushing forces of the ram. Further it has been found that when the “mushy” material drops on the conveyor it must be coaxed to move when the vibrating conveyor is operating. If the material is cooled into a solid after dropping onto the conveyor (see photograph #3), thermal energy flows from the hot apron which is upstream, causing the “mushy” material to solidify and stick against the apron. When this happens, the material stays immobile and builds up in the transition; see photograph #4; in an attempt to coax the material to move on the conveyor; however, a long rod with a crook at its end (see photographs #5 and #6) would be inserted from the discharge end of the conveyor but the material would level itself by virtue of being “mushy” but not move (see photograph #7)

As the material accumulates at the drop point it builds up into the transition below the elbow causing delays and ultimately shut-downs. Since in a commercial application this phenomena will not be acceptable, it was decided to develop a more positive way of insuring
that the material will move once discharged while at the same time maintain the temperature at the apron to minimize the solidification (build-up) of the metallized material against it.

The approach taken was to engineer a refractory slide gate with a hole encased within a steel frame which is equipped with track wheels to run on rails within a housing which would be totally enclosed and the slide gate being activated from outside of the housing by means of a hydraulic cylinder, with the sealing of the rod of the cylinder being effected by means of a gland and a packing box to contain the gasketing. Drawings were prepared on a priority basis and delivered to a structural fabricator for expeditious construction of the steel portion, with the mechanical, electrical, refractory and erection work was left to be done by Calderon’s crew once the steel fabrication was delivered. During the period that the fabrication was being performed, the majority of the in-house crew was engaged in coal gasification work outside the scope of the Contract with DOE; such gasification was funded by Calderon and not charged to the Contract.

Upon delivery of the steel fabrication, work began on insulation and refractory installation. Photograph #8 shows the slide gate steel frame as delivered, photograph #9 the crew installing the castable insulation, and photograph #10 the gate fully lined with the “Ruby” refractory which is good for 3400°F (1920°C), being colored in green. Photograph #11 shows the transition being lined; it engages with the fixed spool below the elbow (see photograph #12) and is part of the slide gate housing. This housing (shown in photograph #13) is adapted to travel on a track along the length of the main structural frame and is also adapted to be raised and lowered by means of jack-screws in order to engage and disengage the transition to and from the fixed spool located beneath the elbow. A secondary track is provided on the inside floor of the housing to accommodate the rolling of the slide gate.
Photograph #14 shows the slide gate installed within the housing and Photograph #15 shows the housing on the main frame in the operating position under the fixed spool. Photograph #16 shows the other end of the slide gate assembly; it is to be noted that the supporting structure (blue columns) had to be widened and elevated on stools in order to accommodate this larger structure as compared to the width of the conveyor which had occupied that space. Photograph #17 shows the hydraulic cylinder rod which engages the slide gate within the housing through the packing gland seal. Photographs #18, #19 and #20 which were taken after Test Run #138 show the different positions of the slide gate. Photograph #18 shows the gate at 100% closure, photograph #19 at 90% closure and photograph #20 at 30% closure.

During Runs #136 and #137, it was noted that more material would stick towards the east of the apron than west and cause build-up. Upon scrutiny, it was found that since the reactor in relation to the elbow is not on the same center line but eastward, the material tends to stick on the eastern part of the apron; see photograph #21. This off-center configuration was provided in the original design of the reactor and elbow in order to avoid the intersecting of the vertical with the horizontal oxygen injection lances. To alleviate this imbalance it was decided to reconstruct the spare elbow so that the reactor discharge, elbow discharge and apron are all on the same center line; see photographs #22 and #23. In addition to this alignment, the discharge from the reactor into the elbow was lined in such a way as to allow the feeding of the processed material to discharge divergently into the elbow which is purposely made larger than the discharge of the reactor to minimize the hot “mushy” material from contacting the walls of the elbow; see photographs #24 and #25. And, to prevent the intersection of the vertical oxygen lance with the horizontal oxygen lance two off-center ports
in the roof of the elbow were provided to accommodate two vertical lance that straddle the horizontal lance; see photographs #26 and #27.

Conclusion

From Runs #136 and #137, there is evidence that the frequency of developing high pushing pressures caused by material build-up at the discharge of the elbow and apron when using the conveyor, was quite excessive; 12 times during a 72 hour test in Run #136 and 11 times during an 83 hour test in Run #137. Whereas in Run #138 when using the slide gate, only two high pushing pressure incidents were experienced in a 74 hour test; this is a significant reduction. Since inherently the metallized material has a propensity to stick and build-up at the discharge, effort will be expended to develop a modified lance practice to enable the discharge of the reactor, the elbow and the apron to maintain a temperature range that will minimize sticking, and consequently the build-up; this effort should be coupled with a monitoring procedure to give early notice that a build-up is occurring. Further a simple piece of equipment needs to be used that once build-up occurs, it will be dislodged from the discharge of the elbow and apron with minimum interruption to the operation. Heretofore, the use of pokers or bars have been utilized to dislodge build-up; (see photograph #28). A better approach needs to be devised. During next quarter work will be focused on such effort and progress towards the three 72 hour tests at a reasonably steady state with a metallization of 80% metallization.

Submitted by:

Albert Calderon
Project Director
References - Not Applicable

The work performed in this quarter which the report covers, was original work. No reference material was relied upon for the work
1. Lowering the transition at the drop-point shows material build-up

2. Frozen material within the spool
3. Frozen material at drop-point of conveyor

4. Material build-up being substantial
5. A long rod inserted through port located at end of conveyor to “coax” the material to move.

6. The long rod provided with a crook at the end to help move the material from the drop-point.

7. Looking into the conveyor drop-point with the gate open. Material not moving.
8. Slide gate carriage frame

Track wheels

9. Lining the slide gate

10. Lined slide gate

Track wheels
11. Lined transition

Transition as integral part of slide gate housing

12. Transition engaged with fixed spool located downstream of elbow
13. Slide gate housing

- Rollers for moving slide gate housing
- Secondary track for gate
- Main structural frame

14. Slide gate installed in housing showing drop hole of transition in registry with drop hole out of the housing

- Gate end
- Packing box for sealing activating cylinder rod with gland

15. Slide gate housing shown in operating position with top of transition engaging the spool and the drum in engagement with the bottom of the transition

- Fixed spool
- Movable transition
- Sealing end plate of slide gate housing
16. Slide gate assembly under elbow

Wide supporting structure

Hydraulic cylinder activating valve

Elevating stool

17. Activating hydraulic cylinder for advancing and retracting slide gate

End plate of slide gate housing

Packing gland seal
18. Slide gate at 100% closure seen from above

19. Slide gate at 90% closure seen from above

20. Slide gate at 30% closure seen from above
21. Elbow prior to repair
22. Modification to elbow
   Structural relocation of reactor discharge

23. Layout of structural changes to provide alignment
   Alignment of centerline of reactor discharge with centerline of elbow

24. Modified elbow
   Discharge of reactor
   Insulation board installation
25. Elbow with bottom being up-ended

- Discharge of reactor

26. Elbow relining
- Ports for two vertical lances
- Port for horizontal lance
- Insulating board
- Castable insulation
- Ruby refractory

27. Revamped elbow mounted to unit
- Dual vertical O₂ lances
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28. Clean-up of build-up