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TECHNICAL REPORT
December 1, 1992 through February 28, 1993

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Project Title: **UTILIZATION OF ILLINOIS SLAGS FOR THE PRODUCTION OF ULTRA-LIGHTWEIGHT AGGREGATES**

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ABSTRACT

The objective of this program is to demonstrate that solid residues (slag) from the gasification of Illinois coals can be utilized to manufacture ultra-lightweight aggregates (ULWA). Conventional ULWAs are made by pyroprocessing perlite ores and have unit weights in the range of 3-15 lb/ft^3. In a previous project, Praxis Engineers demonstrated at the pilot scale that lightweight aggregates with unit weights of 40-55 lb/ft^3 can be produced from Illinois coal slags, which is suitable for making lightweight cement concrete and precast blocks. These tests also indicated that a product with a unit weight of less than 25 lb/ft^3 could be produced from slag. This project is aimed at testing the potential for producing ULWA from Illinois coal slags. Target applications include loose fill insulation, insulating concrete, lightweight precast products such as concrete blocks and rooftiles, and filtration media. Laboratory- and pilot-scale testing is being conducted in Phase I to identify operating conditions for the expansion of Illinois slags to produce ULWA. Following this, a large batch of expanded slag will be produced, for evaluation in various applications in Phase II.

Bench-scale tests conducted during this reporting period using slags derived from gasification of two Illinois coals indicated that the unit weights of products from one slag are 12-20 lb/ft^3 and those of the other are 18-27 lb/ft^3. During this work, the potential for slag clinkering was identified, and two approaches were successfully tested as solutions to this problem: blending perlite ore with the feed slag and acid treatment of the feed slag. An additional approach, namely, modification of the pilot furnace gas burner, is currently being implemented.

Regulatory trends with respect to solid waste disposal, landfill costs, and public concerns make utilization of solid wastes a high-priority issue. Production of value-added products from Illinois coal gasification slag will reduce public resistance to power plant siting, shorten the time required for plant permitting, and enhance the overall gasification process economics, especially when the avoided costs of disposal are considered.

EXECUTIVE SUMMARY

The major objective of this project is to produce ultra-lightweight aggregates (ULWAs) from solid residues or slags generated from the gasification of Illinois coals. Conventional ULWAs, with unit weights between 3 and 15 lb/ft^3, are produced commercially by subjecting naturally occurring expansible perlite ores to thermal processing in a vertical shaft furnace (VSF). The industrial applications for ULWAs include the following:

- Loose fill insulation
- Insulating concrete
- Precast products
- Agriculture applications
- Filtration media

In this project, a thermal expansion concept developed by Praxis in a previous project for the expansion of Utah and Texas coal gasification slags is being applied to Illinois coal slags with the objective of producing ULWAs. The research is proposed to be conducted in two phases, each of one year's duration. The focus of Phase I is on the development of techniques for producing ULWA from Illinois coal slags using laboratory-, pilot- and commercial-scale equipment. The process variables for the VSF system include the following:

- Hot zone temperature
- Combustion air flow rate
- Slag preheat temperature
- Slag particle size and feed rate
- Flame profile (burner design)

Using operating conditions determined during these tests, a test batch of expanded slag aggregate will be produced in a commercial-sized furnace for physical characterization to assess the performance of the VSF operation. Full-scale operating conditions, heat and mass balances, and off-gas analyses will be obtained and compared with those for conventional ULWA. Detailed characterization of the expanded slag and demonstration of its use in various applications will be performed in Phase II of the project.

Bench-Scale Tests. During this reporting period, two Illinois slags were tested for their expansion characteristics at the bench scale using a muffle furnace. These samples were size-classified and processed for removal of impurities such as char prior to testing. Upon expansion, the two samples of Illinois slag resulted in products with unit weights of 12-28 lb/ft^3.

Pilot Tests. Initial tests using a standard perlite ore in a pilot-scale vertical shaft furnace (VSF) at a temperature of 1700°F yielded an expanded product with a unit weight of 8 lb/ft^3.

Preliminary slag expansion tests in the pilot furnace resulted in fusion of slag on the furnace walls due to partial melting of some of the slag particles. It was concluded that this was caused by excessive heating of some of the particles when they came into intimate contact with the flame. Therefore, a different type of burner configuration was designed and procured in which high-temperature air rather than flame comes in contact with the slag particles.

The next batch of pilot tests was run using two Illinois slags blended with perlite, and products with unit weights of 12.5-21.6 lb/ft^3 were produced. These tests demonstrate that Illinois slags can be expanded in a VSF.

Several alternative approaches were also identified to eliminate fusion of the slag particles, including acid treatment of the slag particle surfaces and blending small quantities of perlite ore (20% by weight) with the slag. Initial pilot tests were conducted using a Texas lignite slag since Praxis has considerable data on this slag from another project which is helpful in furnace calibration. The slag was mixed with perlite to act as a buffer, which effectively prevented fusion problems in the furnace. In this test, at 1520°F, 14 x 30-mesh slag expanded to a unit weight of 21.6 lb/ft^3 and the perlite to 15.3 lb/ft^3. As this is the first time a vertical shaft furnace designed for perlite has been used for slag expansion, certain necessary equipment modifications to customize the furnace for a slag feed have been identified. Further testing will be resumed as soon as a new burner configuration more suitable for slag is installed. Since the new burner will provide better control of the heat distribution in the furnace, it is possible that it may also allow production of lower unit-weight products, as were obtained during high-temperature laboratory tests.

Testing in a commercial-scale furnace, scheduled for later in Phase I, will provide valuable operating data and allow assessment of the reproducibility of the product quality under industrial operating conditions. Initial characterization tests of the expanded product will be completed as a means of evaluating VSF operation. These tests will also provide a preliminary assessment of the suitability of the expanded slag as a substitute for conventional ULWAs using appropriate ASTM and Perlite Institute specifications.

OBJECTIVES

The overall objectives of this project are to test and demonstrate the feasibility of producing ultra-lightweight aggregates (ULWA) from slags generated from the gasification of Illinois coals and to evaluate them as substitutes for conventional ULWAs in a number of applications such as precast lightweight products, insulating concrete, and loose fill insulation. These objectives will be met by the following activities:

- Test the potential for producing ULWA from Illinois coal slags using a technology developed by Praxis Engineers in previous work
- Perform characterization tests on expanded slag using ASTM or Perlite Institute procedures
- Evaluate the quality of expanded Illinois coal slag in comparison with conventional ULWA
- Identify applications for which expanded slag can be used as a substitute for conventional materials
- Determine experimentally the suitability of products using expanded slag as a substitute for expanded perlite, such as precast lightweight products, insulating concrete, and loose fill insulation
- Conduct an economic evaluation of VSF expanded slag production, including estimates of equipment size, production rates, and material and heat balances.

The project objectives will be achieved in two phases, each comprising one year of research and development work. The Phase I work is aimed at bench-, pilot-, and commercial-scale testing to adapt the VSF expansion technology to the particular needs of Illinois coal slags and product characterization and testing in accordance with ASTM and industry standards. The Phase I work is being done at the facilities of a large expanded perlite manufacturer. The projected Phase II work, to be undertaken in the second year, will emphasize comprehensive characterization and application-specific test work, culminating in application demonstration tests. The performance of applications using expanded slag generated in Phase I will be monitored, and economic analyses will be conducted with a view to marketing the products. This work is planned to be performed at the facilities of a major

ULWA user. The project will result in a technology transfer package which will assist in the implementation of the VSF technology at coal gasification demonstration projects using Illinois coals such as the Franklin, Indiana, coal gasification project.

INTRODUCTION AND BACKGROUND

Illinois coals have been demonstrated to be excellent feedstocks for coal gasification due to their high volatiles content, high Btu content, and low cost. Their high sulfur content, which reduces their desirability for pulverized coal-fired boilers, is actually an advantage with gasification since the sulfur is recovered in its elemental form and is a saleable by-product. The advantages of Illinois coals in gasification can be further enhanced by processing the gasification solid residue (termed slag) for commercial use rather than disposing of it as a solid waste.

Previous work performed by Praxis established that slags have inherent properties of expansion or bloating upon thermal treatment which reduces their unit weight to between 15 and 55 lb/ft^3, depending on process conditions. This characteristic is similar to that of naturally occurring expansible shales or clays and perlite which are used to manufacture lightweight aggregates (LWA). Praxis has demonstrated the production of LWAs from slag at the pilot scale (50 lb/hour), using a rotary kiln typically used for the expansion of such aggregates from shales and clays. The expanded slags produced in the pilot plant had unit weights ranging between 25 and 55 lb/ft^3. Upon evaluation in accordance with ASTM standards and industry requirements, they were found to be suitable for use as LWA for the production of lightweight concrete and lightweight blocks. The compressive strength of test specimens of concrete made with expanded slag exceeded ASTM requirements for load-bearing lightweight concrete blocks. In addition, the pilot kiln test results confirmed that products with considerably lower unit weights which could be substituted for expanded perlites can be produced from slag.

Basic work to develop techniques for producing ultra-lightweight aggregates (ULWA) from slag has been done, with very satisfactory initial results. Under this project, Praxis will test the expansion potential of Illinois coal slags and produce a large batch of expanded slag to test its potential for use as a substitute for conventional ULWAs.

EXPERIMENTAL PROCEDURES

In order to obtain reproducible results, test procedures for bench- and pilot-scale tests were standardized. A data sheet was developed to record all relevant information about the test conditions. In addition, a standard perlite ore was used periodically to calibrate the furnace.

Test conditions identified for the Illinois slags during bench-scale work were used for pilot testing in a vertical shaft furnace (VSF). The process variables include the following:

- Hot zone temperature
- Combustion air flow rate
- Slag preheat temperature
- Slag particle size and feed rate
- Flame profile (burner design)

Observations of the fusion properties of the slag were made during each test, and the product unit weight measured. The pilot tests, which are exploratory in nature, are being used to identify the test conditions and procedures that will be used as a starting point for commercial VSF expansion of slag.

A sampling and sample preparation procedure was prepared for collection of a large sample of Illinois coal slag from a stockpile, which is currently under way. To ensure that a representative sample is obtained, a large number of increments will be collected from a large area of the stockpile. Various batches of samples will be subjected to compositional analyses to identify any variability in the characteristics of the test feed. The slag used for bench-scale testing will also be analyzed at a commercial laboratory as part of the feed characterization work. The analysis of this sample will be compared with that of the large sample.

TECHNICAL WORK COMPLETED

The technical work completed during the second quarter of Phase I is described by task.

Task 1: Procurement and Preparation of Illinois Slag Samples

Procurement of approximately 2000 lb of slag generated from Illinois basin coal using the Texaco gasification process has been arranged and is currently under way. This quantity will cover the requirements of Phase I and projected Phase II experimental work. This approach is cost-effective and ensures the uniformity of samples over the two project phases. Advance samples from two sources, one of which is the same as

that of the large sample, were obtained for laboratory and pilot test work from reserves on hand at Praxis.

Praxis' previous experience with slag utilization has indicated that preparation of the slag, consisting of char removal and size control, results in a more homogenous feed for production of lightweight aggregates and is important from the viewpoint of product quality control. Arrangements have been made with a commercial laboratory to prepare the slag sample for char removal and size reduction to meet the thermal processing requirements.

Task 2: Characterization

Basic characterization testing of the slag sample used for bench-scale and pilot testing is being undertaken by a commercial laboratory and will consist of the following:

- Particle size distribution
- Unit weight
- Hardgrove grindability index
- Loss on ignition (char content)

This work will be done as soon as processing of the large slag sample is complete. In addition, the compositional analyses of three materials available from earlier projects, i.e., expanded shale, expanded perlite, and expanded slag, was compiled and is presented in Table 1. As may be seen, the values of the major elements, reported as oxides, for expanded slag fall between those for expanded shales/clays and expanded perlites.

Table 1. Chemical Analysis of Expanded Slag vs. Conventional Expanded Shale and Perlite

	Expanded Shale	Expanded Slag		Expanded Perlite
		Illinois No. 6	Utah Coal	
SiO_2	55-65	49.1	55.8	73.8
Al_2O_3	15-20	19.7	18.7	13.9
Fe_2O_3	5-10	20.2	10.8	0.9
CaO	1-3	6.4	11.6	0.9
MgO	Trace	0.87	0.9	0.1
Na_2O	-	0.45	0.70	4.7
K_2O	-	2.26	1.2	4.3
TiO_2	Trace	0.96	0.9	0.1

Task 3: Bench-Scale Testing

Initial expansion testing were performed with two Illinois slags using a laboratory muffle furnace. The objective of these tests was to become familiar with the expansion properties of the slag sample and compare them with those of a known material such as perlite. Problems with slag fusion had been identified previously, and measures to counter this were established. One such method is to blend the slag with a small quantity of perlite before expansion, and another is to treat the slag particle surfaces with a dilute acid. The results of these tests, presented in Table 2, indicate that Illinois slags can be expanded to unit weights as low as 12 lb/ft^3.

Table 2. Results of Bench-Scale Tests Conducted in a Muffle Furnace

Slag	Size, mesh	Slag Prep	Firing Temperature, °F	Product Unit Weight, lb/ft^3
Illinois No. 5 (S)	30 x 70	--	1700	26.7
Illinois No. 5 (S)	30 x 70	AW	1700	18.5
Illinois No. 6 (T)	14 x 30	PB	1700	12.0
Illinois No. 6 (T)	30 x 50	PB	1700	20.0

AW: Slag surface treated with dilute acid.
PB: Slag blended with 20% perlite before expanding.

Task 4: Pilot-Scale Expansion Tests

Pilot Plant Setup. A pilot vertical shaft furnace (VSF) was set up and commissioned for testing. The pilot plant, shown in Figure 1, consists of a 4-in. diameter x 5-ft tall VSF with a 1⅛-inch burner nozzle located at the bottom. The feed to the furnace is drawn from a bin via a vibratory feeder which can achieve a nominal capacity of 10 lb/h for material sized at 0.5-0.3 mm. The pilot plant has the capability of preheating the feed upto 1120°F in a rotary drum preheater prior to entering the furnace. Three feed entry points are located at top, middle, and bottom of the furnace to provide various residence times. The furnace is connected to a 12-inch collection chamber under induced draft conditions. The pressure drop in the collection chamber and the temperature in the furnace are controlled by valve settings.

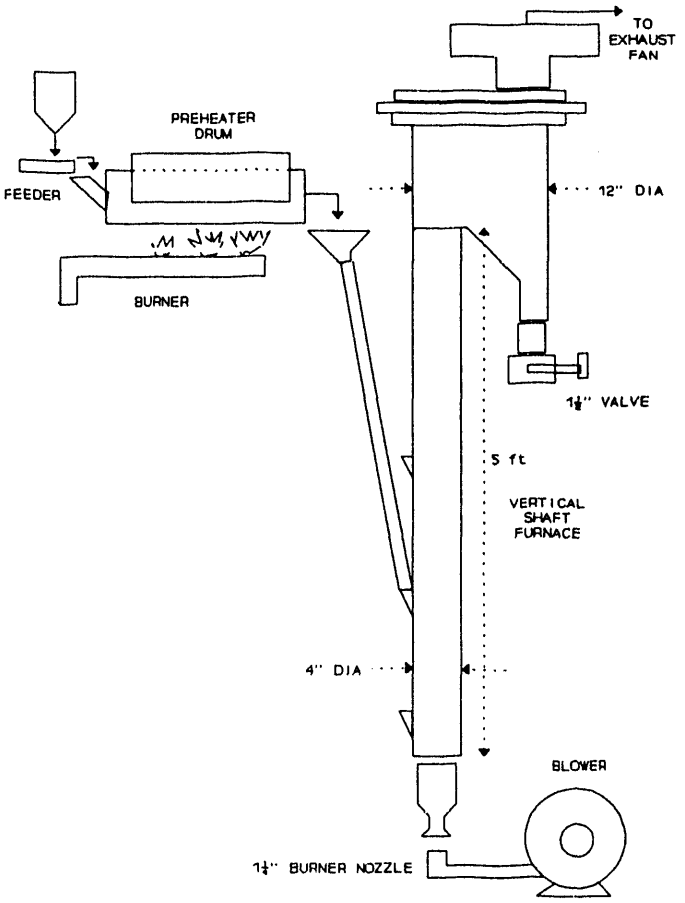

Figure 1. Pilot Plant Setup

Pilot Plant Operation. Using selected operating conditions such as feed rate, induced draft, operating temperature, the furnace is operated for 15 minutes and the operating conditions are then verified prior to starting the feed. Each test is run for a minimum of 15 minutes, after which the operation is shut down to collect the product and examine the furnace for signs of slag fusion. The product, along with any dropout or clinker in the furnace, is weighed and compared to the total feed to check for losses. The unit weight of the product is measured.

RESULTS AND DISCUSSION

Results of Pilot Tests. Initial testing of the pilot furnace was conducted at a temperature of 1700°F using a standard perlite ore which expanded to a unit weight of 8.0 lb/ft^3. All of the pilot tests are summarized in Table 3. Initial tests

using a slag feed in the pilot furnace resulted in fusion of slag on the furnace walls due to melting of some of the slag particles. It was concluded that this was caused by excessive heating of some of the particles when they came in contact with the flame. Therefore, a different type of burner configuration was ordered in which high-temperature air rather than flame comes in contact with the slag particles.

In addition, two alternative approaches for eliminating slag fusion were identified, the first consisting of blending small quantities of a nonfusible material such as perlite with the slag and the second being to treat the slag with an acid to remove fluxing agents such as alkalis from the particle surfaces. While both of these techniques work effectively, use of a modified burner configuration or expansion of slag blended with small quantities of perlite are the preferred alternatives.

Initial pilot tests with a slag feed were conducted using a Texas lignite slag since Praxis has considerable data on this slag from another project which was helpful for calibration of the furnace. The slag was mixed with 33% perlite to act as a buffer and avoid any fusion problems in the furnace. In this test, run at 1520°F, 14 x 30-mesh slag expanded to a unit weight of 21.6 lb/ft^3 and the perlite expanded to 15.3 lb/ft^3.

In the next batch of pilot tests, two Illinois slags were used either blended with perlite or after surface treatment with acid. The results of these tests confirmed that Illinois slags may be expanded in a vertical shaft furnace. Products with unit weights of 20-60 lb/ft^3 were produced by varying the process conditions.

As this is the first time a vertical shaft furnace designed for perlite has been used for slag expansion, certain necessary equipment modifications to customize the furnace for a slag feed have been identified. Further testing will be resumed as soon as a new burner more suitable for slag is installed. It is anticipated that this burner configuration will eliminate the need both acid treatment and blending of slag with a nonfusible buffer.

Table 3. Results of Exploratory Pilot-Scale Tests

Test No.	Size, mesh	Treatment	Preheat Temp, °F	Residence Time, min	Furnace Settings				Product, lb/ft³	Expansion
					Port	Gas	Draft	Temp, °F		
Perlite										
	100 x 0	-	-	-	L	F	-0.8" WG	1700	8	Good
Texas Lignite Slag										
803-8	16 x 30	PB	-	-	L	3/8	-0.37" WG	1300	Slag: 21.6 Perlite: 15.3	Good
Illinois No. 6 Slag										
616-2	16 x 30	None	1000	1.5	U	3/4	-0.8" WG	-	60	Partial
616-3	8 x 16	AW	1000	1.5	-	3/4	-1.0" WG	-	56	Partial
618-6	16 x 30	AW	-	-	L	F	-0.85" WG	1300	20	Good
Illinois No. 5 Slag										
618-5	16 x 30	AW	-	-	M	F	0.8"	1700	26.5	Partial
618-7	30 x 70	AW	1300	-	L	F	-.62"	1700	12.5	Good

AW: Slag surface treated with dilute acid.
PB: Slag blended with 20% perlite before expanding.

CONCLUSIONS AND RECOMMENDATIONS

Based on work completed under Phase I of the project to date it can be concluded that:

- An expanded slag product with a unit weight of 12 lb/ft^3 was produced using 14 x 30-mesh slag, and an expanded product with a unit weight of 20 lb/ft^3 was produced from 30 x 50-mesh slag both derived from Illinois No. 6 coal gasifier feeds.

- When blended with 20% perlite, the Texas lignite slag expanded to 21.6 lb/ft^3, and the perlite expanded to 15 lb/ft^3. Initial tests with 100% Illinois slag indicated that when the slag particles come in direct contact with the flame, partial melting and a slow build-up of slag clinker occur in the flame zone of the expander tube.

- The problem of slag fusion can be compensated for by either acid wash treatment of the slag or by blending a nonfusible material such as perlite with the slag. An additional approach for preventing slag fusion problems by means of modifying the burner configuration will be tested during the next reporting period.

PROJECT MANAGEMENT REPORT
December 1, 1992 through February 28, 1993

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COMMENTS

Praxis received a letter of intent from ICCI regarding funding of the project in the first week of September, 1992. An Environmental Assessment Questionnaire (EAQ) was prepared as per the requirements of DOE (PETC) which is co-funding the project. Upon review of Praxis' response, some additional information was requested and duly submitted. The contract was signed in January 1993.

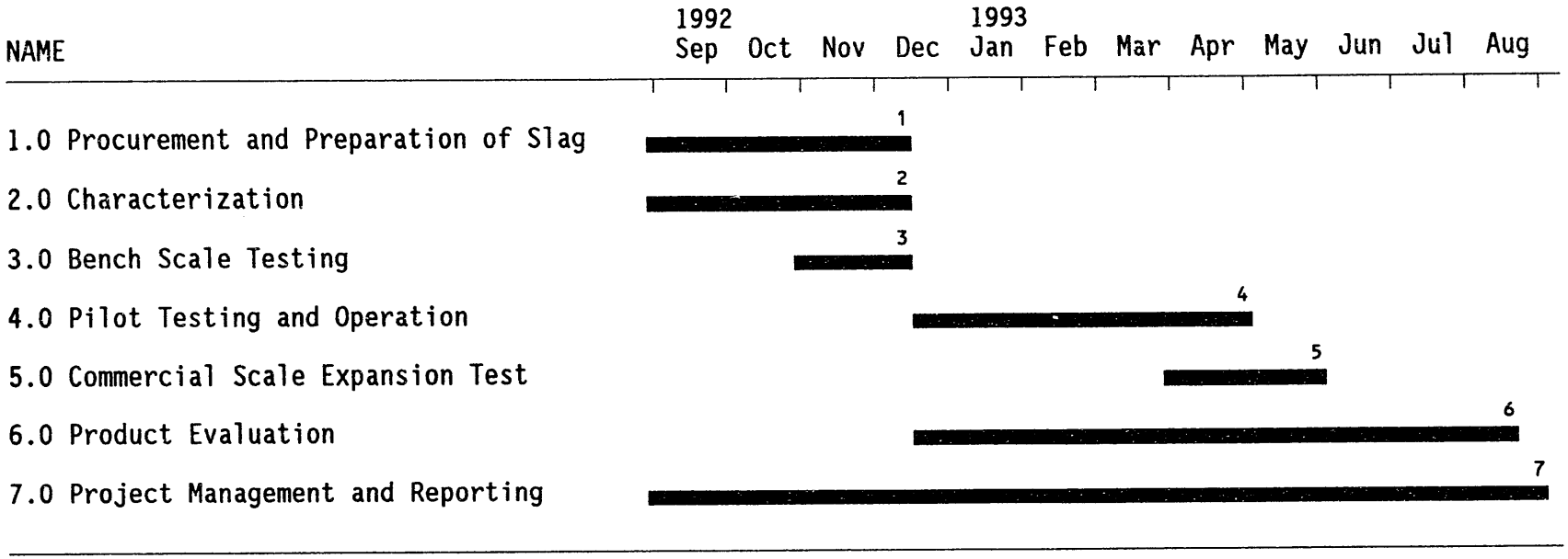
PROJECT EXPENDITURES

The projected expenditure for the first four quarters of the project and estimated expenditure for the second quarter ending 28 February 1993 are given in Table 1 and plotted in Figure 1. As may be seen, the total cumulative expenditure for the first and second quarters is well within the budgeted amount. Expenditure for various categories (labor, materials, and travel) is lower than the projected amounts. The primary reason for this is delay in starting work because the contract was signed in the second quarter. It is anticipated that expenditure will conform to the budgeted amounts in the next quarter as the pace of work accelerates.

Table 2 presents a breakdown of the costs by various categories for the second quarter in both direct and cumulative form, as required by ICCI.

PROJECT SCHEDULE

The present schedule, presented in Figure 2, indicates the project start date of September 1, 1992, and its completion by August 30, 1993. Though the project start was delayed, it is expected that progress will be on schedule by the next quarter. The pilot furnace has been commissioned; slag sample collection has been arranged; and a small advance sample of slag which was received at the test facility is being used for pilot testing. Also, bench-scale testing has been initiated and characterization work is progressing satisfactorily.



LIST OF PROJECT MILESTONES

1. Sample collected and prepared
2. Characterization completed
3. Bench scale testing completed
4. Pilot testing completed
5. Commercial furnace test completed
6. Product evaluation completed
7. Final report completed

Figure 2: Project Schedule

END

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