DEVELOPMENT OF COATINGS FOR PROTECTION
OF COAL DURING TRANSPORT AND STORAGE

Final Report

For the Period December 15, 1977 - September 15, 1978

R. V. Kromrey, R. S. Scheffee
J. A. DePasquale, R. S. Valentine

ATLANTIC RESEARCH CORPORATION
Alexandria, Virginia

NOTICE
This report was prepared as an account of work
sponsored by the United States Government. Neither the
United States nor the United States Department of
Energy, nor any of their employees, nor any of their
contractors, subcontractors, or their employees, makes
any warranty, express or implied, or assumes any legal
liability or responsibility for the accuracy, completeness
or usefulness of any information, apparatus, product or
process disclosed, or represents that its use would not
infringe privately owned rights.

November 1978

Prepared for:

Division of Environmental Control Technology
Assistant Secretary for Environment
The U. S. Department of Energy
Under Contract No. EP-78-C-02-4632.A000

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED *EP*

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency Thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

DISCLAIMER

Portions of this document may be illegible in electronic image products. Images are produced from the best available original document.

TABLE OF CONTENTS

	<u>Page</u>
ABSTRACT	1
1.0 SUMMARY	3
2.0 INTRODUCTION	5
3.0 TECHNICAL DISCUSSION AND RESULTS	7
3.1 Objectives	7
3.2 Task 1 - Analytical Evaluation	7
3.2.1 Filler-Binder Materials Evaluation	7
3.2.2 Current Coal Protection Techniques	8
3.2.2.1 Stockpile Formation	8
3.2.2.2 Stockpile Protection	12
3.2.2.3 Latex Crusting Compounds	13
3.2.3 Application Considerations	13
3.2.3.1 Effect of Atmospheric Pressure Change on Coated Coal Stockpiles	13
3.2.3.2 Effect of Wind Velocity	14
3.2.3.3 Logistics of Coal Coating Applications	14
3.2.3.4 Energy Cost to Heat Hot-melt Coatings	15
3.2.3.5 Surface Preparation for Filled Latex Coatings	15
3.2.4 User Motivation	15
3.2.5 Site Visits	16
3.3 Task 2 - Formulation and Evaluation of Coatings	17
3.3.1 Summary of Results	17
3.3.2 Hot-melt Formulation Results	20
3.3.2.1 Test Panels	23
3.3.2.2 Thermal Expansion Tests	23
3.3.3 Latex Formulation Results	26
3.3.4 Laboratory Procedures for Preparing Coatings	47
3.3.4.1 Procedure for Preparing Hot-melt Coatings	47
3.3.4.2 Procedure for Preparing Filled Latex Coatings	47
3.3.5 Test Procedures	47
3.3.5.1 Visual Tests	47
3.3.5.2 Physical Tests	48
3.3.5.3 Rheological Tests	48
3.3.5.4 Thermal Cycling and Water Penetration	48
3.3.5.5 Test Procedures for Coefficient of Thermal Expansion	49
3.3.5.6 CTE Hysteresis Procedure	49
3.3.5.7 Grindability Test Procedure	49
3.4 Application Techniques	50
3.4.1 Laboratory Techniques	50
3.4.2 Subscale Application System	50
3.4.2.1 Description of System	50
3.4.2.2 Details of Main Components	51
3.4.3 Operating Procedure	54
3.4.4 Results of Application Experiments	54
3.4.5 Requirements for Scale-Up	55
3.5 Task 4 - Preliminary Economic Analysis	55
3.5.1 Steps in Constructing and Protecting Coal Stockpiles	59
3.5.2 Cost Analysis - Coal Stockpile Protection	59
3.5.2.1 Cost Analysis - Coal Pile Construction	59
3.5.2.2 Cost of Monitoring Stockpile	60

TABLE OF CONTENTS
(continued)

	<u>Page</u>
3.5.2.3 Cost Analysis - Coal Pile Protection	61
3.5.2.3.1 Use of Latex Crusting Compounds	61
3.5.2.3.2 Use of Filled Latex Formulations, Case I	61
3.5.2.3.3 Use of Filled Latex Formulations, Case II	62
3.5.2.3.4 Use of Hot Melt Formulation	64
3.5.2.4 Summary of Stockpile Protection Costs	65
3.5.3 Cost Analysis - Rail Car Protection	65
3.5.3.1 Use of Latex Crusting Compounds	67
3.5.3.2 Use of Filled Latex Formulation, Case II	69
3.5.3.3 Use of Hot-Melt Formulation	69
3.5.3.4 Summary of Rail Car Protection Costs	70
3.5.4 Cost/Benefit Analysis - Stockpile Applications	71
3.5.4.1 Cost Factors	71
3.5.4.2 Benefit Factors	71
3.5.4.3 Relative Weighting of Benefit Factors	72
3.5.4.4 Scenarios for Stockpile Protection	73
3.5.4.5 Cost/Benefit Calculation	73
3.5.5 Return on Investment, Stockpile Applications	76
3.5.6 Cost/Benefit Analysis - Rail Car Applications	77
3.5.6.1 Cost Factors	77
3.5.6.2 Benefit Factors	78
3.5.6.3 Relative Weighting of Benefit Factors	78
3.5.6.4 Scenarios for Rail Car Protection	78
3.5.6.5 Cost/Benefit Calculation	79
3.5.7 Return on Investment, Rail Car Applications	79
4.0 CONCLUSIONS AND RECOMMENDATIONS	93
5.0 REFERENCES	95

LIST OF TABLES

<u>Number</u>		<u>Page</u>
I	Filler Materials	9
II	Hot-Melt Binder Materials	10
III	Polymer Latex Binder Materials	11
IV	Summary of Formulations and Tests Conducted	19
V	Physical Properties of Hot-Melt Formulations	21
VI	Characteristics of Hot-Melt and Filled Latex Compositions	22
VII	Test Data Summary for Melt Cover Compositions	25
VIII	Compatibility of Latexes with Dickerson Coal	42
IX	Effect of Size Consist on Film Properties of Coatings Prepared With Everflex GT Latex	43
X	Test Data Summary for Filled Latex Compositions	44
XI	Test Data Summary for Cover Compositions Applied to a Specially Prepared File.	45
XII	Test Data Summary for Commercially Available Crusting Agents	46
XIII	Stockpile Volume and Surface Area	58
XIV	Summary of Stockpile Protection Costs	66
XV	Summary of Rail Car Protection Costs	70
XVI	Weighting of Benefit Factors of Coal Protection Methods for Stockpile	72
XVII	Ability of Stockpile Protective Method to Provide Benefits	74
XVIII	Weighted Effectiveness of Stockpile Protection Methods	75
XIX	Weighting of Benefit Factors of Coal Protection in Rail Cars During Transit	78
XX	Ability of Rail Car Protective Methods to Provide Benefits	80
XXI	Weighted Effectiveness for Rail Car Protection Methods	80

LIST OF FIGURES

<u>Number</u>		<u>Page</u>
1	Dickerson Coal Handling System	18
2	Hot Melt Coating on Test Frame	24
3	Cooling Curve for Formulation 5-1-2	27
4	Coefficient of Thermal Expansion Curve for Formulation 5-1-2	28
5	Cooling Curve for Formulation 5-2-3	29
6	Coefficient of Thermal Expansion Curve for Formulation 5-2-3	30
7	Cooling Curve for Formulation 6-1-2	31
8	Coefficient of Thermal Expansion Curve for Formulation 6-1-2	32
9	Cooling Curve for Formulation 4-28-1	33

LIST OF FIGURES
(continued)

<u>Number</u>		<u>Page</u>
10	Coefficient of Thermal Expansion Curve for Formulation 4-28-1 . .	34
11	Cooling Curve for Formulation 5-15-2	35
12	Coefficient of Thermal Expansion Curve for Formulation 5-15-2 . .	36
13	Cooling Curve for Formulation 5-12-1	37
14	Coefficient of Thermal Expansion Curve for Formulation 5-12-1 . .	38
15	Effect of Coal Percentage Upon Coefficient of Thermal Expansion .	39
16	Effect of Wax Concentration on Coefficient of Thermal Expansion .	40
17	Schematic Diagram: Coal Cover Demonstration Unit	52
18	Subscale Application System	53
19	Panel Coated with Hot-Melt Material	56
20	Application of Hot-Melt Coatings	57

ABSTRACT

The use of coatings to prevent dust emissions and leachates from coal stockpiles was studied under sponsorship of the Department of Energy, Division of Environmental Control Technology. The coatings considered included compositions formed of a filler such as pulverized coal and a binder consisting of a combination of waxes and plastics. Various latex emulsions, both with and without fillers, were also evaluated.

The purpose of coal coatings is to seal the surface of the stockpile. This prevents water penetration into the coal. By sealing the surface of the pile, dust losses are prevented and leachate formation is minimized. Air circulation through the stockpile is also greatly reduced. This yields the added benefits of reduced oxidation of the coal and prevention of spontaneous ignition. Cold weather handling characteristics of the coal are also improved.

Physical properties of the coatings were measured. Included were such characteristics as resistance to water penetration and degradation as a result of thermal cycling. Application techniques were also evaluated. Both hot-applied and cold-applied coatings were considered.

Protective coatings appear to be an attractive means of prevention of fugitive emissions from coal stockpiles. The economic benefits from reduced oxidation and improved handling more than off-set the cost of application. Use of coatings on unit trains or barges may also be attractive.

THIS PAGE
WAS INTENTIONALLY
LEFT BLANK

1.0 SUMMARY

Coal in transit in rail cars or in storage in stockpiles is subject to weathering effects. These effects include dust emissions, formation of leachates, moisture absorption and oxidation. The result of these effects is potential environmental contamination and reduced fuel value. The objective of this program was to investigate the feasibility of low cost protective coatings as a control technology for coal stores which would eliminate moisture penetration and air circulation, thereby reducing the potential for leachates in coal pile runoff and fugitive dust emissions.

An analytical study was made of materials which could be used to protect coal. To provide a cohesive, continuous coating at low cost, a formulation was chosen comprising an inexpensive filler material and a binder substance. In all, seven filler materials and sixteen binder candidates were considered. Based upon cost, availability, environmental factors and properties, pulverized coal was selected as the best filler material. The best binders were found to be mixtures of wax, polyethylene and polypropylene or latex emulsions. The former combination must be heated before application and is referred to as the "hot-melt" composition. The latex emulsions may be applied cold and are called the "filled latex" formulations.

In all, over 60 hot-melt formulations were produced and tested during this program. In addition, 39 filled latex mixes were made and evaluated. The best compositions were subjected to "rainfall" tests, thermal cycling and grindability tests. The compositions selected as best were as follows:

Hot-Melt	77.5% coal 22.5% binder consisting of 66-2/3% slack wax 16-2/3% polyethylene 16-2/3% polypropylene
Filled Latex	50% coal 23% binder consisting of Everflex GT Latex 27% water

A subscale application system was designed and constructed. This system is capable of dispersing one gallon per minute of either of the above formulations. The application system was tested by applying coatings to 4 ft by 8 ft panels.

Economic analysis of the costs of applying coatings led to the following estimates based upon application to a 250,000 ton stockpile:

<u>Treatment</u>	<u>Cost/ton, \$</u>
Build and compact stockpile	0.22
Monitor stockpile for 1 year	0.091
Apply unfilled latex crust	0.034
Apply filled latex coating	0.078
Apply hot-melt coating	0.051

The cost of normal construction and monitoring of a stockpile represents a cost of \$0.31 per ton of coal. Protective coatings may be applied at an additional cost of \$.03 to \$.08 per ton. The direct economic savings from protection with coatings represents 3.5-7% of the value of the coal, or \$0.70-\$1.40 per ton if coal is valued at \$20 per ton.

In addition, intangible benefits accrue from use of coatings which cannot be assessed in terms of dollar savings. If an equivalent value in dollars is assigned to such factors as dust emission prevention and other intangibles, a cost/benefit calculation may be made. Considering all of the potential benefits of protective coatings, the return on investment exceeds the cost by a factor of 10 to 25.

Rail car applications of coatings are also attractive. The most cost effective coating for rail car use is an unfilled latex crusting compound. With a treatment cost of \$0.07 per ton, such coatings provide a benefit return equivalent to over 10 times the cost.

The use of coatings appears technically feasible and economically attractive. Additional work is recommended to evaluate the hot-melt and filled latex coatings further for stockpile applications. Specifically, sub-scale field tests are recommended followed by an user-site evaluation of the best coating on a stockpile of about 50,000 tons.

Coal from mines is transported to its ultimate destination by rail, truck, barge or pipeline. Once it arrives at its consumption point or a processing facility, it is moved over short distances by rubber-tired loaders, conveyors or rail shuttle cars. During the transportation process, the coal is often exposed to weathering effects. This leads to losses in fuel value through moisture absorption and oxidation (ERDA, 1976). Openings in vehicle floors or wind effects can result in physical loss of coal.

Once at the destination, the coal is either used or stored. Most users maintain stockpiles comprising a 90-day supply at their normal use rate. This is done primarily to provide a reserve in the event of temporary loss of supply. This stockpile may stand for a year or more before it is necessary to use it. Some users rotate their coal inventory, using the oldest coal first. This practice would diminish the value of protective coatings.

In the stockpile, the coal is subject to weathering and oxidation. Absorbed moisture from rain or snow may decrease the fuel value by 1 to 8% depending upon initial moisture level and coal rank. This added moisture also can result in plant outages due to difficulty in operating the grinders or pulverizers used to prepare the coal for feeding (Shelton, 1977). It has been observed that the bottom 18 inches of a stockpile can cause particularly serious processing problems due to excessive moisture. Moist coal can also freeze solid in cold weather, greatly increasing handling problems. Oxidation may reduce the heating value up to 5% over a one-year storage period (ERDA, 1976). In one instance, coal stored for 18 years was found to have dropped in fuel value from 8500 BTU/lb to 4600 BTU/lb, a loss of 3.5% per year. In addition, internal oxidation can lead to spontaneous combustion in low rank fuels (ERDA, 1975; Paulson *et al.*, 1975).

Coal stored in open stockpiles generates fugitive emissions and effluents. Areas surrounding large coal stockpiles generally exhibit fugitive dust concentrations in excess of that permitted by the Clean Air Act Amendments of 1977. Coal storage piles are sources of leachates due to drainage and runoff of water as a result of rain penetration. Current laws require such leachates be collected and treated before discharge. The estimated cost of treatment of leachates is \$0.20 to \$0.30 per year per ton of coal.

Closed storage can eliminate weathering effects and combustion hazards. However, enclosed containers are generally limited to about 1000 tons of coal. For a 1000 megawatt generating facility, the stockpile requirements may exceed 750,000 tons making closed storage impractical.

This program addressed the use of protective coatings for coal to resolve the environmental problems associated with transport and storage. The effort was sponsored by the Department of Energy, Division of Environmental Control Technology under Contract No. EP-78-C-02-4632. Mr. Charles Grua served as the Contract Technical Officer.

THIS PAGE
WAS INTENTIONALLY
LEFT BLANK

3.0 TECHNICAL DISCUSSION AND RESULTS

3.1 Objectives

The overall objective of this program was to investigate the feasibility of economical coal coating systems. To accomplish this, the following factors were considered:

- Identification of suitable materials for coal coatings
- Development of formulations which are capable of mitigating the adverse environmental effects of weathering of coal stores
- Identification of acceptable application techniques
- Tests to determine coating properties and provide data for economic analysis
- Economic analysis of coatings compared to unprotected coal
- Cost/benefit analysis
- Recommendations and requirements for a large-scale field demonstration

Accomplishment of these objectives provided an indication of the cost effectiveness of coatings and environmental benefits for protection of coal stockpiles or coal in transit in rail cars.

3.2 Task 1 - Analytical Evaluation

The first program task was intended to provide information to guide the experimental development of coal coatings in Tasks 2 and 3. The factors considered in Task 1 are listed below:

- Evaluation of candidate filler-binder materials
- Review of current coal protection techniques
- Application considerations
- User motivation
- Site visits

3.2.1 Filler-Binder Materials Evaluation

A list of materials was generated which could be considered as candidates for inclusion in coal coating formulations. The candidate materials were screened to establish their characteristics with respect to:

- Cost
- Availability
- Fuel value
- Physical properties
- Environmental pollution potential

The filler materials considered and their characteristics are shown in Table I. Binder materials considered fall into two categories. The first was the materials useful for the hot-melt type of coating. Information on these materials is included in Table II. The second type of binder material was the various latex emulsions. This type of material was considered for use in filled latex coatings. Characteristics of the latex emulsions are given in Table III.

Based upon the information in Table I, pulverized coal and fly ash emerged as the best filler candidates. Both of these materials are available at coal user sites in sufficient quantities. They are both available at little or no cost, taking into account the credit for fuel value of coal. Neither of these materials would cause additional environmental problems upon combustion, as both are normally present in coal combustion systems. The other filler material candidates were either too costly, limited in availability or presented potential environmental problems.

None of the binder candidates listed in Tables II and III could be eliminated on the basis of the qualification factors listed previously. Thus, experiments to evaluate all of them were planned for Task 2.

3.2.2 Current Coal Protection Techniques

The most common current means of protecting coal is to carefully build and compact the stockpile, then monitor it for hot spots. At this time, it is estimated that less than 5% of the users of coal provide additional protection in the form of coatings. The most commonly used coatings are oil sprays or latex crusts. The primary purpose is to prevent dust losses and stabilize the pile surface. Coal is shipped by rail car in as dumped condition. It is estimated that 5-10% of the shippers use latex crusting compounds to prevent wind loss and dust emissions in transit. A discussion of these current protection methods is provided below.

3.2.2.1 Stockpile Formation

Large users of coal generally maintain a stockpile sufficient to provide coal for 90 days in the event of a strike or other loss of supply. A typical power plant requires 4,000 tons per day. Thus, a stockpile of 360,000 tons would be required (Young, 1978). This coal would normally be stored for a year or more before use in those facilities which retain an inactive pile and do not rotate their coal inventory. It is not unusual for an inactive stockpile to be stored for 5 years or more before use.

Stockpiles must be properly constructed; otherwise, the risk of spontaneous combustion is high. Coal stores have been known to ignite spontaneously within 6 days after pile formation (Wilson, 1975). The usual method for constructing a coal stockpile is given below:

1. The coal is dumped from the rail cars either by bottom hopper or car inversion.
2. The coal falls onto a conveyor and passes through a mill where it is ground to <2 inch size pieces.

Table I. Filler Materials

MATERIAL	SOURCES	COST	AVAILABILITY	HANDLING	ECOLOGY	OTHER FACTORS
Coal	Nationwide	\$20 Ton	Abundant on site of application	1) Use dust 2) Grind on site	Same as Coal	Fuel value=Coal 13,000 btu/lb
Paper	Nationwide	\$20 Ton	Must be obtained at large metro centers	1) transport to site 2) Mill to fine size	May biodegrade May contain dyes	May absorb water Fuel value=9000 btu/lb May clog mills
Sawdust	Nationwide	\$12 Ton FOB Plant	Limited	1) Bulk trans. to site 2) Need covered storage	May biodegrade	May absorb water Fuel value=9000 btu/lb May clog mills
Bagasse	South	\$2 Ton + lost fuel value=\$8/ton	Variable-depends on building trends	Bulk transport	May contain pesti- cide residues	Contains ~35% H ₂ O Fuel value=3500 btu/lb
Rice Hulls	South & West	\$30-50/Ton	Commercial demand as cat litter, sweeping compound	Bulk transport	May contain pesti- cide residues	Fuel value=8000 btu/lb
Cottonseed Hulls	South	\$35 Ton wide var in mkt. price	Variable	Bulk transport	May contain pesti- cide residues	Fuel value=8000 btu/lb
Flyash	Coal User Site	Negative Cost \$5 Ton	About 15% of coal burned at coal user sites	1) Easy transport at user site 2) Rail or truck transport to mine	Inert	Abrasive Adds load to precipi- tators Fuel value = 0

Table II. Hot-melt Binder Materials

MATERIAL	SOURCES	COST	AVAILABILITY	HANDLING	ECOLOGY	OTHER FACTORS
Waxes	Petroleum Refiners	5-9¢ lb.	Good-Fair Used for artificial fireplace logs	Tank car	Clean burning	Fuel value= 10,000-11,000 btu /lb
Petro Crude Residues	Petroleum Refiners	6¢ lb.	Good	Tank car	Clean burning	Fuel value= 10,000-11,000 btu/lb
Polyethylene (Reclaimed)	Several reclaimers	9-18¢ lb.	Good	Ground chips	May contain contaminants	Fuel value= 12,000btu/lb
Polyethylene (Virgin)	Several mfgs	29-31¢ lb.	Good	Pellets	Clean burning	Fuel value= 12,000 btu/lb
Polypropylene (Atactic)	Eastman	19¢ lb.	Good for some grades	Tank car (heated)	Clean burning	Fuel value 11,700 btu/lb

Table III. Polymer Latex Binder Materials

<u>Manufacturer</u>	<u>Trade Name</u>	<u>Type of Latex</u>	<u>Bulk Price</u>
W. R. Grace	Daratak SP-1065	Externally plasticized polyvinyl acetate	23c/lb
" " "	Everflex GT	Copolymer of polyvinyl acetate and another plasticizing monomer	25c/lb
" " "	Darex 622L	Styrene-butadiene copolymer, frequently described as synthetic rubber latex	16.8c/lb
" " "	Darex 410	Acrylic/vinyl acetate copolymer	29c/lb
" " "	Daran 820	Polyvinylidene chloride	30.5c/lb
" " "	Darex 3333	Modified styrene butadiene (for coal crusting)	~\$4/gal
ESCO	M105	Proprietary (for coal crusting)	\$4/gal
Dowell	M167.01	Proprietary (for coal crusting)	\$3.15/gal
Rohm & Haas	DLR-H	Acrylic	~40c/lb
" " "	DLR-S	"	~40c/lb

- Notes: 1. All prices are cost per unit weight of latex (wet). Solids content of the latexes are typically 50% by weight, so the costs per unit weight of polymer are typically twice those shown above.
2. All latexes listed above are commercially available in drums or in bulk.
3. All latexes would be clean burning and would have a fuel value of 10,000-12,000 btu/lb.

3. The coal is transported to the stockpile areas either by conveyor or by rubber-tired vehicle.
4. A bulldozer spreads the coal and compacts it. Typical piles are in the form of a truncated cone, 100-200 ft wide at the base and 25 ft high. The length of the pile may be up to thousands of feet.

Coal as dumped has a bulk density of about 50 lb/ft³. After compaction, the bulk density is about 65 lb/ft³ (Paulson, *et al.*, 1975).

The stockpiling technique varies with coal source and rank. Higher rank coal may be formed into larger piles of greater height and stored longer than low rank coals (ERDA, 1975). East coast coals may be stored longer than west coast coals as they are less reactive. The finer the coal, the more reactive it is as a result of greater surface area (Young, 1978).

Small coal stockpiles may be stored as dumped for periods of 1-5 days. Such piles should not exceed 15 feet in height (Wilson, 1975). Longer term storage of uncompacted coal is risky in terms of spontaneous combustion danger.

3.2.2.2 Stockpile Protection

Stockpiles are formed solely by the action of a bulldozer in shaping and compacting the pile. No fines are generally added as a gas barrier either within the pile or on the surface (Young, 1978). Thermal probes are often buried in the coal to monitor pile temperatures. The probes set off an alarm if the pile temperature reaches 130-140°F (54-60°C).

Dust emissions from coal stockpiles are a problem of increasing concern. Some users reduce dust formation by washing the coal before piling and transporting it wet (Wray, 1978). This process generates waste-waters containing particulates and acid leachate which must be treated before disposal. Other users wet the pile after formation or spray it with oil or latex to reduce dust emissions, as mentioned in Section 2.0.

Leachate formation is also a serious problem except in the case of very high grade coal. Water runoff from the pile is collected in a trough around the pile. It is then sent to a holding tank or pond where it is treated before discharge to the environment (Young, 1978). The treatment generally consists of adjusting pH by addition of lime or limestone, introducing a flocculant or precipitating agent to remove dissolved materials, then allowing the solids to settle out before discharge.

Few users currently protect their stockpiles against oxidation and the resultant fuel value losses. ERDA (1976) reports that losses up to 5% may occur in the first year of storage. Leonard (1968) found that properly stored coal of high rank will lose only 1-2% per year of its energy value due to oxidation. However, improper storage was found to result in losses of 3-5% per year.

3.2.2.3 Latex Crusting Compounds

The only protective coating of significance in current use is the latex crusting compound. This material is essentially a paint base, and it is produced by paint manufacturers. Numerous small firms purchase this material and resell it as a protective coating for coal or as a surface stabilizer for earth, sand or other materials stored in stockpiles. The latex compounds are normally applied after dilution by a factor of 3/1 to 20/1. They are sprayed onto the material to be protected using any equipment capable of spraying water.

The current market for coal crusting applications is 6-10 million dollars per year (Dowell, 1978; Rondeau, 1978). Dowell, Inc., is by far the largest current vendor of latex crusting compounds. Their primary application is rail cars. Other firms, such as ESCO, Inc., Johnson March, and Apollo Chemical Corporation, offer services for immobilizing and protecting coal stockpiles with latex crusting compounds. This market exists even though latex crusting, components do not prevent moisture penetration and leachate formation nor do they eliminate air transport and the resultant fuel value losses.

3.2.3 Application Considerations

The application of continuous, waterproof coatings to coal stockpiles brings forth several practical concerns. The use of latex crusting compounds serves as a base-point for consideration. These materials are in current use and, therefore, have passed the test of practicality and cost effectiveness. The use of either the hot-melt coating or the filled latex coating brings up other questions. These questions arise because these coatings are impervious to water and air and because of the special requirements of applying them. They are addressed in the following sections.

3.2.3.1 Effect of Atmospheric Pressure Change on Coated Coal Stockpiles

Normal variations in barometric pressure will cause a coated stockpile to either expel nitrogen or inhale air. If no vent exists, it is possible that the coating would crack open to release pressure. Exhalation from the pile would not be a problem. However, inhalation might concentrate a swift, oxygen-containing air stream at some local point in the pile. This air flow could result in heating and perhaps spontaneous ignition near the point of entry.

Based upon a one-inch of mercury change in barometric pressure, a 750,000 ton stockpile would inhale or expel 246,000 ft³ of gas. If the pile equilibrated in one hour, 68 ft³/sec of gas would flow into or out of the pile. If the vent area were 68 ft² or less, gas velocity would exceed 1 ft/sec.

The critical air velocity from the standpoint of oxidation would be about 1 ft/hr. At this rate, essentially all of the oxygen would be consumed in one foot of depth, increasing the local temperature by 1.4°F (0.8°C) per hour. At either higher or lower velocities, the heating rate would be lower. At higher velocities, excess gas would carry the heat of oxidation away. At lower velocities, the oxygen entry would be less than the maximum rate of consumption.

For a 750,000 ton stockpile, the critical velocity would occur if the vent area were 246,000 ft². This would represent a stockpile with 75% of the surface coated and 25% uncoated. It is unlikely that voids in the coating would ever exceed 1-2% of the surface area. Thus, atmospheric pressure changes will not adversely affect a coated stockpile.

3.2.3.2 Effect of Wind Velocity

Wind directed at a coated stockpile could have two adverse effects. First, the stagnation pressure could force air into the stockpile through voids in the coating. Second, the air traveling over the pile could cause a reduction of surface pressure by the Bernoulli effect and cause the coating to lift off the pile.

At a velocity of 100 mph, the stagnation pressure would be about 0.2 lb/in². This would be the equivalent of a change in barometric pressure of 0.4 in. Hg. As indicated before, this level of pressure change would not create a problem unless the stockpile exhibited coating voids over about 25% of the surface.

On the other hand, an air velocity of 100 mph across the top of the stockpile might cause the coating to separate. This velocity would create a "lift" of about 27 lb/ft² of surface area. This might be sufficient to dislodge relatively thin coatings with limited adhesion to the substrate. Wind effects would probably not harm a hot-melt type coating, but could possibly cause damage to a filled latex coating formed on a surface composed of sand-like fines.

3.2.3.3 Logistics of Coal Coating Applications

The supplies needed to coat a 750,000 ton stockpile with a 1/4 inch hot-melt coating are as follows:

1,012,800 lb	filler (pulverized coal)
202,560 lb	wax
50,640 lb	polyethylene/polypropylene

Based upon application of 1 ft³/minute, 300 hours or about 38 operating days would be required to coat the stockpile. The handling requirements for the components would be:

pulverized coal	3,330 lb/hr
wax	666 lb/hr
plastic	167 lb/hr

Coal is available at the user site. Thus, to coat a stockpile, the contractor must have available to the site 14 drums of wax per day (400 lb/drum) and 3.5 drums of plastic per day. These amounts appear to be practical from a handling standpoint.

3.2.3.4 Energy Cost to Heat Hot-Melt Coatings

Hot-melt coatings must be applied at $250^{\circ}\text{F} \pm 50^{\circ}\text{F}$. Based upon coating a 750,000 ton stockpile in 38 days, the minimum heat load would be 278,520 BTU/hr. Considering typical heating losses, a more realistic value would be 500,000 BTU/hr. The heater may be electric, gas fired, oil fired or coal fired. The most expensive alternative would be electric heat. At \$0.03 per kwh, the heating cost would be 0.1¢ per lb of coating mix, or about 4% of the cost of materials. For the assumed rate of application, the electrical service required would be 666 amps at 220 volts. Coal or oil-fired heaters would be more practical and lower in cost. For example, at \$20 per ton, the cost of heating the coating mix with coal would be only 0.027¢ per lb of coating.

3.2.3.5 Surface Preparation for Filled Latex Coatings

Filled latex coatings are most efficiently applied to a surface consisting of sand-like coal fines. A surface preparation step is required for this type of coating as opposed to the latex crusting compounds or hot-melt coatings which may be applied to a stockpile as formed and compacted.

The primary effect of the surface preparation step is economic, with an estimated cost of about \$0.05 per ton of coal. This is taken into account in the economic analysis, and does not significantly reduce the cost-effectiveness of this type of coating. However, some resistance would be expected on the part of coal users to performing the surface preparation step. The generation and dissemination of fines onto the surface will create dust emissions, and be a very unpleasant job. If the filled latex coatings are to be used, some means of preventing dusting during surface preparation may have to be found.

3.2.4 User Motivation

The value of coal coatings may vary significantly depending upon the vantage point of the user. The advantages may be categorized as follows:

Economic benefits:

- reduced oxidation loss
- reduced physical loss
- reduced maintenance and downtime during freezing weather
- reduced moisture content
- reduced probability of spontaneous ignition
- reduce treatment of coal pile wastewater

Environmental benefits:

- reduced dust emissions*
- prevention of leachates*

* These will also be economic benefits if some form of control is required and/or used.

Mechanical benefits:

- improved handling during freezing weather
- transport to conveyors
- operation of crushers

The mechanical benefits are of primary concern to the on-site operators who are responsible for feeding coal to the burners. These persons in general are less concerned with the environmental or economic factors.

Interest in environmental factors is centered in government agencies such as DOE and EPA and citizens who are in the path of dust emissions or leachates. Environmental factors may be of concern to the owners of coal using facilities when there is a legal requirement to abate the emissions or leachates with the attendant costs.

Economic benefits are primarily of concern to profit-making industries. For such firms, the savings in energy costs are directly translatable into profits. Non-profit users or utilities, which merely pass costs on to their customers, may have less incentive to keep energy costs to a minimum.

Of general concern to the public and to the Government is the conservation of energy. However, these parties are not direct users of coal coatings. Thus, this interest would only indirectly affect the application of coatings to coal stockpiles.

3.2.5 Site Visits

As part of Task 1, two visits were made to PEPCO power plants. The purpose of these visits was to observe coal handling procedures and problems encountered in receiving, storing and transporting coal.

The PEPCO Dickerson Plant, Bealsville, MD., was visited on 11 January 1978. Their method of handling coal is as follows:

1. Unloading - Coal cars, in 100 car unit trains, are weighed and turned over to dump contents into an underground hopper. The hopper feeds a crusher which reduces the nominal 1-1/4 lumps into 1/4 inch and finer.
2. Stacking - Ground coal is transported from the crusher to an elevated belt which drops it onto the main (active) pile.
3. Piling - Two piles are located side by side. The main pile is active and a smaller pile of low sulfur coal is held as an inactive emergency reserve. The main pile was down to approximately 250,000 tons due to the coal strike. Estimated size of the small pile was 40,000 tons.

The active pile resembled a cone truncated at an angle, sloping to ground level. They work the entire top surface to prevent internal oxidation and resultant fires. Most of the exposed surface of this pile is on the worked portion.

The reserve pile has remained unused for approximately 4 years. It was approximately 30 ft high and about 200 ft long and was badly eroded.

The second visit was on 27 January 1978 to the PEPCO Chalkpoint, Acquasco, MD. The method of handling coal here is as follows:

1. Unloading - Coal cars are bottom dumped into an underground conveyor. The conveyor feeds a crusher which delivers coal of the same grind as used by Dickerson.
2. Stacking and Piling - Ground coal is transported from the crusher to a horizontal belt over 700 ft long. The belt feeds an immense device which both puts coal onto the pile and removes it for transport to the bunkers. A schematic of this system is shown in Figure 1.

Two piles are used at Chalkpoint. The working pile is normally 30 ft high and 600 ft long and contains 50,000 to 60,000 tons. The width appeared to be about 100 ft. This pile was empty due to the coal strike. The second pile is their storage pile and normally contains about 200,000 tons. Typical dimensions of this pile are 30 ft high by 200 ft wide and 1000 ft long.

Other than compaction of the coal, no effort is made to control formation of dust or leachate. Both plants regard freezing of the piles and incoming coal cars as their main problem. Frozen cars are unable to dump unless thawed by kerosene torches. When the piles are badly frozen, it is impossible to prevent jamming of the conveyors. Power outages result when the bunkers are not supplied. The coal pile foreman seem to be the best sources of information about problems relating to handling of coal. Management people are more familiar with the internal plant workings.

3.3 Task 2 - Formulation and Evaluation of Coatings

3.3.1 Summary of Results

During Task 2, 119 hot-melt formulations and 39 latex mixes were produced and evaluated. A summary of the formulations produced and the tests conducted is given in Table IV. The types of tests conducted were as follows:

Visual Observation

- cracking tendency
- surface texture
- adhesion to substrate
- anomalies

Compressive Strength

Tensile Strength

Viscosity

Density

Thermal Expansion

Water Permeability

Rheology

Grindability

Figure 1. Dickerson Coal Handling System

Table IV. Summary of Formulations and Tests Conducted

NOT MELT FORMULATIONS

<u>Type</u>	<u>No.</u>	<u>Test</u>	<u>No.</u>
Binder Only	46	Visual	46
Binder Mixed with Coal	25	Visual	25
		Compression	3
		Tensile	2
		Viscosity	1
Binder Mixed with Coal Applied to Coal	16	Visual	16
CTE Strips	18	Thermal Expansion	18
		Hysteresis	10
12" x 12" frames	10	Visual	10
		Thermal Cycling	8
		Water Permeability	8
		Grindability	7
		Density	2
Restrained Ends	4	Thermal Expansion	4

LATEX FORMULATIONS

<u>Type</u>	<u>No.</u>	<u>Test</u>	<u>No.</u>
Mixed with Coal			
Darstak SP-1065	3	Visual	3
		Thermal Cycling	2
		Water Permeability	2
		Grindability	2
Everflex 67	3	Visual	3
DLR-4	3	"	3
DLR-5	1	"	1
Darax 410	1	"	1
Darax 622L	1	"	1
Darax 820	1	"	1
Prepared with Everflex GT Latex	17	Visual	17
		Thermal Cycling	8
		Water Permeability	8
		Viscosity	7
		Grindability	3
Applied to Prepared Coal Pile			
ESCO M105	1	Thermal Cycling	1
		Water Permeability	1
Dowell M167.01	2	Thermal Cycling	2
		Water Permeability	2
Darax 3333	1	Thermal Cycling	1
		Water Permeability	1
Everflex GT	1	Thermal Cycling	1
		Water Permeability	1
Commercially Available Crusting Agents			
ESCO M105	2	Thermal Cycling	2
		Water Permeability	2
Dowell M167.01	1	Thermal Cycling	1
		Water Permeability	1
		Grindability	1
Darax 3333	1	Thermal Cycling	1
		Water Permeability	1
		Grindability	1

Not all tests were run on all formulations. Some tests, such as tensile and compressive strength, were run on a limited number of specimens to establish the order of magnitude of the results. No means of converting strength data into a useful parameter for characterizing the utility of coatings was identified. Thus, the data is only of general interest.

Other tests, such as water permeability, effects of thermal cycling and coefficient of thermal expansion relate directly to the quality of the coatings. Tables V and VI summarize the results of these tests on formulations that were near the optimum compositions for both the hot-melt and filled latex coatings.

Table V presents physical properties data on the best hot-melt compositions. No similar physical properties were measured for the latex coatings, as they are formed in a film too thin to use for such tests. As may be seen from Table V, the tensile strength of the hot-melt material at -30°F was about 200 psi, with about 0.5% strain at failure. This data was taken at the coldest extreme of temperature expected, as this represents the worst case. Compressive strength was about 200-300 psi with about 2% strain at the failure point.

The viscosity of hot-melt composition 5-2-3 ranged from 4 to 8 kilopoise at 250°F . The rheological behavior was pseudoplastic, i.e., the viscosity decreased with increasing shear rate. No yield stress was quantitatively measured, but the hot-melt material does appear to exhibit a small yield stress before flow initiates. The density of the hot-melt material at 70°F is about 1.1 gm/cm^3 .

Table VI presents results of water permeability tests on the best compositions. Note that compositions 5-1-2, 5-2-3 and 48 (Latex) exhibited good water penetration resistance even after thermal cycling from 160°F to -30°F . Typical coefficients of thermal expansion for hot-melt formulations were about $7 \times 10^{-5} \text{ in/in-}^{\circ}\text{F}$. Upon reheating, composition 6-1-2 showed essentially the same degree of expansion and contraction as during the initial cool-down cycle. With the ends of the CTE specimen restrained, the bar exhibited about 0.5% shrinkage before rupture, consistent with the tensile test specimens tested.

The filled latex coating type was found to be easily grindable. The hot-melt compositions appeared to slow the action of the grinder somewhat although it continued to operate. When the coating material was mixed with an equal amount of coal, it appeared to grind satisfactorily. In practice, it would be unusual for the coating to represent more than 1-2% of the material fed to the grinder, so grindability is probably not a problem.

3.3.2 Hot-Melt Formulation Results

As mentioned previously, 119 hot-melt formulations were prepared during Task 2. These were screened by visual examination. Those that cracked badly or exhibited other undesirable characteristics were excluded from further consideration. The characteristics which were used as a basis for exclusion were such things as separation of components, lack of adhesion to coal, gummy or sticky texture or excessively high viscosity at application temperature. The desired characteristics of a hot-melt formulation were:

Table V. Physical Properties of Hot-melt Formulations

ENTRY NO.	COMPOSITION	VISCOSITY			TENSILE PROPERTIES (-30°F)			COMPRESSIVE STRENGTH, (70°F) AT FAILURE (PSI)	STRAIN IN COMPRESSION AT FAILURE (%)	DENSITY, GM/cm ³ (70°F)
		Ave. KP			At Rupture		Tangent			
		RPM			Stress	Strain	Modulus			
		1	2.5	5	(PSI)	(%)	(PSI)			
2-16-4	85% Coal							333	} Avg 342	1.9
	80% Wax							392		1.3
	20% AISC							302		1.6
2-17-1	85% Coal							248	} Avg 258	1.8
	80% SW							278		2.1
	20% VPE							249		2.1
2-17-2	85% Coal							148	} Avg 173	2.2
	80% SW							179		1.9
	20% VPE							192		2.3
5-2-3	77.5% Coal	8	7	4	210	0.4	106,000			1.1
	66 2/3% SW				79	0.7	18,200			
	16 2/3% AUPK									
6-1-2	80% Coal				222	0.4	84,800			1.08
	76% SW				233	0.6	68,200			
	12% AUPK				241	0.5	83,600			
	12% PE									

Table VI. Characteristics of Hot-melt and Filled Latex Compositions

Composition and Reference Numbers	LEAK RATE % OF SPRAY 70°F	+160°F	-30°F	36" CTE STRIP Shrinkage	Reheat Shrinkage	Avg CTE	Restrained Ends Gap	Grindability
5-1-2								
66 2/3% Coal								
16 2/3% AUSC	3.3	8.1	11	0.335"	NM	7.6×10^{-5}	NM	Fair
16 2/3% AUPK								
5-2-3								
77.5% Coal								
66 2/3% SW	1.4	5.2	8.0	0.305"	NM	6.6×10^{-5}	NM	Fair
16 2/3% AUPK								
16 2/3% PP								
6-1-2, 5-30-1								
80% Coal								
76% SW	14	20	78	0.285	0.278	6.2×10^{-5}	0.118"	Fair
12% AUPK								
12% PP								
48								
50% Coal								
23% EVERFLEX GT	7.7	1.8	1.2	NM	NM	NM	NM	Good
27% Water								

NM = Not Measured

Easily applied to coal at 200-300°F
Minimal shrinkage on cooling
Minimal crack formation
Good adhesion to coal substrate

3.3.2.1 Test Panels

Those formulations which appeared to best meet the above criteria were cast onto frames, 12" x 12", with about 3-4" of coal as a substrate. The frames were constructed with wooden pegs spaced at 3/4" intervals around the periphery. The pegs served to restrain the coating from shrinkage to enhance crack formation and present a more realistic test than would an unrestrained coating. The coating was applied in thicknesses ranging from 1/8" to 1/2". Figure 2 shows two views of a test frame with a hot-melt coating in place.

The test frames were subjected to a "rainfall" test. In this test, the equivalent of 2" of rain was sprayed on the surface of the test panel. The quantity of water adhering to the surface or passing through the coating was measured. For the best coatings, less than 10% of the water was retained or passed through the coating. The remainder was repelled and ran off the coating surface. Table VII shows that results of the rainfall tests for several of the selected hot-melt coatings. Note that the water permeability tests were generally run 3 times, at ambient temperature and after exposure to temperatures of +160°F and -30°F.

After the test panels were subjected to thermal cycling and water penetration tests, the coating material was removed and ground. In general, the hot-melt materials were difficult to grind if 100% coating material was placed in the grinder. The hot-melt coatings caused the grinder to labor and coating particles tended to stick to the inner surfaces of the grinder. When the coating material was mixed 50/50 with coal, it appeared to grind satisfactorily. Passing coal through the grinder appeared to clear out adhering coating materials. Thus, the hot-melt coatings will probably not present a grinding problem if they are ground with a sufficient quantity of coal.

3.3.2.2 Thermal Expansion Tests

Thermal expansion or contraction is an important characteristic of hot-melt coatings. If the degree of contraction upon cooling exceeds the strain-to-failure of a coating material, cracking will result. Similarly, if the thermal expansion upon heating exceeds the compressive strain-to-failure, the coating will shatter.

The coatings listed exhibited Coefficients of Thermal Expansion (CTE) ranging from 6×10^{-5} to 14×10^{-5} in/in°F. Thus, for a 100°F temperature change, the degree of expansion or contraction would be about 0.6% to 1.4%. The tensile strain to failure was measured to be about 0.5%. Thus, most coatings would be expected to crack upon cooling by 100°F or more. Heating does not appear to be a problem. Compressive strain-to-failure was measured to be about 2%, and none of the coatings tested expanded that much.

Figure 2. Hot-Melt Coating on Test Frame

Table VII. Test Data Summary for Melt Cover Compositions

File ID	Cover Composition, Wt %	Cover Wt. gm	Test Cond.	Test Wts., gm			Leak Rate, Wt % of Spray	Grindability	Remarks
				File Change	Drain	Total Leak			
B1	24% slack wax (1) 6% PE (2) 70% Coal (-35/+120 mesh, HMD -310u)	1247	Amb	214	950	1164	12	fair	No cracks as received.*
			+160	405	5280	5685	60		No change.
			-30	235	1500	1735	37		" "
			+160	311	1900	2211	47		Repeat of +160 test
B2	20% slack wax 5% PE 75% Coal (-35/+120 mesh, HMD -310u)	1295	Amb	139	175	314	3.3	fair	No cracks as received.*
			+160	590	175	765	8.1		No change.*
			-30	310	200	510	11		Cracking
5-2-2	16.875% slack wax 5.625% PE 77.5 % Coal (440u)	2000	Amb	978	400	1378	29	fair	No cracks as received
			+160	478	1050	1528	32		Large cracks along perimeter of two adjacent sides. Small crack spans opposite corner.
			-30	391	1925	2316	49		Some cracks as above. Seem accentuated. No further cracks develop. All cracks seem due to temp. exposure, not to temp. shock.
5-2-3	75% Coal 15% slack wax 3.75% PE (AUPK) (3) 3.75% PP		Amb	63	25	68	1.4	fair	No cracks as received.
			+160	95	150	245	5.2		Several small cracks.
			-30	178	200	378	6.0		No change.
5-24-1	19.125% slack wax 1.125% PE (AUPK) 2.25 % PP (4) 77.5 % Coal (640u)		Amb	35	450	485	10	fair	No cracks as received.
			+160	835	1500	2335	49		Extensive and severe cracking at the perimeter and on one diagonal. Due to temp exposure, not temp shock.
			-30	352	3800	4352	92		No further cracking, but existing cracks are accentuated.
5-24-3	17% slack wax 1% PE (AUPK) 2% PP 80% Coal (440u)		Amb	240	1700	1940	41	fair	No cracks as received.
			+160	1092	1000	2092	44		Extensive cracking at entire perimeter and on one diagonal.
			-30	110	2800	2910	62		No change, but existing cracks are accentuated.
6-1-1	15.2% slack wax 2.4% PE (AUPK) 2.4% PP 80 % Coal (110u)		Amb	1218	1100	2318	49	fair	No cracks as received.
			+160	2138	1200	3338	71		3 perimeter cracks
			-30	492	2100	2592	55		Small cracks developed in center, leaving dime-size hole.
6-1-2	15.2% slack wax 2.4% PE (AUPK) 2.4% PP 80 % Coal (440u)		Amb	252	400	652	14	fair	Powdery surface. Coal is washed off with runoff.
			+160	438	500	938	20		Perimeter cracking. Coal runoff.
			-30	640	3025	3665	78		Pronounced perimeter cracking. One severe interior crack.

* Spray volume was 2.5 gal.

(1) slack wax is a product of Quaker State.

(2) PE (polyethylene), product of Eastman Chemical.

(3) PL (AUPK) is recombined polyethylene.

(4) PP is isotactic polypropylene.

The CTE is not the only factor in cracking of the hot-melt coatings. The materials were generally cast at 200-250°F. In general, the coatings remained fluid until they cooled to below 200°F. They then start to shrink, if unrestrained. Total shrinkage upon cooling to 70°F ranged from 0.6% to 1.7%. The cooling behavior was a function of the composition, however. The cooling curves and CTE curves for various compositions are shown in Figures 3 to 14.

Figure 3 is the cooling curve for formulation 5-1-2, containing 80% coal and a binder comprised of 80% slack wax and 20% polyethylene. The cooling curve shows a definite inflection point at 120-125°F. This variation in shrinkage rate is even more apparent in the CTE curve shown in Figure 4. This inflection is believed to be the result of a phase change of the slack wax. This material has a melting point near 120°F.

The best hot-melt coating tested was formulation 5-2-3. This coating consisted of 77.5% coal and a binder that was 2/3 slack wax and 1/6 each polyethylene and polypropylene. The cooling curve for formulation 5-2-3 is shown in Figure 5. Note the absence of the inflection point seen in Figure 3. The dip in the CTE curve (Figure 4) is similarly missing in Figure 6.

Formulation 6-1-2 was tested for CTE, then reheated to determine the repeatability of expansion and contraction. As may be seen in Figure 7, the test specimen did not regain its original length upon reheating. The second cooling curve suggested some consolidation of the mixture upon reheating, as the degree of contraction was essentially the same as in the original cooling cycle even though the starting length was shortened by about 0.1 inches. The CTE curve for formulation 6-1-2 again showed a dip at 120-125°F.

Additional typical cooling curves are shown in Figures 9, 11 and 13. Some formulations appear to take a permanent set upon cooling and do not regain their original length upon reheating. Formulation 5-12-1, however, appeared to expand and shrink uniformly through two heat cycles. The corresponding CTE curves are shown in Figures 10, 12 and 14.

The CTE for each formulation appears to be a function of the percent coal in the formulation. Figure 15 shows that the higher the percent coal, the lower the average CTE. Formulations containing over 80% coal are not practical, however, as they are too viscous to be applied readily.

Figure 16 shows the variation in CTE as a function of the percent slack wax in the binder. There does not appear to be a significant effect, regardless of the amount of coal in the formulation.

3.3.3 Latex Formulation Results

A total of 39 latex formulations were prepared and evaluated during Task 2. Included in this number were four tests of commercially available latex crusting compounds for comparison purposes. The remainder of the formulations were filled latexes, in which pulverized coal was used as an extender to improve the waterproofing character of the latexes.

FIGURE 3. COOLING CURVE FOR FORMULATION 5-1-2

FIGURE 4. COEFFICIENT OF THERMAL EXPANSION CURVE FOR FORMULATION 5-1-2

FIGURE 5. COOLING CURVE FOR FORMULATION 5-2-3

FIGURE 6. COEFFICIENT OF THERMAL EXPANSION CURVE FOR FORMULATION 5-2-3

FIGURE 7. COOLING CURVE FOR FORMULATION 6-1-2

FIGURE 8. COEFFICIENT OF THERMAL EXPANSION CURVE FOR FORMULATION 6-1-2

FIGURE 9. COOLING CURVE FOR FORMULATION 4-28-1

FIGURE 10. COEFFICIENT OF THERMAL EXPANSION CURVE FOR FORMULATION 4-28-1

FIGURE 11. COOLING CURVE FOR FORMULATION 5-15-2

FIGURE 12. COEFFICIENT OF THERMAL EXPANSION CURVE FOR FORMULATION 5-15-2

FIGURE 13. COOLING CURVE FOR FORMULATION 5-12-1

FIGURE 14. COEFFICIENT OF THERMAL EXPANSION CURVE FOR FORMULATION 5-12-1

FIGURE 15. EFFECT OF COAL PERCENTAGE UPON COEFFICIENT OF THERMAL EXPANSION

FIGURE 16. EFFECT OF WAX CONCENTRATION ON COEFFICIENT OF THERMAL EXPANSION

Some of the latexes tested were not compatible with coal. In the presence of coal, they coagulated or solidified rapidly. Table VIII shows the results of using various latexes to make filled coatings. The Daratak SP-1065, Everflex GT and DLR-H resins yielded satisfactory coating films. All others were incompatible with the coal.

The probable reason for the observed incompatibility is de-emulsification of the resin by chemical reaction with ionic components of the coal. Another possibility is instability resulting from pH change because of acidic substances in the coal.

The latexes which formed satisfactory films in the presence of coal are noted in Table VIII. Daratak SP-1065 formed rigid films, some of which were brittle. Everflex GT and DLR-H formed flexible films of moderate strength.

The effects of coal loading and particle size were determined, using Everflex GT resin. As Table IX shows, decrease in particle size from 50 mesh to 200 mesh resulted in a somewhat less flexible film. An increase in coal loading from 70 to 80% had a similar effect. In all cases, the films were flexible. The most flexible were "foldable." The less flexible were not "foldable."

Filled latex coatings made with SP-1065 and Everflex GT resins were applied to 1 ft x 1 ft panels similar to those previously described for the hot-melt coatings. Characteristics of these formulations and test results are given in Table X. All of the coatings were leakers in the "rainfall" test. The best of these coatings was an Everflex GT mix with 50% coal, which exhibited only a 13% leak rate.

To improve on the leakage rate with latex coatings, several test panels were made using a specially prepared surface finish on the substrate coal. One-half inch of fines, with a particle size of $<1/8$ " was placed upon the surface before the coatings were applied. Both commercial crusting compounds and an Everflex GT filled latex coating were tested. As seen in Table XI, the unfilled latex sprays did not waterproof the surface even with special preparation. In all cases, 50-90% of the "rainfall" water penetrated the coating. The filled latex coating did form a cohesive film on the surface, however. Less than 8% of the "rainfall" water adhered to the surface or passed through the coating, even after exposure to a temperature range of -30°F to $+160^{\circ}\text{F}$.

Tests on commercial latex crusting compounds showed that they do not provide a significant degree of waterproofing to coal. The minimum leak rate noted was 78%, as may be seen in Table XII. The ESCO product was tested at the recommended concentration and again at 5 times the recommended amount. The leakage rate was similar in both cases. The unfilled latexes cannot be considered as a satisfactory waterproofing agent for coal stores even when applied at substantially higher levels than recommended by the manufacturers for dust control and surface stabilization.

Table VIII
Comptability of Latexes with Dickerson Coal

<u>Composition, Wt %</u>			<u>Latex Type</u>	<u>Results</u>	
<u>Coal (80% -200 Mesh)</u>	<u>Tap Water</u>	<u>Latex</u>		<u>Mix</u>	<u>Film</u>
52	8	40	Daratak SP-1065	Fluid	Rigid, tough
57	9	34	"	"	Rigid, friable
61	11	28	"	"	" "
52	8	40	Everflex GT	Fluid	Flexible, foldable
57	9	34	"	"	" "
61	11	28	"	"	" "
52	4	44	DLR-H	Fluid	Flexible, foldable
56	7	37	"	"	Leathery, not foldable
60	10	30	"	"	" " "
53	4	43	DLR-S	Coagulates	-
43	17	40	Darex 410	Coagulates	-
33.3	-	66.7	Daran 820	Solidifies	-
33.3	-	66.7	Darex 622L	Coagulates	-

Table IX. Effect of Size Consist on Film Properties
of Coatings Prepared With Everflex GT Latex.

<u>Coating Composition, Wt%</u>			<u>Coal Size Consist</u>	<u>Coal/Resin Wt Ratio</u>	<u>Total Water Content, Wt %</u>	<u>Film Properties</u>
<u>Everflex GT</u>	<u>Water</u>	<u>Coal</u>				
42.0	4.2	53.8	64% - 50 Mesh	70/30	23.1	Flexible, foldable
34.8	7.7	57.3	"	75/25	23.4	" "
27.2	13.0	59.8	"	80/20	25.2	Flexible, not foldable
41.7	5.0	53.3	80% - 200 mesh	70/30	23.8	Flexible, not foldable
34.8	7.7	57.5	"	75/25	23.4	" " "
27.8	11.1	61.1	"	80/20	23.6	" " "
42.4	3.4	54.2	70/30 blend of 64% - 50 and 80% - 200 mesh	70/30	22.5	Flexible, not foldable
35.8	5.0	59.1	"	75/25	21.1	" " "
28.6	8.6	62.9	"	80/20	21.5	" " "

Table X. Test Data Summary for Filled Latex Compositions

File ID	Cover Composition, Wt. %, as Applied Wet	Comb Wt., gms, dry (wet)	Test Cond.	Test Wts., gms			Leak Rate, Wt % of SPRAY	Grid- ability	Coal/ Resin Wt. Ratio	Total Water Content, Wt. %	Htg Viscosity, KP	Remarks
				File Change	Drain	Total Leak						
39A	39% GT	337	Amb	1114	900	2014	63	Yes	70/30	29	0.06	Elastomeric coat
	50% Coal (64X -50 mesh)	(500)	+160	1034	2700	3734	79					No change
	11% Water		-30	660	2900	3560	75					No change
39B	38% GT	322	Amb	735	900	1635	35		70/30	30	0.015	Elastomeric coat
	49% Coal	(460)	+160	578	500	1078	23					No change
	13% Water		-30	524	800	1324	28					No change
40A	32% GT	298	Amb	419	500	919	19	Yes	75/25	30	water-like	Elastomeric coat
	52% Coal	(427)	+160	270	600	870	16					No change
	16% Water		-30	274	1530	1824	39					No change
40B	30% GT	275	Amb	764	2000	2764	58	Yes	75/25	33	water-like	Elastomeric coat
	50% Coal	(412)	+160	691	1400	2091	44					No change
	20% Water		-30	443	2900	3343	71					No change
41A	26% GT	307	Amb	690	1000	1690	36		80/20	30	0.06	Leather-like coat
	56% Coal	(438)	+160	392	500	892	19					No change
	18% Water		-30	464	350	814	17					No change
41B	23% GT	276	Amb	516	100	616	13		80/20	37.5		Leather-like coat
	50% Coal	(442)	+160	583	50	633	13					No change
	27% Water		-30	497	50	547	12					No change
42	18% GT	268	Amb.	1254	1300	2554	54		85/15	33	0.08	Leather-like coat
	57% Coal	(402)	+160	896	400	1296	27					No change
	25% Water		-30	680	325	1005	21					No change
43	12% GT	184	Amb	971	2500	3471	73		90/10	36	0.36	Stiff coat
	58% Coal		+160	345	1000	1345	28					Small cracks on drying
	30% Water	(490)	-30	473	1800	2273	48					No change
17	58% SP1065	249	Amb	655	360	1015	21	yes	50/50	35		Tough leather-like
	32% Coal (14 K/17 SN)	(386)	+160	550	400	950	20					coating.
	10% Water		-30	678	1650	2328	49					No change. 2 corner cracks.
18	46% SP1065	235	Amb	360	1100	1460	31	yes	60/40	34		Tough leather-like
	40% Coal	(357)	+160	525	800	1325	28					coating.
	14% Water		-30	626	2250	2876	61					No change. Many small random cracks. Catastrophic failure.
19	35% SP1065 45% Coal 20% Water	325 (500)		Coating cracked extensively during drying.					70/30	35		

Table XI. Test Data Summary For Cover Compositions Applied To
a Specially Prepared Pile.

File ID	Cover Composition, Wt %, as Applied Wet	Cover Wt, gms Dry (wet)	Test Cond.	Test Wts, gms			Leak Rate, Wt % of Spray	Remarks
				Pile Change	Drain	Total Leak		
44	9.1% ESCO M105 90.9% Tap water	5.0 (83)	Amb	1628	1750	3378	71	Cracked on drying
			+160	835	2000	2835	60	No visible change
			-30	530	3800	4330	92	" " "
45	4% Dowell M167.01 0.2% M171 Polymer 95.8% Tap water	5.8 (265)	Amb	1358	1150	2508	53	Excellent crust
			+160	1040	2600	3640	77	No visible change
			-30	445	3100	3545	75	" " "
46	9.1% Darex 3333 90.9% Tap water	7.0 (166)	Amb	1735	1600	3335	70	Excellent crust
			+160	840	3200	4040	85	No visible change
			-30					
47	4% Dowell M167.01 0.2% J223 Polymer 95.8% Tap Water	5.8 (265)	Amb	1812	2000	3812	81	Excellent crust
			+160	1265	2800	4065	86	No visible change
			-30	560	2700	3260	69	" " "
48	23% Everflex GT 50% Coal (220 MMD) 27% water	254 (407)	Amb	115	250	365	7.7	Leather-like coat
			+160	77	10	87	1.8	No visible change
			-30	55	0	55	1.2	2 Hairline cracks

Table XII. Test Data Summary for Commercially Available Crusting Agents

Pile ID	Cover Composition, Wt %	Cover Wt, Gms, Dry (wet)	Test Cond.	Test Wts, gms			Leak Rate, Wt % of Spray	Grind- ability	Remarks
				File Change	Drain	Total Leak			
ESCO 1	9.1% ESCO M105 90.9% Tap Water	5.0 (83)	Amb +160 -30	1277	6085	7362	78		Spray volume was 2.5 gal
				1013	2875	3888	82		
ESCO 2	9.1% ESCO M105 90.9% Tap Water	25 (407)	Amb +160 -30	951	2950	3901	82		Cements the coal pile surface into a tough crust of excellent mechanical integrity
				869	3550	4419	93		
				135	3550	3685	78		
13	22% Dowall M167.01 78% Tap Water	10 (90)	Amb	1278	3200	4478	95	Yes	"
14	22% Darex 3333 78% Tap Water	7.3 (72)	Amb	1403	2930	4333	92	Yes	"

3.3.4 Laboratory Procedures for Preparing Coatings

3.3.4.1 Procedure for Preparing Hot-Melt Coatings

The melt coating material is made from slack wax, polyethylene, polypropylene and pulverized coal. For preparation, the first step is to weigh out the desired amounts of the components. The slack wax is melted and heated to about 250°F. Polyethylene and polypropylene are added next. The mixture is then stirred or mixed for about 15 to 20 minutes until all of the materials are dissolved into a smooth fluid. The temperature is increased to ~300°F, and pulverized coal is added slowly, while stirring the mixture. Stirring is continued for about 15 to 20 minutes until all the coal is moistened and the mixture is homogeneous. The mixture is now ready for application and is applied hot at temperatures between 250-300°F. Fluid mixtures were applied by pouring them over the coal surface. Less fluid mixes were applied by "buttering" them onto the coal surface with a spatula.

3.3.4.2 Procedure for Preparing Filled Latex Coatings

The latex products generally contained about 50% water as purchased. To prepare a filled latex coating, the product was diluted by addition of tap water. Pulverized coal was then stirred into the diluted resin until a uniform mixture was obtained. The consistency of the final mixture was similar to thin paint. The viscosity was on the order of 0.5 kilopoise. The mixtures were poured onto the coal surface, attempting to disperse them as evenly as possible over the test area. The filled latex coatings were allowed to dry for 24 hours before any tests were performed on them.

3.3.5 Test Procedures

3.3.5.1 Visual Tests

The visual tests consisted of observing the hot-melt coal cover mixtures for the following characteristics:

- Texture and flow characteristics of the hot-melt mix
- Thermal shrinkage and cracking
- Ease of application
- Surface voids (steam rising through the coating from wet coal beneath sometimes created holes in the coating)
- Surface texture after cooling
- Phase separation

These visual observations were used as a basis for adjusting formulations and selecting candidates for further testing.

3.3.5.2 Physical Tests

Compressive Strength

Tests were made on samples at ambient temperature and a crosshead rate of 0.2 inches per minute. All 9 samples failed at $\sim 45^\circ$ angle. They cracked but did not crumble or shatter. The samples were cylindrical, 0.9 inches in height and 0.7 inches in diameter.

Tensile Strength

The tensile properties of 2 coal cover materials have been determined at -30°F . JANNAF C tensile samples were milled and machined from cast blocks identified as 5-2-3 and 6-1-2. The samples were difficult to machine due to presence of fissures and voids. The samples were preconditioned at -30°F overnight, then tested at a crosshead rate of 0.5 inches per minute.

3.3.5.3 Rheological Tests

Viscosity

The viscosity of the composition was measured with a Brookfield RVT rotational viscometer fitted with a Type F T-bar spindle. The mix was conditioned overnight at 250°F and well stirred prior to the measurements. The mix temperature was 246°F at the start of the measurement and 243°F at the conclusion.

Pseudoplastic Behavior

The existence of thixotropy, which is defined as time-dependent pseudoplastic behavior could not be determined with the available equipment. However, it may be assumed that the observed existence of pseudoplasticity infers the existence of thixotropy.

3.3.5.4 Thermal Cycling and Water Penetration

The tests of water penetration and effects of thermal cycling were performed. All tests were carried out on small covered coal piles. The piles were housed in a square frame, having inside dimensions of one foot on a side. The frame was prepared of 1" x 4" lumber, with a screen base, and fitted with four 1" legs to permit standoff and prevent deformation of the pile and cover during routine handling and testing. The framing pieces were painted and caulked. The frame was filled with coal to approximately one inch above the frame top at the midpoint of the pile and level with the frame at the sides. Typically, the weight of coal in each pile was about 10 kg. Bituminous coal from the pile at the Dickerson, MD., facility of PEPCO was used as received. The size consist of this coal was 1-1/2" x 0. The characteristic dimensions of the small test piles were sufficiently greater than those of the coal particles to minimize any size effects on the test results.

The top surface of the frame was lined with 1/4" dowels, spaced 1/2" apart, to serve as pins for the melt coatings. The melt coatings were applied to the pile and around the pins. In this way, the coating was fastened securely

to the frame. This pinning technique was not required for any of the latex compositions because of the adhesion of these compositions to the framing pieces.

Procedures for coating the piles were very rudimentary, and varied with the covering material. For the hot-melt compositions, the coatings were applied at about 250°F, by pouring and buttering. The typical coating weight using this technique for the melt compositions was approximately 2 kg/ft² of pile. The filled latexes were applied at ambient temperatures by pouring, at a typical application weight (dry) of 300 gm/ft² of pile. The crusting latexes were spray applied at ambient temperature at the manufacturer's suggested application rate of 5 to 10 gm of latex/ft².

Each covered pile was subjected to the following test procedure:

1. Conditioning to room temperature (and dryness for the latexes)
2. Rainfall test on the as-received conditioned sample
3. Storage overnight at 160°F in a forced draft oven
4. Rainfall test on the sample, at a sample temperature of 160°F
5. Conditioning to room temperature
6. Storage overnight at -30°F
7. Conditioning to room temperature
8. Final rainfall test

Visual observations of the coating were recorded after each step. The rainfall tests comprised spraying the covered pile with 1-1/4 gallon of tap water (50-55°F). This volume was selected to simulate a 2-inch rainfall. An ordinary tank-type garden sprayer was used for this purpose. This sprayer generates a mist of small particles, and disseminates the 1-1/4 gallon in approximately 15 minutes.

3.3.5.5 Test Procedures for Coefficient of Thermal Expansion

A frame was constructed with internal dimensions of 36" long by 2-1/2" wide by 1" deep. It was lined with aluminum foil. The melt coating was cast into the frame with a thermocouple lead approximately centered in the coating. The coating was allowed to cool with measurements for shrinkage taken at 10°F intervals until the sample reached room temperature. Curves were plotted from this data, the slope of which represented the coefficient of thermal expansion.

3.3.5.6 CTE Hysteresis Procedure

The coating materials in the CTE test frames were reheated overnight to 170°F. They were removed and allowed to cool to room temperature with shrinkage measurements made at 10°F intervals. Curves were then made from the data and the coefficient of thermal expansion for the reheat cycle determined.

3.3.5.7 Grindability Test Procedure

After completion of rainfall tests, the piles were broken up and samples comprised to about 50% coating and 50% coal were crushed to 1/2" x 0 for

use as feed to a hammermill. The mill used here was a Bantam Mikro-pulverizer. The hammer speed was 13,800 rpm and the screen pattern and size was a herring-bone pattern with 27-mil slots. These mill operating conditions give a product size consist that is 80%-200 mesh, which is the usual requirement for pulverized coal burners. Grindability was determined by visual observation of the mill during grinding, and inspection of the screen and working surface after grinding. Grindable materials cause no audible or visible changes in mill operation, and the screen and working surface were found to be clean after the mill run. Non-grindable materials fill the screen and working surface and cause the mill to labor during operation. The laboring was audible during operation, and if allowed to persist, overloaded the motor, tripped the circuit breaker, and terminated operation. Visual inspection of the mill after such an event showed the screen and working surface to be filled with the coating material.

3.4 Application Techniques

3.4.1 Laboratory Techniques

Task 3 application experiments were intended to assess characteristics of hot-melt materials. The principal object was to assure that the materials could be pumped without loss of prime due to vapor lock or problems due to viscous effects. Initial experiments showed that compositions containing 80% coal were easily transported through a 1" diameter tube with less than 2 psig pressure drop.

Additional tests were conducted with a cylinder/piston gun to determine material flow as a function of pressure at various temperatures. These tests were qualitative, as internal pressures and accurate force measurements were not monitored. The results of these tests indicated that all of the hot-melt materials flow very well at temperatures above 240°F. Most materials were found to be quite mobile at 220°F.

Hot-melt flow was also investigated on inclined coal surfaces. These tests were made to determine the film thickness and flow characteristics of several coal cover material candidates. It was observed that films as thin as 1/8 inch resulted when the material temperature exceeded 260°F. It appeared that improved flow was gained more by the higher temperature prolonging fluidity than by the lowering of viscosity. These tests were considered relevant as full-scale application methods could apply successive layers. If sufficiently fluid, these layers could then flow and meld with less thickly coated areas or flow onto uncoated areas.

3.4.2 Subscale Application System

3.4.2.1 Description of System

A system capable of applying hot-melt materials comprises the following elements:

- a) Crusher/grinder
- b) Polymer melt vessel
- c) Coal preheater

- d) Metering system
- e) Mixing vessel (heated)
- f) Slurry pump (heated)
- g) Service lines (heated)
- h) Steam boiler
- i) Dispensing system

Design and assembly of the subscale applications system for this task was concerned mainly with integrating the slurry pump (f), service lines (g), steam boiler (h) and dispensing system (i). The other elements, when used, were not assembled as integral parts of a continuous system. This approach was selected to focus the work on slurry transport, which was expected to be the most difficult task.

A schematic of the system is shown in Figure 17. As shown, a mixing vessel is included in the current subscale apparatus. This mixer is used as a batch heater and dispenser rather than continuous, as would be required in practice. Figure 18 shows a photograph of the application system assembled for this program.

3.4.2.2 Details of Main Components

a) Crusher/grinder - A Quaker City Mill #4 laboratory crusher was used to produce the ground coal for Tasks 2 and 3. The crusher was supplied with a hand crank, which was removed. A 2-1/2 rpm 450 lb/in gearmotor was attached to the shaft for continuous service.

The capacity of the mill was approximately 5 lb/hr. This capacity was not sufficient for a continuous supply to an integrated dispensing system. Therefore, coal was ground and stored for batch processing.

b) Polymer melting, coal heating, metering, and mixing - Production of hot-melt coatings was done on a batch basis to build up a stock of premixed material. A large quantity of coating material was required for pump and systems testing, so this material was made in advance. Thermostatically controlled electrically heated vessels were used to prepare the mixture.

c) Remelting - An Atlantic Research Corporation Model 8 CV vertical cone mixer was used to reheat and agitate the preprepared hot-melt materials. The mixer had a capacity of 2 gallons and was heated by hot oil. It was equipped with a variable speed reversible motor.

d) Pump - A Cherry-Burrell RPD 75 Uniflow positive displacement rotary pump was used in these tests. The pump was driven by a 1 HP C motor with speed controlled by a SECO Model 210-1HP controller. The pump system was rated for 1-3 gpm of coal slurry at 50 psig.

e) Service Lines - Two lines were used to supply the application system. A steam line was used to preheat the pump and the coal slurry delivery hose to prevent chilling the melt. Steam was also provided to the dispensing system to propel the molten slurry onto the coal pile specimens.

Figure 17. Schematic Diagram:
COAL COVER DEMONSTRATION UNIT

Figure 18. Subscale Application System

f) System Boiler - An Oster/Teledyne portable steam generator was obtained to provide the steam. This unit was the smallest propane fired boiler considered suitable for use. It was equipped with a 1/3 HP feedwater pump and 24 gallon LPG tank. The steam temperature, pressure and flow rate were controlled by orifices in the delivery system. Nominal operating conditions were 80 psig and 320°F.

g) Dispensing System - Hot-melt materials were to be applied both as a spray and as a non-atomized stream onto the simulated coal piles. Development of spray techniques was directed to both high pressure application techniques and to steam-assisted methods. The power available to the pump used on this task was not sufficient for direct spraying without steam assist, so this technique was not investigated further.

Steam-assisted spraying was done with Penberthy ejector valves. Two sizes, GH 1/2 and GH 3/4, were used. The steam was directed to both the center and annular portion of the valves. Direct flow methods consisted of allowing a stream of the hot-melt slurry to run onto the coal surface.

3.4.3 Operating Procedure

a) Prepared hot-melt material was placed in the oil heated mixer. The temperature was maintained at 300°F. Two hours were allowed for thorough heating.

b) Steam was directed through the pump and delivery system for one hour to preheat the system.

c) The mixer was pressurized to 30 psig.

d) The pump was started at 100% power setting.

e) Steam flow was diverted from the pump and delivery system to the drain.

f) The mixer valve was opened slowly to avoid excessive steam pressure caused by residual moisture in the system.

g) Hot mix material was dispersed by flow application and by steam ejection in the smaller Penberthy valve. When steam was required, the ejector valve was opened and the drain closed.

h) On completion, the mixer valve was closed and steam was directed through the system to flush the lines.

3.4.4 Results of Application Experiments

The use of steam to propel the coal cover materials appeared to be satisfactory. However, problems were encountered with the system used on this program because the steam was too wet. The small steam generator could not deliver dry steam without overheating and shutting down automatically. The quality of material dispersed through the system was affected by the excess water.

Hot flow application resulted in an excellent layer of coating on an inclined 4 x 8 foot panel. The material thickness varied from 1/8 to 1/4 inch thick. A photo of the test panel is shown in Figure 19. Figure 20 shows a technician in the process of coating a 4 x 8 foot panel. The hot-melt materials applied by stream application were thinner, more uniform and more easily applied than those applied manually as in Task II.

3.4.5 Requirements for Scale-Up

The application system developed in Task III is capable of applying a gallon per minute of coating material. For practical applications, a system capable of applying 10-40 gallons per minute would be desirable. The requirements for constructing a 10 gallon per minute system are listed below:

- a) Steam Generator - Oil fired 30 HP complete with fuel tanks, water tank, water softener, pump and fittings.
- b) Crusher/Mill - A 15 HP mill would be capable of grinding 6000 lb of coal per hour. The mill would be fed by a hopper system.
- c) Binder Melt Vessel - A 100-200 gallon heated container for pre-mixing and melting the binder material.
- d) Coating Mixer - A heated ribbon mixer which would combine the pulverized coal and binder material and heat it to application temperature.
- e) Slurry Pump - A 10 gallon per minute gear pump capable of delivering 5-10 poise material at 50-100 psig outlet pressure.

This system would be installed in a platform with all hoses, nozzles and fittings required for a 50-100 foot span. The system would be transported to the application site on a trailer equipped with a boom. The boom plus the momentum of sprayed material would permit application to a pile 50-60 feet high from ground level. This system would be suitable for application of either hot-melt or filled latex type coatings.

3.5 Task 4 - Preliminary Economic Analysis

The following section is an evaluation of the costs and benefits which would accrue from the use of protective coatings for coal. Uses of latex crusting compounds, filled latex coating and hot-melt coatings are considered. Both stockpiles and rail car applications are evaluated.

For stockpile applications, a truncated conical stockpile is used as a basis for analysis. Such a pile is depicted below, along with the assumptions used. The pile volume and surface area calculations are shown.

Figure 19. Panel Coated with Hot-Melt Material

Figure 20. Application of Hot-Melt Coatings

Stockpile Dimensions

Assumptions:

$$\text{Compacted coal} = 65 \text{ lb/ft}^3$$

$$\begin{aligned} \text{Pile volume} &= \frac{100 + 50}{2} (25) (l) - (25) (25) (75) \\ &= 75(25) l - 75(25) (25) \\ &= 75(25) (l - 25) \\ &= 1875 (l - 25) \end{aligned}$$

$$\begin{aligned} \text{Surface area} &= 50(l) + \frac{(l + l - 50)}{2} (\sqrt{1250}) + (75) (\sqrt{1250}) \\ &= 50 l + \frac{(2l - 50)}{2} (35.4) + 75(35.4) \\ &= 50 l + (l - 25) 35.4 + 75 (35.4) \\ &= 50 l + (l + 50) 35.4 \\ &= 85.4 l + 1768 \end{aligned}$$

Table XIII presents the volume and surface area of stockpiles containing various amounts of coal.

Table XIII. Stockpile Volume and Surface Area

l ft	$V=1875(l-25)$ ft^3	$S=85.4l+1768$ ft^2	Tons Coal $V(65)/2000$
100	140,625	10,308	4,570
500	890,625	44,468	28,945
1000	1,828,125	87,168	59,414
2000	3,703,125	172,568	120,352
5000	9,328,125	428,768	303,164
10,000	18,703,125	855,768	607,852

3.5.1 Steps in Constructing and Protecting Coal Stockpiles

Current practice for forming coal stockpiles was described in Section 3.2.2. The steps involved in forming and protecting a stockpile are shown below:

Dump coal from cars
Grind to < 2"
Transport to pile
Unload on pile
Form and compact pile

} Current practice,
unprotected piles

3.5.2 Cost Analysis - Coal Stockpile Protection

The following sections provide an estimate of the costs of constructing and protecting a coal stockpile.

3.5.2.1 Cost Analysis - Coal Pile Construction

Cost of Emptying Unit Train

Basis: 1 unit train/8 hr day
1 operator @ \$200/day
100 cars/unit train
100 tons coal/car

$$\begin{aligned}\text{Cost} &= \$200/100 \text{ cars} = \$2/\text{car} = \$2/100 \text{ tons} \\ &= \$0.02/\text{ton}\end{aligned}$$

Cost of Transporting Coal and Unloading on Pile

Basis: 50 rail cars/8 hr day

1 operator @ \$200/day

1 loader vehicle @ \$100/day

1 driver @ \$200/day

1 dump truck @ \$100/day

Grinding to 2" size - part of normal operation, no cost

$$\begin{aligned}\text{Cost} &= \$600/50 \text{ cars} = \$12/\text{car} = \$12/100 \text{ tons} \\ &= \$0.12/\text{ton}\end{aligned}$$

Cost of Formation and Compacting of Stockpile

Basis: 50 rail cars/8 hr day

1 operator @ \$200/day

1 bulldozer @ \$200/day

$$\begin{aligned}\text{Cost} &= \$400/50 \text{ cars} = \$8/\text{car} = \$8/100 \text{ ton} \\ &= \$0.08/\text{ton}\end{aligned}$$

Total Cost of Construction of Stockpile = \$0.22/ton

For 50,000 T pile Cost = \$11,000

250,000 T pile Cost = \$55,000

750,000 T pile Cost = \$165,000

3.5.2.2 Cost of Monitoring Stockpile

Basis: 1 hr/day to monitor 100,000 T pile

Labor cost = \$25/hour

$$\begin{aligned}\text{Cost} &= \$25/100,000 \text{ T} = \$0.00025/\text{T/day} \\ &= \$0.091/\text{T/year}\end{aligned}$$

Total Cost of Monitoring Stockpile

For 50,000 T pile Cost = \$ 4,550/yr

For 250,000 T pile Cost = 22,750/yr

For 750,000 T pile Cost = 68,250/yr

Value of coal = \$20/T

Cost of storing and monitoring for 1 year

$$\begin{aligned}&= \$0.22 + \$0.091 = \$0.311/\text{T/yr} \\ &= 1.6\% \text{ of value of coal}\end{aligned}$$

3.5.2.3 Cost Analysis - Coal Pile Protection

3.5.2.3.1 Use of Latex Crusting Compounds

Basis: Cost \$4.00 per gallon

Dilution 4/1

Application rate = 1 gal/40 ft² diluted basis

or 1 gal/200 ft² undiluted basis

Materials Cost = $\$4.00/200 \text{ ft}^2 = \$0.02/\text{ft}^2$

Application Cost

Basis: 1 operator @ \$200/day

Rental spray equipment @ \$200/day

Operator treats 100,000 ft²/day

One day of operation costs:

Operator	\$200
Equipment	200
Materials	2,000
(500)\$4.00	
	<u>\$2,400</u>

<u>Pile size,</u> <u>tons</u>	<u>Surface Area</u> <u>ft²</u>	<u>Days</u> <u>req'd</u>	<u>Cost to treat</u> <u>\$</u>	<u>Cost/ton</u> <u>\$</u>
50,000	73,000	0.73	1,750	0.035
100,000	140,000	1.4	3,360	0.034
250,000	350,000	3.5	8,400	0.034
500,000	700,000	7.0	16,800	0.034
750,000	1,050,000	10.5	25,200	0.034

3.5.2.3.2 Use of Filled Latex Formulations, Case I

Basis: Everflex GT resin @ \$0.50/lb

80:20 coal/resin ratio

50 mil coating on surface fines

application rate = 10 GPM (dry basis)

1 gallon treats 29 ft² of surface

Total Cost of Surface Preparation = \$1696/50,000 ft²

Time required = 2.8 days/50,000 ft²

Total Costs to Treat 50,000 ft²

Surface preparation	\$1,696
Application cost	<u>2,148</u>
	\$3,844

Pile size, tons	Surface Area, ft ²	Days req'd	Cost to treat, \$	Cost/ton, \$
50,000	73,000	5.5	5,612	0.112
100,000	140,000	10.6	10,763	0.107
256,000	350,000	26.6	26,908	0.107
500,000	700,000	53.2	53,816	0.107
750,000	1,050,000	79.8	80,724	0.107

Note: Surface preparation costs would remain constant regardless of coating thickness.

Application costs would be reduced proportional to coating thickness. Cost per ton treated would be as follows for a pile of 100,000 tons or larger:

25 mil coating	\$0.078/ton
50 mil coating	0.107/ton
100 mil coating	0.168/ton

3.5.2.3.3 Use of Filled Latex Formulations, Case II

Basis: Everflex GT resin @ \$0.50/lb

80:20 coal/resin ratio

1/8" coating on as formed surface

application rate = 10 GPM (dry basis)

1 gallon treats 11.6 ft² of surface

Materials Cost:

Same as previous case = \$0.84/gallon mix

\$0.84/11.6 = \$0.0724/ft² treated

Materials Cost:

$$\text{dry weight} = 70 \text{ lb/ft}^3$$

$$= 8.4 \text{ lb/gallon}$$

$$8.4(.2) = 1.68 \text{ lb resin per gallon mix}$$

$$(1.68) (.50) = \$0.84 \text{ per gallon mix}$$

Coal cost is \$20/ton, but is offset by fuel value
so net cost is zero.

$$\text{Materials Cost} = \$0.84/29 = \$0.029/\text{ft}^2 \text{ treated}$$

Application Cost

Basis: 2 operators @ \$200/day

equipment cost \$300/day

$$\text{treatment rate} = 50,000 \text{ ft}^2/\text{day}$$

One day of operations costs:

operators \$400

equipment 300

materials 1,448

50,000/29 (.84) _____

\$2,148

Cost of surface preparation

Basis: 1/2 inch of fines on surface

$$(50,000 \text{ ft}^2) \left(\frac{1}{24}\right) = 2084 \text{ ft}^3 \text{ coal fines/day}$$

Crusher grinds 6,000 lb/hr

$$(2084/\text{ft}^3) (65 \text{ lb/ft}^3) = 135,400 \text{ lb/day req'd}$$

$$\text{Grinding time} = 135,400/6000 = 22.6 \text{ hours}$$

Labor cost = \$25/hr

Equipment cost = \$12.50/hr.

$$\text{Cost of grinding fines} = \$848/50,000 \text{ ft}^2$$

Cost of applying fines

Basis: 1 man can apply 6,000 lb/hr

labor cost \$25/hr

equipment cost \$12.50/hr

$$\text{Cost of spreading fines} = \$848/50,000 \text{ ft}^2$$

Application Cost

Basis: 2 operators @ \$200/day
equipment cost = \$300/day
treatment rate = 30,000 ft²/day

One day of operation costs

Operators	\$400
Equipment	300
Materials	2,172
30,000/11.6(.84)	<u> </u>
	\$2,872

<u>File size,</u> <u>tons</u>	<u>Surface area,</u> <u>ft²</u>	<u>Days</u> <u>req'd</u>	<u>Cost to treat,</u> <u>\$</u>	<u>Cost/ton,</u> <u>\$</u>
50,000	73,000	2.4	6,988	0.140
100,000	140,000	4.7	13,402	0.134
250,000	350,000	11.7	33,506	0.134
500,000	700,000	23.3	67,011	0.134
750,000	1,050,000	35	100,516	0.134

3.5.2.3.4 Use of Hot Melt Formulation

Basis: Wax/polyethylene/polypropylene binder
80:20 coal/binder ratio
1/8" coating on as formed surface
application rate = 10 GPM
1 gallon treats 11.6 ft² of surface

Materials Cost

Mix weighs 70 lb/ft³

= 8.4 lb/gallon

8.4 (0.2) = 1.08 lb binder per gallon mix

Based upon 80/10/10 binder formulation:

1.34 1b wax @ \$0.07/lb

0.17 1b polyethylene @ \$0.15/lb (reclaimed)

0.17 1b polypropylene @ \$0.19/lb

1.68

binder cost = 1.34 (\$0.07) = \$0.094
 0.17 (\$0.15) = 0.026
 0.17 (\$0.19) = 0.032
 \$0.152/gallon
 $\$0.152/11.6 = \$0.013/\text{ft}^2$ treated.

Application Cost

Basis: 2 operators at \$200/day
 equipment cost = \$300/day
 treatment rate = 30,000 ft²/day

One day of operation costs

operators	\$400
equipment	300
materials	393
30,000/11.6(.152)	<u> </u>
	\$1,093

File size, tons	Surface area, ft ²	Days req'd	Cost to treat \$	Cost/ton, \$
50,000	73,000	2.4	2,623	.052
100,000	140,000	4.7	5,137	.051
250,000	350,000	11.7	12,788	.051
500,000	700,000	23.3	25,466	.051
750,000	1,050,000	35	38,255	.051

NOTE: Increasing thickness of the hot melt coating to 1/4"
 would double the costs and time requirements listed above.

3.5.2.4 Summary of Stockpile Protection Costs

Table XIV shows a summary of the costs of building and protecting a coal stockpile. A 250,000 ton stockpile was used as a basis for comparison.

3.5.3 Cost Analysis - Rail Car Protection

The next section presents the estimated costs of providing protection for coal in transit in rail cars.

Table XIV. Summary of Stockpile Protection Costs

Basis: 250,000 ton stockpile			
<u>Treatment</u>	<u>Time Required Days</u>	<u>Total Costs \$</u>	<u>Cost/ton, \$</u>
Build and Compact Stockpile	50	55,000	0.22
Monitor Stockpile for 1 year	365	22,750	0.091
Latex Crusting compound, 1 gal/ 200 ft ²	3.5	8,400	0.034
Filled Latex on surface fines, .025"	13.3	19,500	0.078
Filled Latex on surface fines, .050"	26.6	26,908	0.107
Filled Latex on surface fines, .100"	53.2	42,000	0.168
Filled Latex on normal surface, 1/8"	11.7	33,506	0.134
Hot-melt on normal surface, 1/8"	11.7	12,788	0.051
Hot-melt on normal surface, 1/4"	23.4	25,576	0.102

3.5.3.1 Use of Latex Crusting Compounds

Basis: Cost \$4.00 per gallon

Dilution 10/1

1 rail car = 500 ft² surface, contains 100 tons coal

Application rate = 1 gallon/rail car

= 1 gallon/500 ft² (undiluted)

Materials cost = \$4.00/500 ft² = \$0.008/ft²

Application Cost

Basis: 1 operator @ \$200/day

Spray equipment @ \$100/day

Operator treats 100 rail cars/day

One Day of Operation Costs:

Operator	\$200
Equipment	100
Materials (100 x \$4.00)	<u>400</u>
	\$700

Total cost = \$700/100 rail cars = \$7.00/rail car

= \$7.00/100 tons = \$0.07/ton

Use of Filled Latex Formulations, Case I

Basis: Everflex CT resin @ \$0.50/lb

80:20 coal/resin ratio

50 mil coating on surface fines

1 gallon treats 29 ft² of surface

Material Cost

dry weight = 70 lb/ft³

= 8.4 lb/gallon

8.4 (0.2) = 1.68 lb resin per gallon mix

1.68 (.50) = \$0.84 per gallon mix

Coal cost is \$20 per ton, but is offset by fuel value so net cost is zero.

$$\text{Material Cost} = \$0.84/29 = \$0.029/\text{ft}^2 \text{ treated}$$

Application cost

Basis: 2 operators @ \$200/day
equipment cost \$300/day
treatment rate = 100 card/day
= 50,000 ft²/day

One day of operation costs:

Operators	\$400
Equipment	300
Materials 50,000/29 (.84)	1,448
	<hr/>
	\$2,148

Cost of surface preparation

Basis: 1/2" fines on surface
(50,000 ft²) 1/24 = 2084 ft³ coal fines/day
crusher grinds 6,000 lb/hr
(2084 ft³) (65 lb/ft³) = 135,400 lb/day required

Grinding time = 135,400/6000 = 22.6 hours
labor cost = \$25/hour
equipment cost = 12.50/hour
Cost of grinding fines = \$848/50,000 ft²

Cost of applying fines

Basis: 1 man can apply 6000 lb/hour
labor cost = \$25/hour
equipment cost = 12.50/hour
Cost of applying fines = \$848/50,000 ft²
Total cost of surface preparation = \$1696/50,000 ft²
Total cost to treat 100 rail cars (50,000 ft²)

Surface preparation	\$1,696
Application Cost	<u>2,148</u>
	\$3,844

Total Cost = \$3,844/100 rail cars = \$38.44/rail car
= \$38.44/100 tons = \$0.38/ton

3.5.3.2 Use of Filled Latex Formulation, Case II

Basis: Everflex GT resin @ \$0.50/lb
80:20 coal/resin ratio
1/8" coating on as dumped surface
1 gallon treats 11.6 ft² of surface

Materials Cost

Same as previous case = \$0.84/gallon mix
 $\$0.84/11.6 = \$0.0724/\text{ft}^2$ treated

Application cost

Basis: 2 operators @ \$200/day
equipment cost = \$300/day
treatment rate = 50,000 ft²/day

One day of operation costs:

operator	\$400
equipment	300
materials	3,620
50,000/11.6(.84)	<hr/>
	\$4,320

Total cost = \$4,320/100 rail cars = \$43.20/rail car
= \$43.20/100 tons = \$0.43/ton

3.5.3.3 Use of Hot-Melt Formulation

Basis: Wax/polyethylene/polypropylene binder
80:20 coal/binder ratio
1/8" coating on as dumped surface
1 gallon treats 11.6 ft² of surface

Materials Cost:

Mix density = 70 lb/ft³

= 8.4 lb/gallon

(8.4)(0.2) = 1.68 lb binder per gallon mix

based upon 80/10/10 binder formulations:

1.34 lb wax @	\$0.07/lb
0.17 lb polyethylene @	0.15/lb (reclaimed)
<u>0.17 lb polypropylene @</u>	<u>0.19/lb</u>
1.68	

$$\begin{aligned}\text{binder cost} &= 1.34 (\$0.07) = \$0.094 \\ 0.17 (\$0.15) &= 0.026 \\ 0.17 (\$0.19) &= \underline{0.032} \\ &\$0.152/\text{gallon} \\ \$0.152/11.6 &= \$0.013/\text{ft}^2 \text{ treated}\end{aligned}$$

Application Cost

Basis: 2 operators @ \$200/day
 equipment cost 200/day
 treatment rate = 50,000 ft²/day

One day of operation costs:

operators	\$400
equipment	300
materials	655
50,000/11.6 (.152)	<u>1,355</u>
	\$1,355

Total Cost = \$1,355/100 rail cars = \$13.55/rail car
 = \$13.55/100 tons = 0.14/ton

3.5.3.4 Summary of Rail Car Protection Costs

Table XV is a summary of the costs of various techniques for protecting coal in rail cars.

Table XV. Summary of Rail Car Protection Costs

Basis: 1 unit train = 100 rail cars containing 100 ton/car
 treatment rate = 100 cars/day

<u>Treatment</u>	<u>Total Cost, \$</u>	<u>Cost/ton, \$</u>
Latex Crusting Compound, 1 gallon/500 ft ²	700	0.07
Filled Latex on Surface Fines, .050"	3,844	0.38
Filled Latex on as Dumped Surface, 1/8"	4,320	0.43
Hot-Melt on as Dumped Surface, 1/8"	1,355	0.14

3.5.4 Cost/Benefit Analysis - Stockpile Applications

This section and the following Section 3.5.5 illustrate the benefits to be derived from coal protection and the estimated return on investment. The results are summarized below, based upon protection of a 250,000 ton stockpile for a period of one year. The value of the coal is assumed to be \$20 per ton.

Treatment	Treatment of Cost \$/ton	Direct \$ Savings \$/ton	Total Benefits Value equivalent \$/ton
Compaction	0.08	.275	.61
Latex Crust	0.114	.65	1.09
Filled Latex Coating	0.158	1.04	1.65
Hot-melt Coating	0.131	1.04	1.90

The direct dollar savings noted above result from reduced moisture levels, reduced oxidation losses and reduced handling costs. The total benefits value includes other less tangible factors as listed below in Section 3.5.4.2. The total benefits value is based upon estimates of the equivalent dollar value of the less tangible factors plus the direct dollar savings.

3.5.4.1 Cost Factors

The following list shows the cost of each alternative considered for the protection of coal stockpiles.

	<u>Cost, \$/Ton</u>
Form uncompacted pile	0.14
Build and compact pile	0.08
Monitor stockpile	0.091
Apply latex crusting compound	0.034
Apply filled latex coating, 0.025"	0.078
Apply hot-melt coating, 1/8"	0.051

3.5.4.2 Benefit Factors

Listed below are the benefits which would derive from use of coatings to protect coal stockpiles.

- Reduce or eliminate dust emissions
- Reduce or eliminate leachate formation
- Maintain or reduce moisture content (fuel value effect)
- Minimize freezing of coal into large agglomerates

- Prevent increase in moisture content (grinder operation)
- Prevent stockpile migration
- Reduce or eliminate oxidative energy loss
- Reduce or eliminate spontaneous ignition
- Prevent wind or rain erosion
- Reduce need for snow removal
- Reduce monitoring costs
- Reduce fire prevention and extinguishment requirements

3.5.4.3 Relative Weighing of Benefit Factors

Some of the factors noted represent economic benefits, other environmental or intangible benefits. The following table is an estimate of the relative importance of each factor on a scale of 1 to 10. It is recognized that such a scale is subjective. The relative weighing would vary regionally, by type of coal, by season and by individual preference. For example, an operator in a cold climate might consider prevention of freezing as the dominant factor to him, while an environmentalist might consider prevention of dust loss as most important. The following table represents a "typical" viewpoint of a composite observer interested in economics, the environment, energy conservation, and operating problems of the coal user.

Table XVI. Weighing of Benefit Factors of Coal
Protection Methods for Stockpiles

	<u>Weighing Factor</u>
1. dust emissions	6
2. leachate formation	6
3. moisture (energy effect)	2
4. freezing	8
5. moisture (grinder effect)	2
6. migration	4
7. oxidative energy loss	8
8. spontaneous ignition	7
9. wind or rain erosion	3
10. snow removal	1
11. monitoring costs	1
12. fire prevention and extinguishment	2

NOTE: Factor of 1 = very limited importance
Factor of 5 = relatively important
Factor of 10 = critically important

3.5.4.4 Scenarios for Stockpile Protection

1. Form stockpile as dumped, no compacting, monitor daily.
2. Form compacted stockpile, monitor daily.
3. Form compacted stockpile, protect with latex crusting compound, monitor daily.
4. Form compacted stockpile, protect with filled latex coating 0.025" thick on surface fines, monitor daily.
5. Form compacted stockpile, protect with hot-melt coating 1/8" thick on as formed surface, monitor daily.

Based upon these scenarios, Table XVII shows the ability of each method to provide the noted benefit. The scale is 0 to 100% effective. Table XVIII shows the weighed effectiveness of each protective method.

3.5.4.5 Cost/Benefit Calculation

The basic cost of forming a stockpile without compacting is \$0.14 per ton. This is common to all methods and represents the zero-protection case.

The cost of monitoring the stockpile for one year is \$0.091/ton. This is also common to all methods.

<u>Method</u>	<u>Cost/ton, \$</u>				
	<u>File Formation</u>	<u>Compacting</u>	<u>Monitoring</u>	<u>Protection</u>	<u>Total</u>
as dumped	0.14	0	0.091	0	0.231
compacted	0.14	0.08	0.091	0	0.311
latex crust	0.14	0.08	0.091	0.034	0.345
filled latex coat	0.14	0.08	0.091	0.078	0.389
hot-melt coat	0.14	0.08	0.091	0.051	0.362

The cost/benefit ratio of each protection method is the cost for storage for one year divided by the benefits provided.

<u>Method</u>	<u>Table XVIII</u>		
	<u>Total Cost, \$ 250,000 tons</u>	<u>Benefit Value</u>	<u>Cost/benefit Ratio</u>
as dumped	57,750	0	∞
compacted	77,750	1220	63.7
latex crust	86,250	2180	39.6
filled latex coat	97,250	3290	29.6
hot-melt coat	90,500	3790	23.9

Table XVII
Ability of Stockpile Protective Method to
Provide Benefits

	S1	S2	S3	S4	S5
	<u>% Effective</u>				
1. dust emission	0	20	100	100	100
2. leachate formation	0	20	50	100	100
3. moisture energy affect	0	20	50	100	100
4. freezing	0	10	30	50	50
5. moisture grinder effect	0	10	30	80	80
6. migration	0	20	100	100	100
7. oxidation energy loss	0	40	50	90	90
8. spontaneous ignition	0	40	80	90	90
9. wind or rain erosion	0	30	100	100	100
10. snow removal	0	10	100	100	100
11. monitoring*	0	0	0	0	0
12. fire prev. and ext.	0	30	60	90	90

* all scenarios here include daily monitoring. It is possible, after qualification, that protected stockpiles would require little or no monitoring.

S1 = unprotected, as dumped pile

S2 = compacted pile

S3 = compacted pile with latex crust

S4 = compacted pile with filled latex coating

S5 = compacted pile with hot-melt coating

} all stockpiles
monitored daily.

Table XVIII
Weighted Effectiveness of Stockpile Protection
Methods

	S1	S2	S3	S4	S5
	% Effectiveness x Weighting Factor				
1. dust emission	0	120	600	600	600
2. leachate formation	0	120	300	600	600
3. moisture energy effect	0	40	100	200	200
4. freezing	0	80	240	400	400
5. moisture grinder effect	0	20	60	160	160
6. migration	0	80	400	400	400
7. oxidation energy loss	0	320	400	720	720
8. spontaneous ignition	0	280	560	630	630
9. wind or rain erosion	0	90	300	300	300
10. snow removal	0	10	100	100	100
11. monitoring	0	0	0	0	0
12. fire prev. and ext.	<u>0</u>	<u>60</u>	<u>120</u>	<u>180</u>	<u>180</u>
sub-total	0	1220	3180	4290	4290
Subtractive factors*					
application affected by weather	0	0	<1000>	<1000>	0
must be applied hot	<u>0</u>	<u>0</u>	<u>0</u>	<u>0</u>	<u><500></u>
total	0	1220	2180	3290	3790

S1 = unprotected, as dumped pile

S2 = compacted pile

S3 = compacted pile with latex crust

S4 = compacted pile with filled latex coating

S5 = compacted pile with hot-melt coating

} all stockpiles
monitored daily

*These factors are based upon characteristics of the various coatings which detract from their overall utility. The values are proportional to the estimated importance of the effect.

The above figures show that any means of protecting a stockpile is desirable. Compacting is always done on any pile which will be stored for over a few days. The use of latex crusting compounds, filled latex coatings or hot-melt coating appear to be cost effective, with the hot-melt system potentially returning nearly twice the benefits per unit cost as the crusting compounds. Of course, the benefits may be weighed differently by different people in varied circumstances, so the above comparison would not necessarily apply in every case.

3.5.5 Return on Investment, Stockpile Applications

The economic return by protecting coal stockpile is difficult to assess, as many of the benefits of protection cannot be measured directly in dollars. Some direct dollar savings that would accrue from protection of stockpiles are estimated below, based on an uncompacted stockpile.

Reduced moisture levels	0.5 - 1%
Reduced oxidation losses	2.0 - 4%
Reduced handling costs	1.0 - 2%
	3.5 - 7%

Thus, direct cost savings might represent 3.5-7% of the value of the coal per year of storage. If coal is valued at \$20/ton, this represents savings of \$0.70 to \$1.40 per ton. Since the cost of protective treatment ranges from \$0.114 to \$0.158 per ton including compacting, the direct dollar savings could be from 6 to 9 times the cost of protection.

Considering the factors which are intangible in terms of dollar savings, assume that a value of 400 in Table XVIII represents a 1% equivalent cost saving. Thus, the net savings would be the equivalent of \$0.20/ton for every 400 points the protection system offers. The net returns are shown below.

<u>Method</u>	<u>Total effectiveness Value (Table XVIII)</u>	<u>Equivalent Savings, \$/ton</u>	<u>Treatment* Cost, \$/ton</u>	<u>Annual Return on Cost, %</u>
Compacted	1220	0.61	0.08	763
Latex crust	2180	1.09	0.114	956
Filled latex coating	3290	1.65	0.158	1,044
Hot-melt coating	3790	1.90	0.131	1,450

* includes compacting plus coating costs

Thus, use of a hot-melt coating would return 14.5 times the cost in total equivalent benefits including both tangible and intangible items.

Stockpiles are normally compacted. The return on the cost of protection of a previously compacted stockpile with a coating is given below.

<u>Method</u>	<u>Increase in Protection Effectiveness</u>	<u>Equivalent Savings \$/ton</u>	<u>Treatment Cost \$/ton</u>	<u>Annual Return on Cost, %</u>
Latex crust	960	0.48	0.034	1,412
Filled latex coating	2070	1.04	0.078	1,333
Hot-melt coating	2570	1.29	0.051	2,529

The incremental cost of coatings beyond the normal compacting step is even more attractive in terms of return on investment. A hot-melt coating would cost about \$0.05 a ton applied to a compacted pile, and would return total benefits valued at \$1.29.

3.5.6 Cost/Benefit Analysis - Rail Car Applications

This section and the following Section 3.5.7. illustrate the benefits to be derived for protection of coal in rail cars and the estimated return on investment. The results are summarized below, based upon protection of a unit train of 100 cars containing 100 tons each of coal. The value of the coal is assumed to be \$20 per ton.

<u>Treatment</u>	<u>Treatment Costs, \$/ton</u>	<u>Direct \$ Savings, \$/ton</u>	<u>Total Benefit Value, Equivalent \$/ton</u>
Latex Crust	.07	.54	.74
Filled Latex Coating	0.38	.61	.81
Hot-melt Coating	0.14	.61	1.01

The direct dollar savings noted above result from reduced wind losses and reduced moisture levels. The total benefits value includes other loss tangible items as listed below in Section 3.5.6.2. The total benefits value is based upon estimates of the equivalent dollar value of the less tangible items plus the direct dollar savings.

3.5.6.1 Cost Factors

The following list shows the costs of the alternatives considered for the protection of coal in rail cars.

	<u>Cost, \$/ton</u>
Fill car	base case - no cost
Apply latex crusting compounds	0.07
Apply filled latex coating, 0.050"	0.38
Apply hot-melt coating 1/8"	0.14

3.5.6.2 Benefit Factors

The benefits obtained from use of coatings to protect coal in rail cars are listed below.

- Reduce or eliminate dust emission.
- Reduce wind losses.
- Prevent moisture increase (fuel value effect).
- Prevent moisture increase (grinder operation).
- Prevent freezing of coal into large agglomerates.
- Reduce or eliminate spontaneous combustion.

3.5.6.3 Relative Weighing of Benefit Factors

The benefit factors noted above pertain to dollar savings, environmental pollution and coal handling problems. The following table shows an estimate of the relative importance of each factor. It is recognized that such a scale is subjective. The relative weighing would vary geographically, by type of coal, by direction of travel, by weather conditions and by individual interests. The table represents the viewpoint of a composite observer, interested in conserving energy, environmental factors and in the practical problems of handling coal.

Table XIX. Weighing of Benefit Factors of Coal Protection in Rail Cars During Transit.

	<u>Weighing Factor</u>
1. Dust emissions	8
2. Wind losses	8
3. Moisture (energy effect)	4
4. Moisture (grinder operation)	3
5. Freezing	6
6. Spontaneous combustion	2

Note: Factor of 1 = very limited importance
Factor of 5 = relatively important
Factor of 10 = critically important

3.5.6.4 Scenarios for Rail Car Protection

1. Fill car by conveyor, normal loading practice.
2. Fill car normally, protect with latex crusting compound.
3. Fill car normally, protect with filled latex coating, 0.050" thick on surface fines.
4. Fill car normally, protect with hot-melt coating, 1/8" thick on as filled surface.

Based upon these scenarios, Table XX shows the ability of each protection method to provide the noted benefit. The scale is 0 to 100% effective. Table XXI shows the weighed effectiveness of each protective method for rail cars.

3.5.6.5 Cost/Benefit Calculation

The basic cost of filling a rail car with coal is part of the normal price of the coal and is not considered separately. This is the base case of no added protection, and represents zero cost for purposes of comparison.

<u>Method</u>	<u>Fill Coal Car</u>	<u>Protection Cost, \$/ton</u>	<u>Total</u>
as dumped	0	0	0
latex crust	0	0.07	0.07
filled latex coating	0	0.38	0.38
hot-melt coating	0	0.14	0.14

The cost/benefit ratio is the cost of protecting one unit train divided by the weighed benefits provided.

<u>Method</u>	<u>Total Cost, \$ 100 cars</u>	<u>Table XXI Benefit Value</u>	<u>Cost/Benefit Ratio</u>
as dumped	0	0	∞
latex crust	700	1480	0.47
filled latex coating	3,800	1720	2.21
hot-melt coating	1,400	2020	0.69

The above figures show that latex crusting compounds are the most cost effective for protecting rail cars. The cost per unit of protection is about 2/3 that of the hot-melt coating. It appears that for rail car protection, latex crusting compounds offer sufficient protection at a low price and in a cost-effective manner.

3.5.7 Return on Investment, Rail Car Applications

As with stockpiles, some of the benefits of protecting rail cars are intangible. The primary economic loss in transport of coal is the wind loss, which has been measured to exceed 2% of the load in some cases.

Using the same basis as with stockpiles, assume that the equivalent value of 400 points in Table XXI represents 1% of the value of the coal, or \$0.20. The net return on protection of rail cars is given below.

Table XX. Ability of Rail Car Protective Methods to Provide Benefits

	% Effective			
	S1	S2	S3	S4
1. dust emission	0	100	100	100
2. wind loss	0	100	100	100
3. moisture (energy effect)	0	40	60	60
4. moisture (grinder operation)	0	40	60	60
5. freezing	0	10	20	20
6. spontaneous combustion	0	20	40	40

S1 = as filled rail car, no protection

S2 = rail car with latex crust

S3 = rail car with filled latex coating

S4 = rail car with hot-melt coating

Table XXI. Weighed Effectiveness for Rail Car Protection Methods

	S1	S2	S3	S4
	% effectiveness x weighting factor			
1. dust emission	0	800	800	800
2. wind loss	0	800	800	800
3. moisture (energy effect)	0	160	240	240
4. moisture (grinder effect)	0	120	180	180
5. freezing	0	60	120	120
6. spontaneous combustion	<u>0</u>	<u>40</u>	<u>80</u>	<u>80</u>
Sub total	0	1980	2220	2220

Subtractive factors*

application affected by weather	0	<500>	<500>	
must be applied hot	<u>0</u>	<u>0</u>	<u>0</u>	<200>
Total	0	1480	1720	2020

S1 = as filled rail car, no protection

S2 = rail car with latex crust

S3 = rail car with filled latex coating

S4 = rail car with hot-melt coating

*These factors are based upon characteristics of the various coatings which detract from their overall utility. The values are proportional to the estimated importance of the effect.

<u>Method</u>	<u>Total Effectiveness Value (Table XXI)</u>	<u>Equivalent Savings, \$/ton</u>	<u>Treatment Cost, \$/ton</u>	<u>Return on Cost, %</u>
latex crust	1480	0.74	0.07	1,057
filled latex coating	1720	0.86	0.38	226
hot-melt coating	2020	1.01	0.14	720

The use of latex crusting compounds to protect rail cars would yield an equivalent return of 10.6 times the cost of application, including both tangible and intangible benefits.

THIS PAGE
WAS INTENTIONALLY
LEFT BLANK

4.0 CONCLUSIONS AND RECOMMENDATIONS

Based upon the results of this technical effort, the following conclusions are presented:

1. Commercially available latex resins used as coal crusting compounds can prevent dust loss and wind erosion, but do not waterproof the coal surface.
2. Hot-melt formulations consisting of about 77.5% coal, 15% slack wax, 3.75% polyethylene and 3.75% polypropylene are capable of sealing a coal surface against water penetration.
3. A filled latex formulation consisting of 50% coal, 23% Everflex GT resin and 27% water is capable of sealing a coal surface against water penetration provided the surface is coated with fines of less than 1/8" particle size.
4. The quality of a hot-melt or filled latex coating is significantly affected by the application technique. To prevent moisture penetration, the coating must be cohesive and void-free.
5. Filled latex coatings are easily grindable. Hot-melt coatings may present some difficulty in grinding unless mixed with at least an equal amount of coal.
6. Latex crusting compounds and filled latex coatings must be applied at temperatures over 50°F and must dry for 12-24 hours before exposure to rainfall.
7. Hot-melt coatings may be applied under any weather conditions. However, the requirement for heating the coating mix to 250±50°F before application requires special application equipment and may present a safety hazard.
8. Hot-melt coatings appear to be most cost effective for application to coal stockpiles.
9. Latex crusting compounds appear to be the most cost effective means of protecting coal in rail cars.
10. The anticipated return in dollars and intangible benefits by use of any of the coal protection methods described herein is in the range of 10-20 times the cost of such protection.
11. Both hot-melt and filled latex coatings are worthy of continued development and evaluation.
12. Implementation of Phase II of this program is recommended. This work would involve continued development of coating materials and a field demonstration on a coal stockpile of up to 50,000 tons in size.

THIS PAGE
WAS INTENTIONALLY
LEFT BLANK

- Dowell, Inc. (1978), personal communication.
- ERDA (1975), Report ERDA-TR-120, "The Storage of Solid Fuel at Dumps of Thermo-electric Power Stations of the USSR, Methods of Preventing Dusting and Spontaneous Combustion of Fuel in Piles."
- ERDA (1976), "Energy from Coal," ERDA TR-76-67, Prepared by Tetra Tech, Inc., under Contract No. E(49-18)-2225.
- Leonard, M. *et al.* (1968). "Coal Preparation," American Institute of Mining, Metallurgical and Petroleum Engineering, Inc.
- Paulson, L.E.; Axeley, S.A.; Wegert, C. and Ellman, R.C. (1975), "Experience in Transportation of Dried Low-rank Western Coals," Society of Mining Engineers of AIME, Prepoint No. 1 75-B-337.
- Rondeau, W. (1978), personal communication (ESCO, Inc.).
- Shelor, D. (1977), personal communication.
- Wilson, H.S. (1975), "An Update on Coal Storage Technology," *Combustion*, 47, 33-36 (August).
- Young, R. (1978), personal communication.