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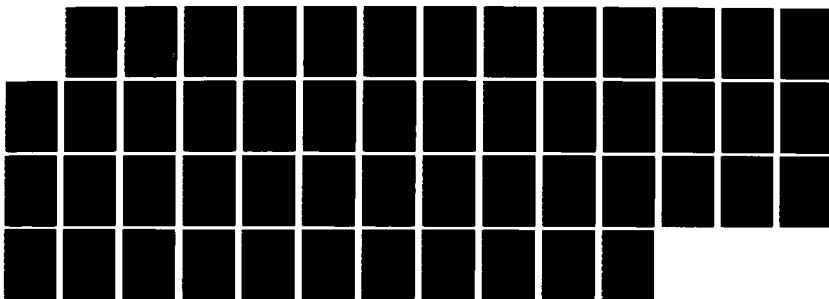
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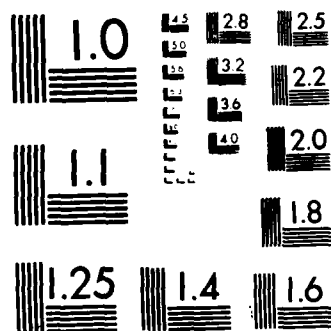
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FINAL REPORT

"PIPELINE CORROSION AND FRICTION REDUCTION COATINGS"

Contract DAAK 70-85-C-008⁸₅

Prepared for:

US ARMY BELVOIR RESEARCH AND DEVELOPMENT CENTER
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June, 1986

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SUMMARY

The objective of this program was to demonstrate the feasibility of coating tactical pipelines with coatings other than coal tar epoxy. These alternate coatings must be suitable for internal and external surfaces, provide corrosion protection and reduce friction when pumping fuel.

Twenty-five commercially available coatings were evaluated for their corrosion protection and friction reduction characteristics. Of these coatings, seven were qualified through corrosion and adhesion evaluations. However, following frictional evaluations, only three of the seven are recommended.

As a cost effective means to improve commercially available coatings, two methods were examined to reduce friction coefficients. While these methods, which include coating reformulation with lubricating additives and surface fluorination, appear promising they will require substantial research and development efforts to optimize.

Therefore, this program recommends three commercially available coatings as identified below for further evaluation:

- Glid-Guard Chemical Resistant Epoxy
- Integral Fuel Tank Coating
- Dacromet 320 and Plus

I. BACKGROUND

The U.S. Army currently stores tactical pipelines in warehouses indefinitely, or until required, in the event of an assault. They consist of 20 foot sections of 6 and 8 inch diameter pipe. These pipes, many of which have been stored 20-plus years, exhibit a significant amount of interior surface corrosion.

The corrosion protective measures employed for these pipes consists of applying a thick Coal-Tar coating on exterior surfaces. However, to date no coating has been applied to interior surfaces. Unfortunately there are several drawbacks to this coating system.

1. The coating becomes softened and tacky during exposure to warm atmospheric conditions.
2. The coating embrittles during exposure to cold atmospheric conditions.
3. The external coating offers no corrosion protection for internal surfaces.
4. The coating exhibits a degree of solubility when exposed to various fuels.

It would be advantageous from the Government's perspective to identify a corrosion inhibitive coating which could easily be applied to both internal and external surfaces. Ideally, this coating should resist corrosion and abrasion for 20-plus years as well as offer advantages of reduced friction across the internal surface.

The goal of this Phase I SBIR effort was to identify and evaluate other corrosion inhibitive coatings suitable to afford corrosion protection for tactical pipelines. In addition to their corrosion inhibitive role, coatings were selected based on their ability to reduce surface drag (friction) when in contact with fuels. Reduced friction will decrease the energy required to transport materials through the pipeline.

As a means of reducing friction, this program examined modification through reformulation and fluorination as a means of altering the surface chemistry, surface texture, as well as increasing surface lubricity. These methods were examined as a means of producing an inexpensive coating system.

The best coatings will be further examined in a Phase II SBIR program.

A. Task 1: Information Search and Procurement of Coating Materials

This portion of the program consisted of an extensive literature search as well as establishing communications with several coating and lubricant manufacturers who could recommend coatings as well as lubricant additives which may impart reduced friction in pipeline coatings.

1. Literature Search and Procurement

A significant portion of the literature search was conducted using the Dialog Information Retrieval Service from Dialog Information Services, Inc. The computerized search included the following data bases:

- NTIS- National Technical Information Services
- CA Search - Chemical Abstract Search
- Metadex - Developed by the American Society of Metals and the Metals Society
- Claims/U.S. Patents
- Federal Research in Progress
- Fluidex - BHRA Fluid Engineering
- Ei Engineering Meetings - Engineering Information, Inc.

From these data bases, nine reports and two patents were requested for review. Of those requested, six reports and one patent were received. Additional citations were made from monthly publications including "Modern Paint and Coatings" and the "Journal of Coatings Technology".

2. Materials Procurement

Prior to the procurement of selected coatings and lubricant additives, telephone contacts were established with forty-five companies considered manufacturers, producers or experts in the area of coatings. Additional contacts were made with eleven companies that produce lubricate additives for coatings and polymers. A detailed list of the contacts generated is contained in Appendix 1.

As a result of these conversations thirty coatings were recommended for evaluation as tactical pipeline coatings. However, only twenty-five were received in time for evaluation. Contact with the lubricant producers resulted in procurement of twenty-one low friction additives for the re-formulation work performed in Task 4.

B. Task 2: Initial Screening for Corrosion Resistance

This task involved screening each candidate coating for its corrosion inhibiting characteristics as well as its adhesion characteristics when applied to standard steel panels.

Twenty-one coatings were applied to 3" x 6" standard steel panels using a Devilbiss type JGK-501 spray gun. While four powder coatings were applied to our standard steel panels by the coating manufacturers. The standard steel panels are identified as QD-36 and were obtained from the Q-Panel Company. Each panel was thoroughly degreased using a 1,1,1-trichloroethane wash, followed by a methanol rinse prior to coating.

Each of the twenty-five coatings was assigned a sample I.D. number and is described as such throughout the report. Following is a brief discussion of each coating as well as its applied thickness and assigned identification number.

- #20251:Pulle-Kote, The B. F. Goodrich Company

A synthetic rubber coating developed as a corrosion and rust resistant friction coating for pulleys.

For our evaluation, the coating was sprayed as 2 coats. After each application, solvent was flashed off for 5 minutes at 200°F followed by a 5 minute cure at 385°F. The resulting coating was of 1 mil thickness.

- #20252:Glid-Guard Resistant Epoxy, Glidden Coatings and Resins

A converted epoxy-polyamide coating formulated to provide maximum durability and chemical resistance in both interior and exterior environments.

This is a two component system. Components A and B were mixed in equal volumes and sprayed as a single coat. Following room temperature cure, the resulting coating was approximately 3 mils thick.

- #20256 :Impreglon 218, Michian Impreglon Center

Impreglon 218 refers to a metal treatment process followed by the application of a solvent based fluoropolymer coating. The finished surface exhibits excellent friction reduction, as well as resistance to abrasion and corrosion. This coating was applied by the manufacturer to our panels at an approximate 1.5 mil thickness.

- #20258 : Tankguard #3, Seaguard Fine Marine Paints and Industrial Coatings

An extremely durable epoxy primer offering excellent water, chemical, solvent and abrasion resistance. This primer complies with MIL-P-23236, Type 1, Class 1.

This is a two component epoxy. Components A and B were mixed in equal volume and sprayed as a single coat. Following room temperature cure, the resulting coating was approximately 4 mils thick.

- #20259, 463-6-40 Zinc Dust Primer, Sikkens Aerospace Finishes

A two component corrosion inhibitive, epoxy polyamide. Component A, 463-6-40 was mixed at a 3:1 volume ratio with component B, X411. The coating was applied as a single sprayed coat and cured at room temperature. The resulting coating was 3 mils thick.

- #20260: Epoxy Ester 1207, Cargill Chemical Products Division

This epoxy ester was designed for use as a bake or air-dry appliance primer. It exhibits excellent chemical and corrosion resistance as well as good hardness and adhesion.

Following stirring, this single component coating was sprayed onto panels and discs, then cured at room temperature - a 2 mil coating resulted.

- #20261: Xylan 1014, Whitford Corporation

This coating is described as fluorocarbons in matrix of polymers to make a composite of combined good properties - low friction, release, chemically inert, tough, durable, wear and weather resistant, corrosion resistant, with good adhesion to metals.

The coating was sprayed, dried, then fused for 10 minutes at 440°F resulting in a 2 mil coating.

- #20262: Epoxy Ester 1222, Cargill Chemical Products Division

This epoxy ester is described as a cost effective bake or air dry industrial coating exhibiting good durability and impact resistance. The coating was sprayed as was the 1207 with a 1 mil coating resulting.

- #20263: P/C #9100 Epoxy Topcoat, Peterson Chemical Corporation

This coating is a two component free flowing liquid polyamide epoxy resin combination. It cures to a very hard, tough, durable, flexible thermosetting plastic coating which exhibits resistance to humidity,

water, salt water, corrosion, solvents, alkalies, acids, heat, cold, oils, fungus growth, chipping, cracking, weather and marring.

Panels and discs were coated by combining equal volumes of components A and B. The coating was sprayed, then cured at room temperature. The resulting coating was 1 mil thick.

- #20264:LPS Formula 3885 Hard Film, Rust Preventative, Holt Lloyd Corp.

This coating, a dark colored amber liquid, deposits a hard waxy film which affords long term protection to metal surfaces. It exhibits excellent humidity, salt spray, and acid/alkali fume resistance.

Panels and discs were sprayed with 2 coats. After coating, solvents were flashed off at 100°C for 5-10 minutes. The resulting coating was 1 mil thick.

- 20266:Uniset A-316, Amicon

This coating is a de-aerated, 100 percent solids, one part heat cured epoxy. Cured, this coating features exceptional thermal stability and resistance to acids, bases and solvents.

Due to its high viscosity, the coating was diluted with a 2:1 epoxy to solvent ratio. The diluent was a 50/50 solution of methyl ethyl ketone (MEK) and toluene. The coating was sprayed as two coats. Following each application, the coating was cured for 1/2 hour at 120°C. The resulting coating was approximately 8 mils thick.

- #20267-1:Chemglaze 9965 Epoxy Primer, Lord Industrial Coatings

This coating consists of a two component high-build epoxy polyamide primer. It was selected for its good penetrating properties as well as good corrosion and chemical resistance and excellent adhesion to prepared steel substrates.

The primer components were mixed in equal volumes, then diluted with a 4:1 coating to solvent dilution consisting of 50/50 MEK and toluene. The coating was sprayed and air dried overnight resulting in a 2 mil coating.

- #20267-2: Chemglaze 9965 Epoxy Primer/Chemglaze A-487 Polyurethane, Lord Industrial Coatings

This coating system consists of a two component high-build epoxy-polyamide primer and a moisture curing aliphatic polyurethane topcoat. The primer exhibits good penetrating properties as well as good corrosion and chemical resistance and excellent adhesion to prepared steel substrates.

The polyurethane topcoat provides excellent resistance to corrosion, abrasion, chemicals and impact.

The epoxy primer components were mixed in equal volumes, then diluted with a 4:1 coating to solvent dilution. The diluent consisted of a 50/50 solution of (MEK) and toluene. The primer was sprayed, then dried overnight. The polyurethane topcoat was sprayed on the primer surface. Following an ambient cure, the resulting coating was approximately 2.5 mils thick.

- #20268-2: Chemglaze 9420 Urethane Primer/Chemglaze A-487 Polyurethane, Lord Industrial Coatings

This coating system consists of an aluminum pigmented moisture curing urethane primer as well as a moisture curing aliphatic polyurethane topcoat. The polyurethane topcoat provides excellent resistance to corrosion, abrasion, chemicals and impact.

The 9402 primer was homogenized and sprayed, then cured overnight at ambient conditions. Following, the topcoat was sprayed and cured at room temperature. The resulting coating was approximately 2 mils thick.

- #20269: PR-319, Products Research and Chemical Corp.

This coating, a one part moisture cure polyurethane coating, is based on a tough propriety chemical called Permapol[®]. It is formulated to resist long term exposure to weather and industrial atmospheres. It offers excellent adhesion characteristics to many substrates without primer or elaborate surface preparation.

Following homogenization, the coating was sprayed, then cured at room temperature. The resulting coating was 2 mils thick.

- #20270: Bitumastic 300-M, Koppers Co. Inc.

This coating is a two part coal tar epoxy. It will serve as the control for the corrosion testing portion of this program.

Components A and B were mixed until homogenous. The A/B ratio was 4:1 by volume. The mix required dilution with a 5:1 ratio of coating to diluent. The diluent consisted of a 50/50 solution of (MEK) and toluene. Panels and discs were sprayed and cured under ambient conditions. The resulting coating was 4 mils thick.

- #20271: 1-2577 Conformal Coating, Dow Corning

This silicone coating is being evaluated due to its low surface energy or low friction surface. In order to spray, the coating required dilution with a 25 weight percent loading of toluene. Since the coating is a moisture cure, it was cured at room temperature. The resulting coating was 2 mils thick.

- #20273: Xylan 1070, Whitford Corporation

This coating is described as fluorocarbons in matrix of polymers to make a composite of combined good properties - low friction, release, chemically inert, tough, durable, wear and weather resistant. Corrosion resistant, with good adhesion to metals.

The coating was sprayed, dried, then fused for 10 minutes at 440°F resulting in a 1 mil coating.

- #20274: Dacromet 320 and Plus, Metal Coatings International, Inc.

This system consists of a coating and topcoat. Dacromet 320 is a corrosion resistant coating composition composed of an aqueous coating dispersion containing chromium, proprietary organics and zinc flake. Plus is an inorganic sealer applied over Dacromet 320. Together these coatings function synergistically to enhance corrosion protection. This coating was applied to our panels and discs by the manufacturer.

- #20275: 750-B-3, Chrysler Chemical Division

This coating is described as a black water based dip coating. Prior to application, the coating was agitated for approximately 2 hours. In order to apply a 1 mil coating, it was diluted with 10 percent water prior to application.

The coating was air dried several days, followed by a post cure for 1 hour at 220°F.

- #20276: Pitt-Guard 145 DTR Coating, PPG

This coating is a one coat, self priming high build barrier type coating for metal substrates. It is based on a two component polyamide-epoxy.

The coating components were mixed in equal volumes, then diluted with a 50:50 mixture of MEK/Toluene at a 3:1 ratio of coating to solvent. The coating was sprayed to a 3 mil thickness and air cured.

- #20277: Synthex Pipe Coating 588-J-023, DeSoto, Inc.

This coating was described to us as a solvent based alkyd coating. The coating was applied as received, and air dried to a 1 mil thickness.

- #20278: Integral Fuel Tank Coating, DeSoto, Inc.

This polyurethane coating system consists of 3 components, an isocyanate, a resin and a thinner. A 1 mil coating was applied and allowed to cure several days prior to testing at room temperature.

- #20283: Porcelain Enamel Coating XG-620, Ferro Corp.

Ferro Corporation applied a high temperature enamel coating, which they felt was suitable for tactical pipelines, to panels and discs for our evaluation. The resulting coating was 6 mils thick.

- #20284: Fluoroshield, W.L. Gore and Associates, Inc.

This coating is based on fluorocarbon chemistry. It exhibits the important properties of fluorocarbon polymers including chemical inertness, broad temperature range, non-contaminating, low coefficient of friction, excellent release characteristics, and low dielectric coefficients.

Gore & Associates applied their coating on our panel and discs for evaluation. The resulting coating is 35 mils thick.

- #20285 : Halar Coating, Austi Mont Compo; formerly Allied Engineering Plastics

This coating is a powder coating based on a ethylene chlorotri-fluoroethylene copolymer. This coating offers advantages of chemical resistance, micro-smooth surface, ultra high purity and low permeability.

A 10 mil coating was applied to our panels and discs by the manufacturer for evaluation.

Prior to testing, each coated panel was allowed sufficient cure time exceeding the recommended cure schedules provided by each coating manufacturer. Testing consisted of subjecting individual coated panels to each of the following chemical exposures.

- Salt Spray - ASTM B117

Two panels of each coating, one crosshatched, one as is, were subjected to a two week salt spray exposure at 95°F using a 5 percent salt concentration.

- Jet Fuel Immersion

Crosshatched panels of each coating were immersed in JP-5 jet fuel for two weeks at 70°F.

- H₂O Immersion

Crosshatched panels of each coating were immersed in deionized water for two weeks at 70°F.

Following each of these chemical exposures, each coating was rated for its degree corrosion inhibition using a scale of 0-5. Zero indicates the coating afforded no corrosion resistance while 5 indicates complete corrosion inhibition. Additionally, those panels exposed to JP-5 and water immersions were rated for their degree of adhesion to the steel panel versus an unexposed control panel by means of knife-prying. Table 1 indicates the results of these tests.

As a control for these evaluations, coating #20270, Bitumastic 300-M a coal tar epoxy was simultaneously evaluated. As indicated in Table 1, the overall corrosion characteristics of this control rated 14 out of a possible 15 points. These points equal the sum of the corrosion ratings for each chemical exposure. Additionally, the coal tar coating demonstrated excellent adhesion following each immersion test.

As a result of these tests, seven coatings can be recommended as having corrosion and adhesion properties similar to, or equal to, the coal tar control. Three of these coatings rated with corrosion inhibition values of 15 points and demonstrated excellent adhesion to steel. They include:

- #20274 Dacromet 320 and Plus
- #20278 Integral Fuel Tank Coating
- #20285 Halar Powder Coating

The four remaining coatings demonstrated equal corrosion inhibition characteristics to the coal tar along with good to excellent adhesion characteristics. Those coatings qualifying with corrosion inhibition values of 14 points include:

#20252 Glid-Guard Chemical Resistant Epoxy
#20259 Sikkens Zinc Dust Primer
#20283 Ferro Porcelain Enamel XG-620
#20284 Fluoroshield Coating

Therefore these seven coatings which may be coated on both internal, as well as external, pipe surfaces are recommended based on Task 2 testing.

C. Task 3: Initial Screening For Friction Reduction

This task as detailed in our proposal was to screen each candidate coating for its frictional characteristics when in contact with deionized water, and also JP-5 jet fuel. To accomplish this, we proposed coating standard steel discs machined from QD-612 Standard Steel Q Panels. Several hundred discs were machined at 5.5 inch diameters x 0.020 inches.

Each coating from Task 1 was applied to these discs in a manner similar to the applications described in Task 2. However, these discs were rotated during the coating application to insure a uniform coating thickness.

Following cure, each disc was to be evaluated for friction differentials versus an uncoated control as stated in the proposal. Unfortunately, our original described test method was not sensitive enough to distinguish differences between coated and uncoated discs spun at speeds up to 100 RPM using a Brookfield viscometer. Therefore, a new test method was developed.

The newly developed test method was able to rotate coated and uncoated discs at velocities ranging to several thousand RPM while submerged in a liquid test medium. Frictional determinations were made in both polar and non-polar liquids, deionized water and JP-5 jet fuel respectively.

Each frictional determination was performed by immersing a rotating disc into a cylindrical container mounted on a semi-frictionless turntable. The cylindrical container contained 1000 mls of either deionized water or JP-5 jet fuel depending on the test.

Uncoated control discs, as well as the coated discs, were spun at 1000, 2000, and 2500 RPM. As a means for measuring surface drag or friction across the coating surface, duplicate measurements of the tangential force imparted to the turntable were recorded at each RPM for each rotating disc. The percent increase or decrease in tangential force is felt to be directly related to the amount of drag created by the coating to the fluid medium versus an uncoated panel. Therefore, this percentage indicates increases or decreases in surface friction when rotated in each liquid medium. A schematic in Figure 1 illustrates the device used to determine differences in friction coefficients.

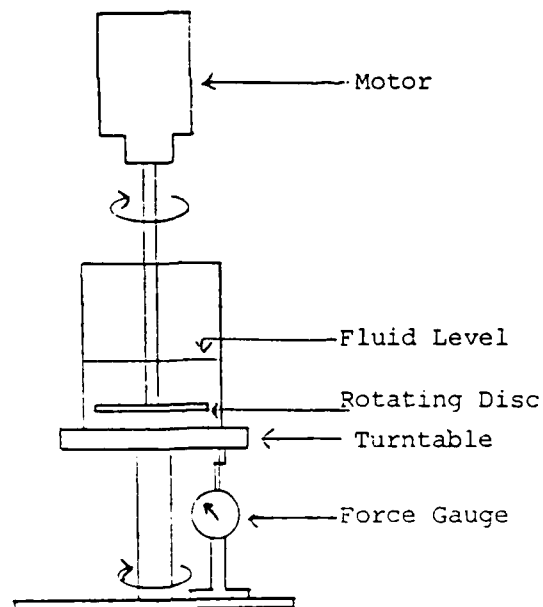


Figure 1: Rotating Disc Friction Measuring Device

Table 2 contains the friction characteristics of the commercial coatings from Task 1 in H₂O.

Table 3 contains the friction characteristics of the commercial coatings from Task 1 in JP-5 jet fuel.

As indicated in Table 2, only four coatings demonstrated average reductions in friction when spun in deionized water at 1000, 2000 and 2500 RPM. They are indicated below along with their degree of friction reduction versus an uncoated steel control.

#20256	Impreglon 218	- 8.1 % reduction
#20261	Xylan 1014	- 2.4 % reduction
#20263	P/C #9100 Epoxy Topcoat	- 2.2 % reduction
#20271	1-2577 Conformal Coating	- 1.6 % reduction

However, eleven coatings as indicated in Table 3 demonstrated average reductions when spun in JP-5 jet fuel at 1000, 2000, and 2500 RPM. Each is indicated below along with its percent reduction versus an uncoated steel control.

#20271	1-2577 Conformal Coating	- 10.9% reduction
#20252	Glid-Guard Epoxy	- 8.8% reduction
#20256	Impreglon 218	- 7.3% reduction
#20269	PR-319	- 7.3% reduction
#20261	Xylan 1014	- 6.2% reduction
#20257-1	Chemglaze 9965 Epoxy Primer	- 5.9% reduction
#20278	Integral Fuel Tank Coat- ing	- 5.5% reduction
#20277	Synthex Pipe Coating	- 5.3% reduction
#20258	Tankguard #3	- 4.3% reduction
#20276	Pitt-Guard #145 DTR Coat- ing	- 3.5% reduction
#20274	Dacromet 320 and Plus	- 0.5% reduction

Referring back to Task 2, seven of the twenty-five coatings evaluated demonstrated the corrosion and adhesion characteristics required for tactical pipeline protection. Of these seven coatings, three were qualified in Task 3 as demonstrating reduced friction when in contact with JP-5 jet fuel. (However, none of which qualified when in contact with deionized water.)

Since tactical pipelines are primarily used for transporting fuels, we recommend the following coatings based on the Task 1 and 2 results.

#20252 Glid-Guard Epoxy
#20278 Integral Fuel Tank Coating
#20274 Dacromet 320 and Plus

Reynolds numbers were calculated for each test velocity in both deionized water and JP-5 jet fuel. The calculated values are outlined below. An outline of the calculation is described in Appendix 2.

<u>RPM</u>	<u>Re in JP-5</u>	<u>Re in H₂O</u>
1000	451,108	724,000
2000	902,216	1,448,000
2500	1,127,769	1,810,000

In addition, flow rates and Reynolds numbers were calculated for 5, 10 and 15 miles of tactical pipelines transporting JP-5 jet fuel using a 6 inch I.D. pipe and an initial pressure of 650 psi. These values assume the pipeline to be open ended. Each value is reported below, with calculations outlined in Appendix 3.

<u>Pipeline Length</u>	<u>Velocity</u>	<u>Reynolds Number</u>
5 miles	12 ft/sec	350,000
10 miles	8.2 ft/sec	240,000
15 miles	6.7 ft/sec	195,000

D. Task 4: Friction Reduction With Internal Additives

This task involved the reformulation of two candidate coatings with select organic and inorganic additives to determine if friction reduction can be accomplished through reformulation.

Coatings 20252 and 20259, Glid-Guard Epoxy and Sikkens Zinc Dust Primer respectively, were reformulated utilizing 20 different additives as outlined in Table 4. Both coatings are two component epoxy systems. Prior to coating, each was formulated to contain each additive in the resin component. Following this addition, the resin and additive were tumbled end over end for 24 hours to insure a homogeneous dispersion. The dispersion was then combined with component B and sprayed onto panels and discs.

Following cure, 13 of the 20 additives produced smooth textured surfaces in the Glid-Guard formulations. Therefore, only these additives were evaluated in the Sikkens Coating. Sample discs of each were evaluated for percent change of friction coefficients, while panels were evaluated for corrosion characteristics.

Tables 5 and 6 outline differences in friction coefficients for each reformulated Glid-Guard Epoxy coating versus the 20252 control. Table 5 indicates the results of testing in deionized water, while Table 6 is JP-5 Jet Fuel data.

As indicated, 6 of the reformulated coatings demonstrated average friction reductions at 1000, 2000, and 2500 RPM in deionized water. However, increases were observed in the JP-5 jet fuel testing. Those demonstrating friction reductions in deionized water are indicated as follows:

#20282-7	5% LPS 885	- 6.9% reduction
#20282-5	2.5% 9381 Emery	- 6.2% reduction
#20282-2	5% Kant Stik FX7	- 4.0% reduction
#20282-1	5% Isolube ON	- 2.6% reduction
#20280-5	5% TL-115	- 1.5% reduction
#20282-3	5% Kant Stik SP-48	- 0.7% reduction

Tables 7 and 8 outline differences in friction coefficients for each reformulated Sikkens Zinc Dust Primer Coating versus the 20259 control in deionized water and JP-5 jet fuel, respectively.

As indicated in Table 7, eight reformulated coatings demonstrated friction reductions when evaluated in deionized water. These coatings and reductions are indicated below.

#20287-2	5% Slip-eze	- 6.3% reduction
#20287-8	5% TL-115	- 4.8% reduction
#20287-6	5% .85 Fluorinated Graphite	- 3.4% reduction
#20287-7	5% 1.0 Fluorinated Graphite	- 3.4% reduction
#20287-13	5% Isolube ON	- 3.4% reduction
#20287-14	5% Kant Stik FX7	- 2.4% reduction
#20287-17	2.5% 9381 Emery	- 2.4% reduction
#20287-12	5% Calcium Stearate Powder	- 1.6% reduction

As outlined in Table 8, six reformulated coatings demonstrated slight friction reductions when evaluated in JP-5 jet fuel. Each is indicated below with its respective reduction.

#20287-15	5% Kant-Stik SP-48	- 2.8% reduction
#20287-8	5% TL-115	- 1.8% reduction
#20287-14	5% Kant-Stik FX7	- 1.4% reduction
#20287-6	5% .85 Fluorinated Graphite	- 0.2 % reduction
#20287-9	5% TL-126	- 0.1% reduction
#20287-13	5% Isolube ON	- 0.1% reduction

Based on the data from Tables 5, 6, 7 and 8, it appears that the friction reductions are quite random for each additive. Each additives effects do not reproduce in different coatings when evaluated under similar conditions. However, since some effect does exist, it may prove practical as a cost savings means for reducing coatings surface friction. Though based on this data, extensive experimentation would be required to develop this concept in a predictable manner.

As a further means of qualifying these reformulated coatings for tactical pipeline applications, each was evaluated for its corrosion inhibition characteristics. Coated panels were subjected to a 2 week salt spray exposure as outlined in Task 2. These results are outlined in Table 9.

As indicated in Table 9, nearly every reformulated coating demonstrated poorer corrosion resistance than either of the control coatings. However, there were three exceptions where the reformulated coatings demonstrated similar corrosion characteristics to the control. These coatings 20280-1, 20282-1 and 20282-7 contained 5 percent .85 fluorinated graphite, 5 percent Isolube ON and 5 percent LPS 885 respectively. Unfortunately none of these coatings exhibited reduced friction when tested in JP-5 jet fuel.

Based on this task's results, significant reformulation and experimentation is required to develop reformulated coatings which offer equal or greater advantage over those selected from Tasks 2 and 3.

E. Task 5: Friction Reduction by Fluorination of the Coating

This task was designed to determine the feasibility of reducing a coating's surface energy by direct exposure to fluorine gas. Since low energy surfaces are both hydrophobic and oleophobic, they form a high contact angle with, and are not wet by, fluids. We believe the surface friction would be reduced. Some of the lowest surface energy materials are found in the fluorine containing polymers.

The mechanism of fluorination consists of a fluorine atom replacing the hydrogen of a C-H bond or adding across a double bond of a polyolefin. The result is a modified surface possessing a lower surface energy, i.e., a lower friction surface.

Due to the toxic nature of fluorine gas we elected to have Air Products and Chemicals, Inc. perform the fluorine coating exposures. They suggested treatments under three different conditions, identified as 8717-XX. These treatments were based on their past experience in reducing the coefficient of friction. Unfortunately, their treatments are of a proprietary nature and were not detailed to us.

Air Products and Chemicals were provided with three different commercial coatings evaluated in Tasks 2 and 3 for exposure. The submitted samples are outlined below:

<u>I.D. No.</u>	<u>Coating Name</u>	<u>Coating Type</u>	<u>Manufacturer</u>
20259	463-6-40 Zinc Dust Primer	Two component epoxy polyamide	Sikkens Aerospace Finishes Division, Akzo Coating America, Inc.
20260	Epoxy Ester 1207	Epoxy Ester	Cargill, Inc.
20269	PR-319	Polyurethane	Products Research & Chemical Corporation

Following return of the exposed samples, each was evaluated for changes in friction coefficients versus unexposed controls as previously described. The results of these exposures are contained in Table 10. As indicated, these exposures produced increases or minimal changes in coefficients of friction, therefore without further investigation, coating fluorination is not recommended for friction reduction based on this data.

III. CONCLUSION AND RECOMMENDATIONS

Based on the data generated during this Phase I SBIR program, we conclude the following:

- Seven commercial coatings offered corrosion and adhesion properties equal to, or greater than, that of a coal tar epoxy control.
- Four commercial coatings demonstrate lower coefficients of friction than steel when in contact with deionized water.
- Eleven commercial coatings demonstrate lower coefficients of friction than steel when in contact with JP-5 jet fuel.
- Feasibility does exist for reformulating commercial coatings to reduce friction, however a great deal of further experimentation is required for coating optimization.
- Reduction of friction coefficient by surface fluorination was not demonstrated based on the available data.
- Three commercially available coatings demonstrate excellent corrosion inhibition characteristics as well as friction advantages over experimental controls. These coatings are:
 - #20252 Glid-Guard Chemical Resistant Epoxy
 - #20278 Integral Fuel Tank Coating
 - #20274 Dacromet 320 and Plus

As a further course of action to be continued in a Phase II effort we recommend the following.

- Scale experimentation up to 20 foot pipe sections.
- Set up an experimental test loop for each coating to accurately determine coefficients of friction as well as performing evaluations under "in use" conditions.

- Extend coating evaluation studies i.e. coating wear, outdoor aging, accelerated life tests, impact testing, etc.

TABLE 1
TASK 2. INITIAL SCREENING OF CORROSION COATINGS

Sample I.D.	Generic Type	Coating Thickness (mils)	Corrosion Characteristics*			Adhesion Characteristics			Comments
			Salt Spray 2 wks.	H ₂ O 2 wks.	JP-5 2 wks.	Control	H ₂ O 2 wks.	JP-5 2 wks.	
20270	Coal Tar Epoxy	3.5	4	5	5	excellent	excellent	excellent	some rusting at edges and etch marks
20251	Synthetic rubber	1	1	5	5	excellent	excellent	excellent	salt spray samples rusted exhibiting flaking and brittleness
20252	Epoxy-Polyamide	3	4-3	5	5	excellent	good	excellent	one salt spray sample exhibited peeling
20256	Fluoropolymer Treatment	1.5	2	4	5	excellent	excellent	excellent	salt spray samples exhibit corrosion at edges, signs of peeling
20258	Epoxy-Polyamide Primer	4	1	4	5	good	fair	excellent	coating fell off following salt spray exposure
20259	Epoxy-Polyamide Primer	3	4	5	5	excellent	good	excellent	slight rusting at edges following salt spray exposure
20260	Epoxy Ester	2	2	3	5	good	good	good	coating turned white and exhibited corrosion following salt spray exposure
20261	Polytetrafluoroethylene	2	1	4	5	excellent	excellent	excellent	salt spray sample exhibited chipping, bubbling and rusting
20262	Epoxy Ester	1	1	4	5	excellent	excellent	coating dissolved	coating slowly disintegrated in salt spray
20263	Epoxy-Polyamide	1	1	3	5	fair	fair	good	coating became brittle in salt spray
20264	Wax	1	1	3	5	excellent	excellent	coating dissolved	should be evaluated as a low friction additive
20266	Epoxy	7	3	5	5	excellent	excellent	excellent	coating delaminated off panels following salt spray
20267-1	Epoxy-Polyamide Primer	2	1	3	5	excellent	none	excellent	coating delaminated following salt spray and water immersion
20267-2	Epoxy-Polyamide Primer/Aliphatic Polyurethane topcoat	2.5	3	3	5	excellent	none	excellent	coating exhibited delamination following water immersion
20268-2	Urethane Primer/Aliphatic Polyurethane topcoat	2	2	4	5	fair	poor	fair	coating blistered following salt spray exposure
20269	Polyurethane	2	1-2	5	5	excellent	excellent	excellent	salt spray exposure caused blistering, embrittlement, and delamination
20271	Silicone	2	1	2	5	excellent	excellent	excellent	coating partially dissolved during JP-5 exposure
20273	Polytetrafluoroethylene	1	1	4	5	excellent	excellent	excellent	corrosion and blistering occurred after salt spray exposure
20274	Aqueous dispersion	0.5	5	5	5	excellent	excellent	excellent	
20275	Black Water Based Dip Coating	1	0	3	5	excellent	excellent	excellent	coating is totally corroded
20276	Polyamide-Epoxy	3	1	5	5	excellent	fair	excellent	coating peeled off following salt spray
20277	Alkyd	1	0	3	5	fair/good	poor	fair/good	coating blistered and flaked during water immersion
20278	Polyurethane	1	5	5	5	excellent	excellent	excellent	
20283	Porcelain Enamel	6	4	5	5	excellent	excellent	excellent	slight corrosion on edges following salt spray exposure
20284	Fluoropolymer	15	4	5	5	excellent	good	excellent	slight corrosion on edges following salt spray exposure
20285	Fluoropolymer	10	5	5	5	excellent	excellent	excellent	

*Samples rated 0-5: 0 equals worst; 5 equals best

TASK 3: FRICTION CHARACTERISTICS OF COMMERCIAL COATINGS
vs UNCOATED STEEL IN H₂O

<u>SAMPLE</u>	<u>%</u> <u>1000 RPM</u>	<u>%</u> <u>2000 RPM</u>	<u>%</u> <u>2500 RPM</u>	<u>%</u> <u>AVERAGE</u>
20251	0.0	- 0.9	+ 4.1	+ 1.1
20252	0.0	+ 1.7	+ 3.4	+ 1.7
20256	-15.0	- 5.1	- 4.2 ⁽⁵⁾	- 8.1
20258	+ 4.5	0.0	+ 2.0	+ 2.2
20259	+ 2.4	+ 2.6	+ 6.1	+ 3.7
20260	0.0	0.0	+ 0.7	+ 0.2
20261	- 7.1	- 0.9	+ 0.7	- 2.4
20262 ⁽¹⁾				
20263	- 7.1	- 0.9	+ 1.4	- 2.2
20266	+ 4.5	+ 2.6	+ 5.4	+ 4.2
20267-1	+ 2.4	0.0	+ 2.0	+ 1.5
20269	+ 3.3	0.0	- 0.4 ⁽⁵⁾	+ 1.0
20271	- 4.5	- 1.7	+ 1.4	- 1.6
20273	+ 7.1	- 1.7	0.0	+ 1.8
20274	+10.0	- 2.6	- 3.2 ⁽⁵⁾	+ 1.4
20275 ⁽²⁾				
20276	+ 9.5	+ 4.3	+ 4.1	+ 6.0
20277	+ 9.5	- 2.6	0.0	+ 2.3
20278	+ 9.5	- 1.7	+ 0.7	+ 2.8
20283 ⁽⁴⁾				
20284 ⁽³⁾				
20285	+ 7.1	+ 2.6	+ 3.4	+ 4.4
20286	+ 9.5	- 1.7	+ 0.7	+ 2.8

(1) Coating deformed upon storage

(2) Coating was not suitable for friction measurements

(3) Coating is too thick for testing

(4) Disc warped during coating cure cycle

(5) Extrapolated from 1000, 2000, and 3000 RPM values

**TASK 3: FRICTION CHARACTERISTICS OF COMMERCIAL COATINGS
vs UNCOATED STEEL IN JP-5 JET FUEL**

<u>SAMPLE</u>	<u>% 1000 RPM</u>	<u>% 2000 RPM</u>	<u>% 2500 RPM</u>	<u>% AVERAGE</u>
20251	- 2.7	+ 6.7	+ 6.1	+ 3.4
20252	0.0	-13.8	-12.7 ⁽⁵⁾	- 8.8
20256	- 2.1	- 9.6	-10.2 ⁽⁵⁾	- 7.3
20258	- 2.1	- 4.8	- 5.9 ⁽⁵⁾	- 4.3
20259	- 2.7	+ 6.7	+ 4.4	+ 2.8
20260	- 2.7	+ 6.7	+ 4.4	+ 2.8
20261	0.0	- 9.0	- 9.7	- 6.2
20262 ⁽¹⁾	-	-	-	-
20263	0.0	+ 3.3	+ 7.0	+ 3.4
20266	- 2.7	+ 8.9	+ 7.0	+ 4.4
20267-1	+ 6.2	- 9.0	-15.0 ⁽⁵⁾	- 5.9
20269	+10.4	-15.2	-17.0 ⁽⁵⁾	- 7.3
20271	+10.4	-15.2	-28.0 ⁽⁶⁾	-10.9 ⁽⁷⁾
20273	-10.8	+11.1	0.0	+ 0.1
20274	0.0	0.0	- 1.4	- 0.5
20275 ⁽²⁾	-	-	-	-
20276	-13.5	+ 2.2	+ 0.9	- 3.5
20277	- 8.1	+ 1.1	- 8.8	- 5.3
20278	-13.5	- 2.2	- 0.9	- 5.5
20283 ⁽³⁾	-	-	-	-
20284 ⁽⁴⁾	+37.5	-	-	-
20285	- 2.7	+ 4.4	+ 8.8	+ 3.5
20286	+13.5	+ 2.2	- 0.9	+ 4.9

(1) Coating deformed upon storage

(2) Coating was not suitable for friction measurements

(3) Coating is too thick for testing

(4) Disc warped during coating cure cycle

(5) Extrapolated from 1000, 2000, and 3000 RPM values

(6) Extrapolated from 1000 and 2000 RPM values

(7) Average may be unrealistically high as per item (6)

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TABLE 4

TASK 4: COMMERCIAL COATING REFORMULATIONS

<u>Glid Guard Epoxy</u>	<u>Sikkens Zinc Dust Primer</u>	<u>Additive, Concentration and Generic Type</u>
20279-1 (1)		0.5% Tullanox 500 Fumed amorphous silica powder hydrophobed with an organic silicone-like compound
20279-2	20287-2	5.0% Slip-eze An internal lubricant for polymer processing
20279-3 (1)		5.0% Eramide An internal lubricant for polymer processing
20279-4 (1)		5.0% Vyn-eze An internal lubricant for polymer processing
20279-5	20287-5	5.0% Molybdenum Sulfide A common organic solid lubricant
20280-1	20287-6	5.0% Fluorinated Graphite and Carbon Ratio 0.85 fluorocarbon lubricant
20280-2	20287-7	5.0% Fluorinated Graphite and Carbon Ratio 1.0 fluorocarbon lubricant
20280-5	20287-8	5.0% TL-115 Tetrafluoroethylene general lubricant
20281-1	20287-9	5.0% TL-126 A white polytetrafluoroethylene general lubricant
20281-2 (1)		5.0% TL-120 A white fluorinated ethylene propylene powder
20281-3 (1)		5.0% Zinc Stearate Dispersion A common processing lubricant
20281-4	20287-11	5.0% Zinc Stearate Powder A common processing lubricant
20281-5 (1)		5.0% Calcium Stearate Dispersion A common processing lubricant
20281-6	20287-12	5.0% Calcium Stearate Powder A common processing lubricant
20282-1	20287-13	5.0% Isolube ON A polymeric non-volatile internal lubricant
20282-2	20287-14	5.0% Kant-Stik FX7 A micronized crystalline aliphatic hydro- carbon powder
20282-3	20287-15	5.0% Kant-Stik SP-48 A micronized crystalline aliphatic hydrocarbon powder
20282-4 (1)		2.5% 9380 Emery An additive containing fatty lubricating groups
20282-5	20287-17	2.5% 9381 Emery An additive containing fatty lubricating groups
20282-6 (1)		2.5% 9382 Emery An additive containing fatty lubricating groups
20282-7	20287-19	5.0% LPS 885 A rust inhibitor additive

(1) Additive produced a rough surface, therefore it was not further reformulated.

TABLE 5

TASK 4: FRICTION CHARACTERISTICS OF REFORMULATED GLID-GUARD
EPOXY COATINGS vs A CONTROL GLID-GUARD EPOXY COATING
IN H₂O

<u>SAMPLE</u>	<u>%</u> <u>1000 RPM</u>	<u>%</u> <u>2000 RPM</u>	<u>%</u> <u>2500 RPM</u>	<u>%</u> <u>AVERAGE</u>
20279-2	+ 7.7	+ 1.1	- 4.0	+ 1.6
20279-5	+10.2	0.0	- 3.3	+ 2.3
20280-1	+ 7.7	+ 2.0	- 0.7	+ 3.0
20280-2	+12.8	+ 3.9	- 2.7	+ 4.7
20280-5	+ 5.1	+ 1.1	-10.7	- 1.5
20281-1	+ 7.7	+ 3.8	- 1.3	+ 3.4
20281-4	+10.2	+ 4.8	+ 6.0	+ 7.0
20281-6	+17.9	+ 2.9	- 2.0	+ 6.3
20282-1	- 8.7	+ 1.7	- 0.8	- 2.6
20282-2	- 8.7	0.0	- 3.3	- 4.0
20282-3	- 8.7	+ 5.0	+ 1.7	- 0.7
20282-5	-10.9	- 2.5	- 5.2	- 6.2
20282-7	-15.2	- 1.7	- 3.9	- 6.9

TABLE 6

TASK 4: FRICTION CHARACTERISTICS OF REFORMULATED GLID-
GUARD EPOXY COATINGS vs A CONTROL GLID-GUARD
EPOXY COATING IN JP-5

<u>SAMPLE</u>	<u>%</u> <u>1000 RPM</u>	<u>%</u> <u>2000 RPM</u>	<u>%</u> <u>2500 RPM</u>	<u>%</u> <u>AVERAGE</u>
20279-2	- 5.5	+ 7.2	+ 8.6	+ 3.4
20279-5	0.0	+ 8.5	+ 8.6	+ 5.7
20280-1	- 2.8	+ 5.9	+11.5	+ 4.9
20280-2	- 5.5	+ 7.2	+11.5	+ 4.4
20280-5	- 5.5	+15.0	+18.5	+ 9.3
20281-1	- 8.3	+13.7	+27.5	+11.0
20281-4	+16.7	+10.0	+13.6	+13.4
20281-6	+13.9	+11.1	+10.1	+11.7
20282-1	+16.7	+12.2	+13.6	+14.2
20282-2	- 2.8	+ 7.7	+13.6	+ 6.2
20282-3	+ 8.3	+12.2	+18.1	+12.9
20282-5	+ 8.3	+ 8.9	+10.1	+ 9.1
20282-7	+13.9	+10.0	+10.1	+11.3

TASK 4: FRICTION CHARACTERISTICS OF REFORMULATED
SIKKENS ZINC DUST PRIMER COATINGS vs A
CONTROL SIKKENS ZINC DUST PRIMER COATING
IN H₂O

<u>SAMPLE</u>	<u>%</u> <u>1000 RPM</u>	<u>%</u> <u>2000 RPM</u>	<u>%</u> <u>2500 RPM</u>	<u>%</u> <u>AVERAGE</u>
20287-2	- 4.2	- 5.4	- 9.3	- 6.3
20287-5	+ 2.1	+ 8.2	+ 4.7	+ 5.0
20287-6	- 2.1	- 2.7	- 5.3	- 3.4
20287-7	- 8.3	0.0	- 2.0	- 3.4
20287-8	- 8.3	- 2.7	- 3.3	- 4.8
20287-9	+ 2.1	+ 2.7	+ 1.3	+ 2.0
20287-11	- 4.2	+ 4.5	+ 6.0	+ 2.1
20287-12	- 4.2	0.0	- 0.7	- 1.6
20287-13	- 4.2	- 2.7	- 3.3	- 3.4
20287-14	- 4.2	- 0.9	- 2.0	- 2.4
20287-15	- 2.1	+ 5.4	+ 2.0	+ 1.8
20287-17	- 8.3	+ 1.8	- 0.7	- 2.4
20287-19	- 4.2	+ 8.2	+ 6.0	+ 3.3

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TABLE 8

TASK 4: FRICTION CHARACTERISTICS OF REFORMULATED SIKKENS
ZINC DUST PRIMER COATINGS vs A CONTROL SIKKENS ZINC
DUST PRIMER COATING IN JP-5

<u>SAMPLE</u>	<u>% 1000 RPM</u>	<u>% 2000 RPM</u>	<u>% 2500 RPM</u>	<u>% AVERAGE</u>
20287-2	+10.5	+ 2.0	+ 7.9	+ 6.8
20287-5	- 2.6	0.0	+ 7.9	+ 1.8
20287-6	+ 2.6	- 4.0	+ 0.8	- 0.2
20287-7	+ 2.6	- 4.0	+ 3.2	+ 0.6
20287-8	+ 2.6	- 4.9	- 3.2	- 1.8
20287-9	+ 2.6	- 2.0	- 0.8	- 0.1
20287-11	+10.5	0.0	+ 5.5	+ 5.3
20287-12	+ 7.9	- 4.9	- 0.8	+ 0.7
20287-13	+10.5	- 7.9	- 2.4	+ 0.1
20287-14	+ 2.6	- 5.9	- 0.8	- 1.4
20287-15	0.0	- 5.9	- 2.4	- 2.8
20287-17	+10.5	- 2.0	+ 0.8	+ 3.1
20287-19	+ 5.3	- 2.0	+ 0.8	+ 1.4

TABLE 9

TASK 4: SALT SPRAY CHARACTERISTICS OF REFORMULATED COATINGS

<u>Sample I.D.</u>	<u>Additive</u>	<u>Corrosion Characteristics</u> <u>Salt Spray (2 weeks)</u>
20252	Glid-Guard Epoxy (Control)	4 - 3
20279-1	0.5% Tullanox 500	1
20279-2	5.0% Slip-eze	2
20279-3	5.0% Eramide	1
20279-4	5.0% Vyn-eze	1
20279-5	5.0% Molybdenum Sulfide	2
20280-1	5.0% .85 Fluorinated Graphite	4
20280-2	5.0% 1.0 Fluorinated Graphite	3
20280-5	5.0% TFE Powder TL115	2
20281-1	5.0% TFE Powder TL126	1
20281-2	5.0% FEP Powder TL120	2
20281-3	5.0% Zinc Stearate Dispersion	1
20281-4	5.0% Zinc Stearate Powder	2
20281-6	5.0% Calcium Stearate Powder	2
20282-1	5.0% Isolube-ON	4
20282-2	5.0% Kant Stik FX7	2
20282-3	5.0% Kant Stik SP-48	1
20282-4	2.5% #9380 Emery	3
20282-5	2.5% #9381 Emery	2
20282-6	2.5% #9382 Emery	1
20282-7	5.0% LPS 885	4
20259	Zinc Dust Primer (Control)	4
20287-2	5.0% Slip-eze	1
20287-5	5.0% Molybdenum Sulfide	1
20287-6	5.0% .85 Fluorinated Graphite	1
20287-7	5.0% 1.0 Fluorinated Graphite	2
20287-8	5.0% TFE Powder TL115	2
20287-9	5.0% TFE Powder TL126	1
20287-11	5.0% Zinc Stearate Powder	2
20287-12	5.0% Calcium Stearate Powder	1
20287-13	5.0% Isolube-ON	1
20287-14	5.0% Kant Stik FX7	3
20287-15	5.0% Kant Stik SP-48	3
20287-17	2.5% #9381 Emery	1
20287-19	5.0% LPS 885	1

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TABLE 10

TASK 5: FRICTION CHARACTERISTICS OF FLUORINATED COATINGS
vs UNFLUORINATED CONTROLS

<u>SAMPLE</u>	<u>%</u> <u>1000 RPM</u>	<u>%</u> <u>2000 RPM</u>	<u>%</u> <u>2500 RPM</u>	<u>%</u> <u>AVERAGE</u>
<u>Tested in H₂O</u>				
Sikkens Zinc Dust Primer				
A.P. 8717-19 ⁽¹⁾	+ 2.5	+ 7.2	- 0.5	+ 3.1
A.P. 8717-20 ⁽¹⁾	+12.5	- 5.2	- 4.4	+ 1.0
Cargil Epoxy Ester 1207				
A.P. 8717-19 ⁽¹⁾	- 5.1	+ 2.7	0.0	- 0.8
Products Research & Chemical Corp. PR-319				
A.P. 8717-21 ⁽¹⁾	- 1.0	+ 1.0	- 2.3	- 0.8
<u>Tested in JP-5</u>				
Sikkens Zinc Dust Primer				
A.P. 8717-19 ⁽¹⁾	+17.0	- 6.3	- 8.0	+ 0.9
A.P. 8717-20 ⁽¹⁾	+19.9	- 0.6	+ 2.5	+ 7.3
Cargil Epoxy Ester 1207				
A.P. 8717-19 ⁽¹⁾	+25.6	+ 0.3	- 0.5	+ 8.5
Products Research and Chemical Corp. PR-319				
A.P. 8717-21 ⁽¹⁾	- 6.9	+19.0	+32.5	+14.9

(1) Indicates Air Products and Chemicals, Inc.
proprietary exposure method used.

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APPENDIX I

COATING MANUFACTURERS AND SUPPLIERS

Telephone Contacts:

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B.F. Goodrich 500 S. Main Street Akron, OH 44318 Jerry Hurt	(216) 374-2000
Boyd Coatings Research Co., Inc. 24 Parmenter Road Hudson, MA 01749	(617) 562-9622
Carboline Company 350 Hanley Industrial Court St. Louis, MO 63144 Bill Shilling	(314) 644-1000
Cargill, Inc. Chemical Products Division P.O. Drawer 5630 Minneapolis, MN 55440 Al Heitkamp	(612) 475-6502
Chromalloy Research & Technology FAA Repair Station 118-5 Orangeburg, NY 10962 Charles L. Ammann	(914) 359-4700
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APPENDIX 2

REYNOLDS NUMBER DETERMINATION FOR A
SPINNING DISC IN A FLUID MEDIUM

Reynolds number equation:

$$Re = \frac{(\text{Velocity}) (\text{Diameter}) (\text{Density of Liquid})}{(\text{Viscosity of Liquid})}$$

Four parameters must be known, velocity, diameter, liquid density and viscosity of liquid.

(1) Velocity

Rotational velocity must be converted to linear velocity using the following equation:

$$(\text{Rotational Velocity}) \times (\text{Circumference}) = \text{Linear Velocity}$$

A radial point was selected whose linear velocity equaled the average linear velocity of all points along the radius. This point is 1.945 inches from the center of a 5.5 inch disc. A circumference of .31 meters was calculated from a 1.945 inch radius. Inserting this value into the equation for linear velocity reduces that equation to the following relationship.

$$(\text{RPM}) (.31\text{m}) = \text{Linear Velocity in meters/second}$$

Therefore the following linear velocities are calculated:

RPM	Linear Velocity (m/s)
1000	310
2000	620
2500	775
3000	930

- (2) Disc Diameter = 5.5 inches or .14 meters
- (3) The densities and Viscosities for JP-5 Jet Fuel and deionized water are:

JP-5 Jet Fuel	810,000 g/m ³	1.3 cp measured
Water	1,000,000 g/m ³	1 cp reported

Inserting these values into the Reynolds number equation, the following Reynolds numbers were calculated:

<u>RPM</u>	<u>Re JP-5</u>	<u>Re Deionized Water</u>
1000	451,100	733,000
2000	902,200	1,466,000
2500	1,128,000	1,833,000
3000	1,353,000	2,199,000

CALCULATED FLOW RATES AND REYNOLDS NUMBERS FOR JP-5
THROUGH A PIPELINE

The following parameters are known:

Pressure Initial = 650 psi

Pressure at Pipe End = 19.7 psi

Pressure Differential = 630.3 psi

Pipe I.D. = 6 inches

JP-5 Jet Fuel Density = .81 g/cc measured

JP-5 Jet Fuel Viscosity = 1.3 cp measured

It was desired to calculate the flow rates and Reynolds number for JP-5 fuel passing through a pipeline 5 miles, 10 miles, and 15 miles in length.

The fluid velocity and Reynolds number for each case were determined using an iterative procedure based on two equations. The first equation utilized was the Darcy-Weisbach equation for steady incompressible flow through a simple pipe system:

$$\Delta p = f \frac{\Delta L}{2 r_o} \rho \frac{V^2}{2}$$

Where Δp = pressure differential across the pipe

f = fanning friction factor

ΔL = length of pipe

$2 r_o$ = inside of radius of pipe

V = velocity of fluid in pipe

ρ = density of fluid in pipe

In addition, the equation for Reynolds number was used:

$$Re = \frac{D V \rho}{\mu}$$

Where: D = inside diameter of pipe
V = velocity of fluid in pipe
 ρ = density of fluid in pipe
 μ = viscosity of fluid in pipe

Utilizing both equations and the moody diagram (which relates flow rates to friction factors) the method employed is demonstrated for the case of the 5 mile length of pipe line.

- (1) An assumed Reynolds number of 350,000 was used .
- (2) For a $Re = 350,000$ and a relative roughness of 7.5×10^{-5} for a steel surface. A friction factor of .015 was determined using a Moody diagram which relates Reynolds number to Fanning Friction Factor.
- (3) Using the Darcy-Weisbach equation, the known parameters and the Fanning Friction Factor determined from the assumed Reynolds number a value of 3.68 meters/sec is obtained for the velocity of the Jet Fuel in the pipe line.
- (4) A Reynolds number is calculated using the calculated velocity, $Re = 349,754$, this is within 5 percent to the assumed Re , therefore considered reasonably accurate.

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Results

<u>Distance</u>	<u>Velocity</u>	<u>Reynolds No.</u>
5 miles	12 ft/sec	350,000
10 miles	8.2 ft/sec	240,000
15 miles	6.7 ft/sec	195,000

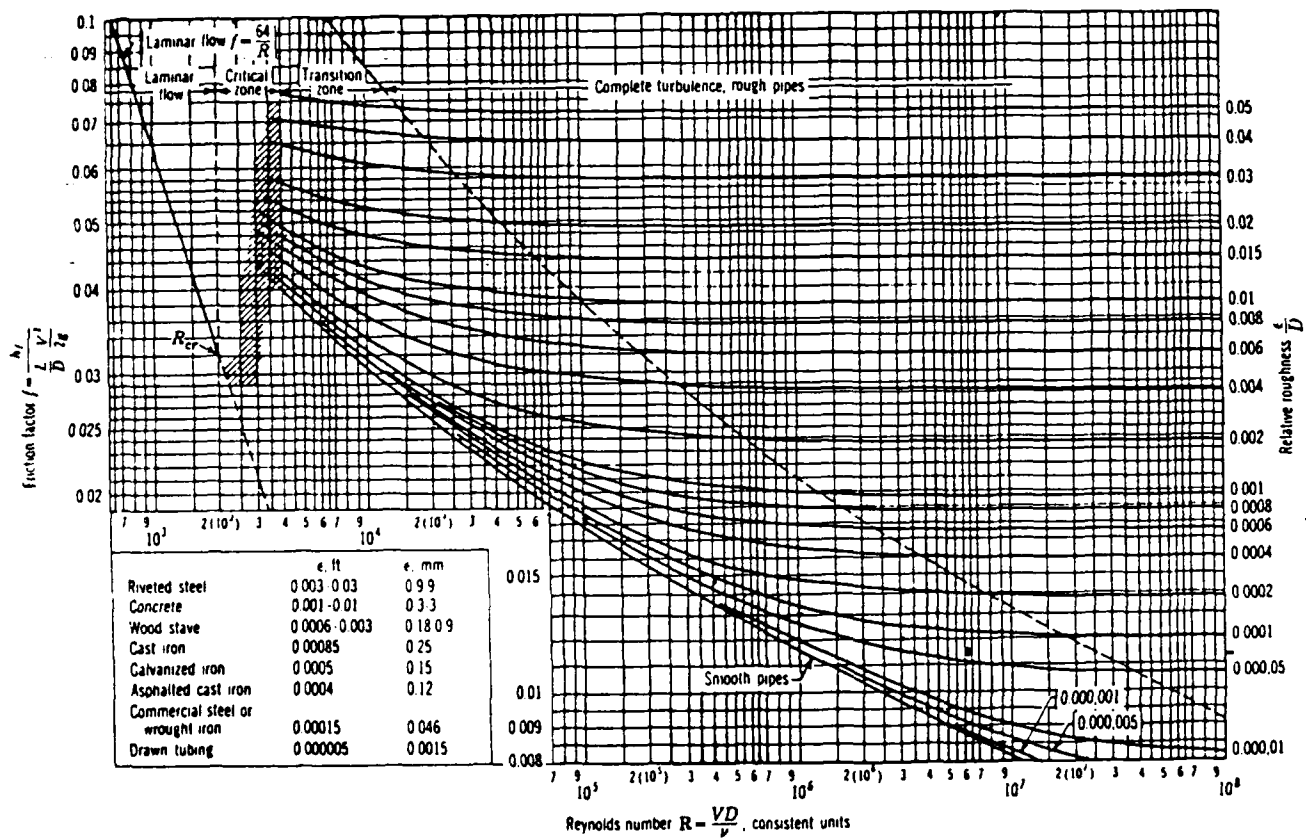


Figure 5.32 Moody diagram.

END

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