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Pipe Behaviour in Bottom Ash Slurry Systems

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Summary

This study presents the results of an 18-year long investigation of pipe deterioration in cyclone slag slurry transport. The goal was to study pipe behaviour in this extremely abrasive service and select an optimum piping material. Comparisons are given for high quality alloy cast steel pipes and pipes lined with cast basalt rings marketed under the name Abresist. Based on the results, thoughts are offered on the broader meanings of certain findings.

1. Introduction

The side product of burning coal in industrial size boilers is a large amount of ash which either falls down within the furnace to the bottom or travels upward with the flue gasses. The widely accepted terminology for these two different types of ash are bottom ash and fly ash (or top ash), respectively.

The bottom ash is a very abrasive substance which is usually transported in water slurry in piping to an adequately located pond. The fly ash is usually less abrasive. At large size coal burning power stations the bottom ash and fly ash transportation systems are usually separated. The bottom ash slurry lines are usually long, varying between a few hundred feet to a few miles. The installation of these pipe lines is expensive.

Rapid deterioration of the bottom ash piping is usually a serious common problem. The quality of the ash — which is an individual characteristic of each boiler and ash system — is one of the most important factors in the process of abrasive deterioration. It was found that cyclone furnace ash is a particularly abrasive substance.

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2. Field Research Results

The results of a field test program of eighteen year duration at two power stations are reported in this paper and a discussion is offered on the major factors of service life.

In the early sixties, rapid erosive-corrosive deterioration occurred at a generating station of an East Coast power company (Atlantic Electric) in a slurry piping system in which bottom ash from a cyclone furnace was transported. A research project was initiated to determine the optimum piping material for this service. The investigation was extended in 1965 to another power station where two slurry piping systems experienced similar problems. Pipe deterioration and replacement data were gathered on pipe behavior from 1963 to the present time in these slurry lines, which are schematically shown in Fig. 1. The top portion depicts the piping of a generating unit at a river water station. The bottom portion represents the piping systems of two generating units at another power station where sea water is utilized.

All three systems are composed of 8" I.D. pipes. The major parameters of all these systems are described in Fig. 2.

In the first phase of this research program four different, top quality, cast iron pipes with promising chemical compositions, heat treatments, high Brinell hardness and extremely heavy wall were installed in series. These pipes are referred to in Fig. 1 by the following code names: "W", "X", "Y", and "Z". All these pipes are still widely used in abrasive-corrosive service conditions and they are still considered the best quality cast iron pipes for this type of service.

Due to severe erosive-corrosive deterioration, all these pipes failed within 2.5 to 4 years in all the above systems. The typical wear patterns are shown in Figs. 3, 4 and 5. When the pipe depicted in Fig. 5 was rotated about 180°, double wear developed at both sides around the horizontal center plane. Due to this double wear, one pipe section, shown in Fig. 6, actually broke into two parts. The extremely rough bottom portion of this pipe section played an important role in this study when the friction coefficient between the pipe and slurry was studied.

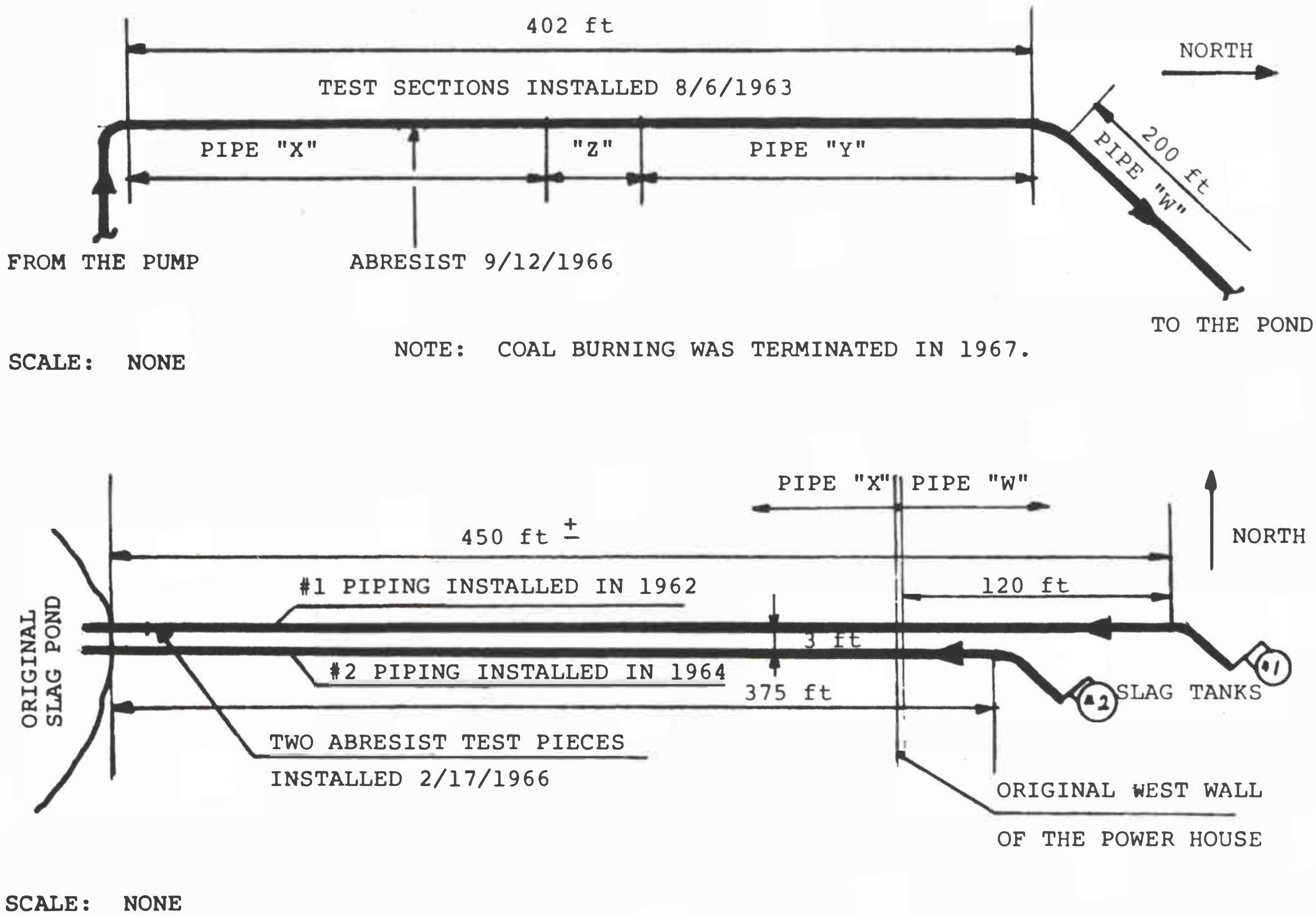

Fig. 1: Slurry piping layout at Deepwater Station # 1 (top) and at B. L. England Station (bottom)

Name of Station		DW	B.L. England	
Unit Number		1	1	2
Rated Capacity	MW	87	132	163
Service Started	Date	2/31/58	10/22/62	11/24/64
Quantity of Slag (Ave.)	T/Month	1300	2700	3000
Nominal I.D. of Slurry Piping	Inch	8	8	8
Length of Pipe (Original)	Ft.	630	480	385
Water Supply Quality		Brackish River	Brackish Sea	
Water Supply	GPM	1470	1200	1200
Operation	Intermittent Continuous	C	I	I
Mixture Ratio: Slag/Water	%	3 - 5	6 - 50	6 - 50
PH of Slurry		4.9 to 5.8	6.3 to 6.7	
Slurry Velocity	FPS	11.5	10.6	12.5
Specific Gravity of Slag (1966 Values)		2	1.9	
Average Particle Size	mm	-	2 - 3	2 - 3

NOTE: All boilers are of B&W with cyclone furnaces.

Fig. 2: Major parameters of slurry systems

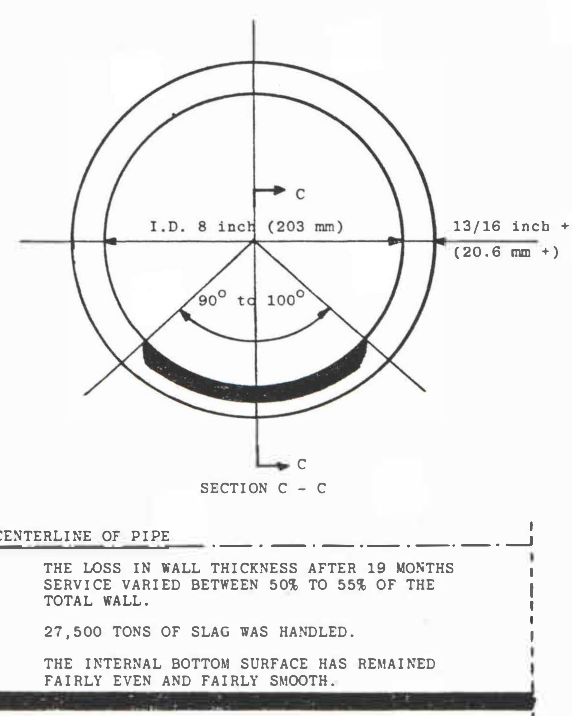

Fig. 3: Typical wear pattern observed in pipes "W", "X", and "Y" at Deepwater Station

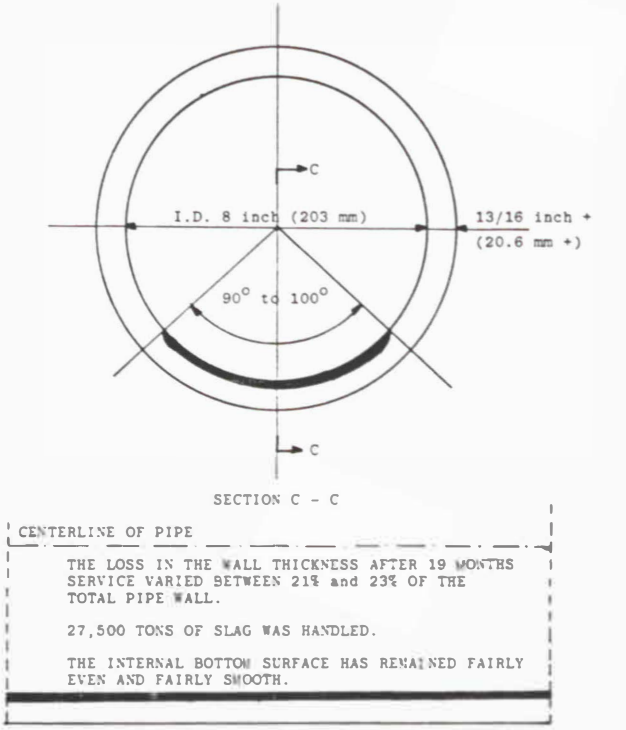

Fig. 4: Typical wear pattern observed in pipe "Z" at Deepwater Station

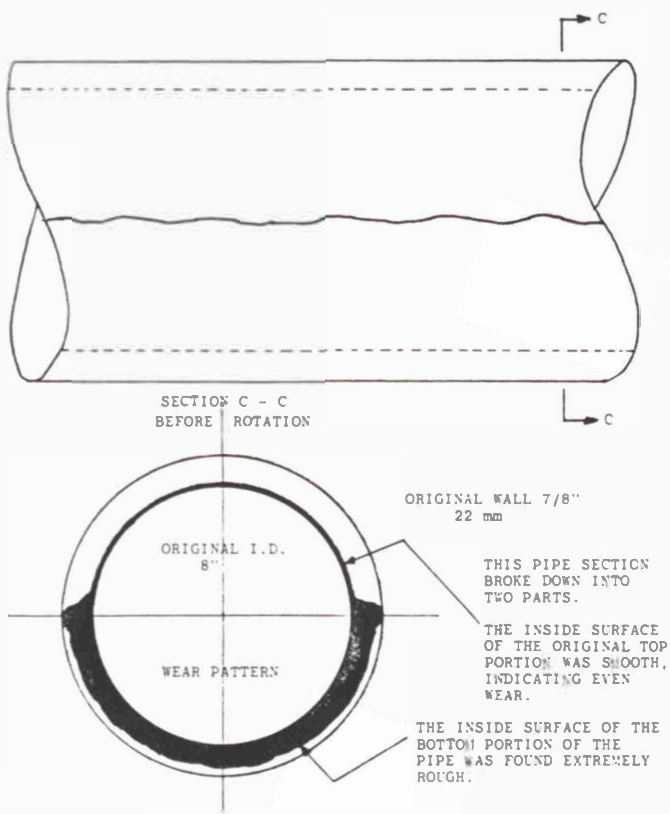

Fig. 6: The failure of a type "Y" pipe section at B. L. England Station

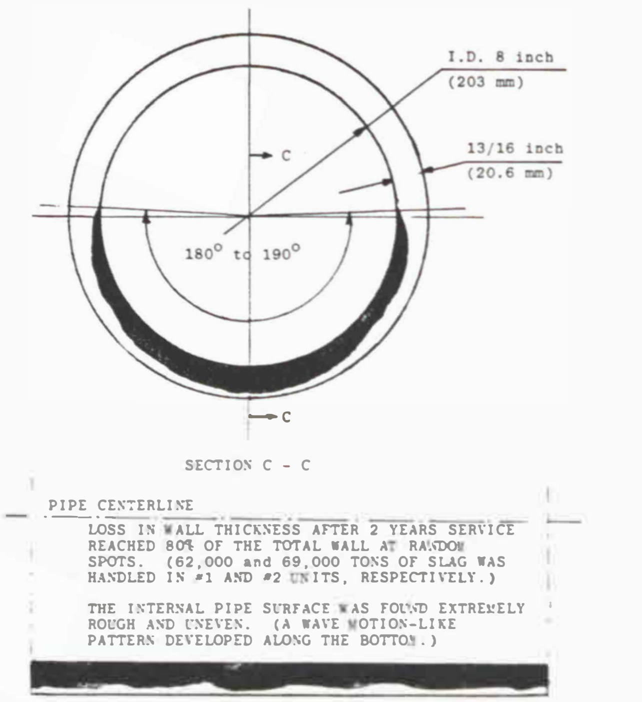

Fig. 5: Typical wear pattern observed in all types of cast iron pipe at B. L. England Station

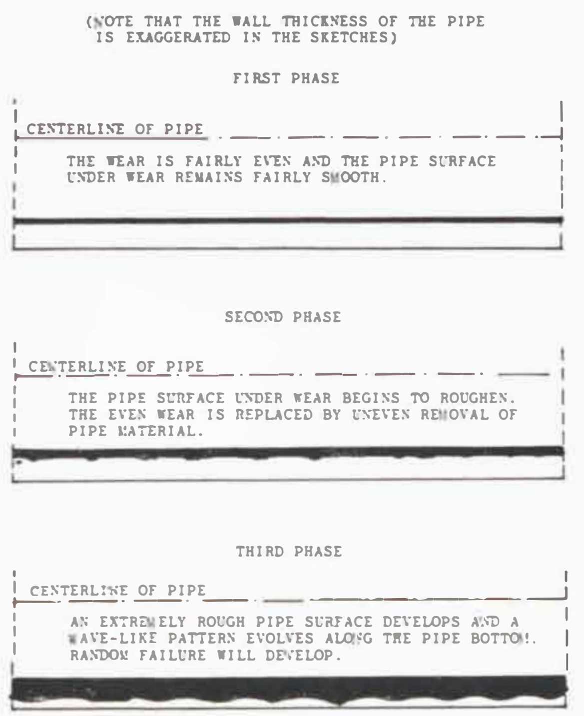

Fig. 7: The sequence of abrasive deterioration in cast iron pipe

Observations revealed that all cast iron pipes showed three phases of deterioration as illustrated in Fig. 7. In the first phase, the wear in the cast iron pipes was even and created a smooth surface. In the second phase, the pipe surface became rough. Finally, in the third phase, an extremely rough surface developed followed by random pipe failure after a few years of service.

3. Basalt Lined Pipes

The second phase of the test program has been much more encouraging than the first phase. In 1966, a new pipe appeared on the market under the trade name of Abresist which has been used very successfully in Europe in similar service conditions. This pipe shown in Fig. 8, contains basalt rings which are installed in a steel casing with a special mortar. Basalt is a volcanic material which has been used in Europe and elsewhere for road cover since ancient times when Roman legions needed reliable roads. For instance, in the Appian Way in Rome, the original basalt has survived 2,000 years. Basalt for this Abresist pipe is mined in West Germany. It is crushed, liquified around 2,300 °F and poured into molds. Recrystallization in a well controlled annealing process yields a homogeneous material with diamond like hardness. (Mohs' scale hardness is approximately 8.)

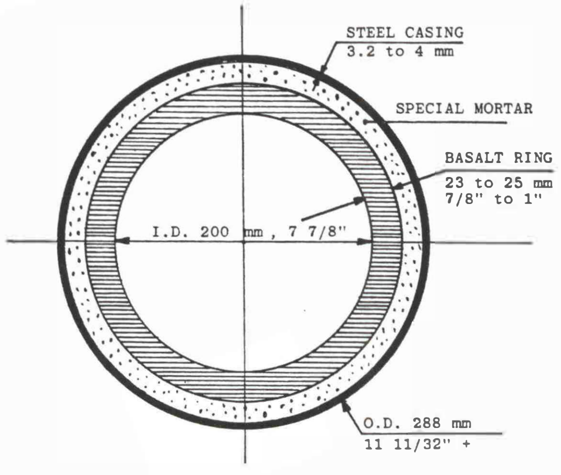

Fig. 8: Typical new Abresist pipe

Test sections of this basalt lined pipe were installed in 1966 at both generating stations in the bottom ash lines. The pipe locations are indicated in Fig. 1.

In 1967 the generating unit at the river water station (Deepwater) was converted to oil burning and the research at that station was terminated.

In July 1967, the Abresist test sections were inspected at both stations. The results were surprising. No appreciable wear could be established by field measuring devices. The only appreciable change in the pipe was that its bottom portion became very smooth. These findings suggested the selection of Abresist pipe for the replacement of cast iron pipe "Z" (which was installed two years before) in both lines at B. L. England Station.

The pipe replacement record is shown in Fig. 9 and the service lives of all pipes are described in Fig. 10.

Abresist pipe has been in maintenance free service ever since its installation in 1968 in both slurry lines. None of the straight pipe sections failed or required replacement.

The following most important characteristics of this pipe have emerged: It wears evenly with an extremely low rate and the surface under wear becomes extremely smooth. These characteristics were revealed by numerous inspections. The typical pipe condition after 11.5 years of service is shown in

Fig. 10: Actual service lives of various pipes

	(Number of Months)		
	At DW Station with rotation	At B. L. E. Station without rotation	
Pipe Description	# 1 Unit	# 1 Unit	# 2 Unit
Steel, Schedule 80	—	4	3
Standard cast iron	12	7	6
Improved cast iron, type "W"	40	30	23
Improved cast iron, type "X"	40	30	25
Improved cast iron, type "Y"	36	—	—
Improved cast iron, type "Z"	48	30	26
Abresist	—	Still in excellent condition after 11.5 years service (138 months)	

Fig. 9: Pipe replacement record for B. L. England Station

No. 1 Slurry Line

Service started: 10/22/1962

Original installation:

Improved cast iron type "W": Inside Building
Improved cast iron type "X": Yard
Major failure: April to June, 1965
Slag handled: Approx. 78,000 tons

First replacement: 12/1/1965 to 2/1/1966

Improved cast iron type "Z": Entire piping
Major failure: February to June, 1968
Slag handled: Approx. 71,000 tons

Second replacement: 6/1 to 6/14/1968

Abresist piping: Entire piping
Latest inspection: 10/30/1981
The pipe was found in excellent condition.
No maintenance was needed during 13 years.
Slag handled: Approx. 369,000 tons

No. 2 Slurry Line

Service started: 11/24/1964

Original installation:

Improved cast iron type "W": Inside building
Improved cast iron type "X": Yard
Major failure: January 1966
Slag handled: Approx. 42,000 tons

First replacement: 2/16/1966 to 3/10/1966

Improved cast iron type "Z": entire piping
Major failure: February 1968
Slag handled: Approx. 72,000 tons

Second replacement: 6/15 to 6/30/1968

Abresist piping: Entire piping
Latest inspection: 1976 (Excellent condition)
No failure has occurred. No maintenance was needed during 13 years.
Slag handled: Approx. 416,000 tons

Note: Oil was burned in both units in 1971 and 1972.

Fig. 11. Only 1/8" basalt layer was removed by abrasion. The pipe surface under wear has become extremely smooth and even. Around 370,000 tons of slag were transported in this pipe which could yield 20 more years of maintenance free service. (These statements are related to the straight portions of the piping systems only.)

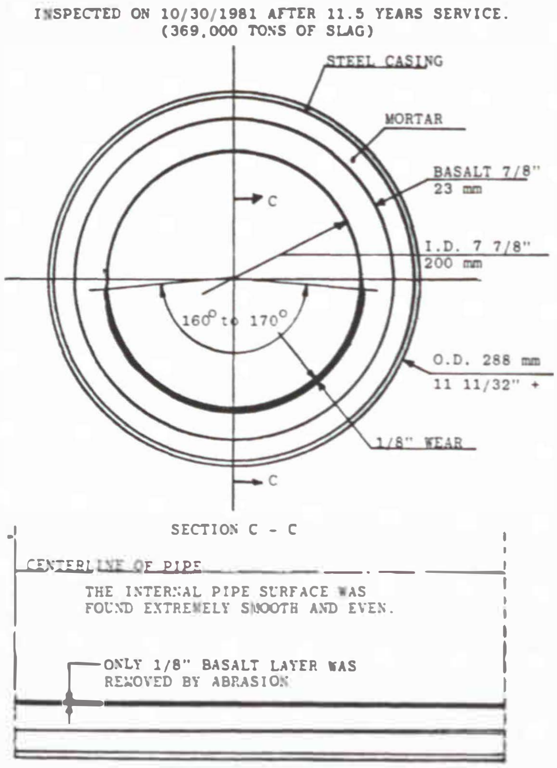

Fig. 11: Abresist pipe section at B. L. England Station of Location A

4. Service Life and Friction Head

Based on the above and other observations, the following generalizations are inferred. In bottom ash slurry service, all pipes can be separated into two groups as follows: In the first group, all pipes develop increasingly rougher internal surfaces, the friction head increases, and failures occur at random in shorter periods than expected. In the second group, pipes develop smoother than original internal surfaces, the friction head decreases, and these pipes show unusually long service lives. In this test program, only one pipe, the basalt lined Abresist, satisfied the second category. However, other research programs may reveal additional pipes with similar characteristics. (It is noted here that no synthetic pipe was included in this program.)

Static friction coefficient tests were conducted by a physics lab method on extremely rough and extremely smooth surfaces. The broken cast iron pipe which was shown in Fig. 6, and an Abresist pipe section after 34 months service, were used to represent those two extreme surface conditions. The results showed for the extremely rough pipe surface $\mu = 4.16$ and for the extremely smooth pipe surface $\mu = 0.87$. The ratio between the above two static friction coefficients was found to be 4.78.

It is claimed that this ratio is significant when ash falls out of suspension and drags on the pipe bottom. The ratio implies that in pipes with extremely rough surfaces, almost five times as much pump work is required to overcome friction than in pipes with extremely smooth surfaces. It should be noted that such surfaces were gained in actual service.

Other tests revealed that the quality of bottom ash requires attention. It was found that particle size distribution and specific gravity would influence the degree of deterioration. In addition, an interrelation between the expected angle of wear and the slurry density has emerged in this program as described in Fig. 12.

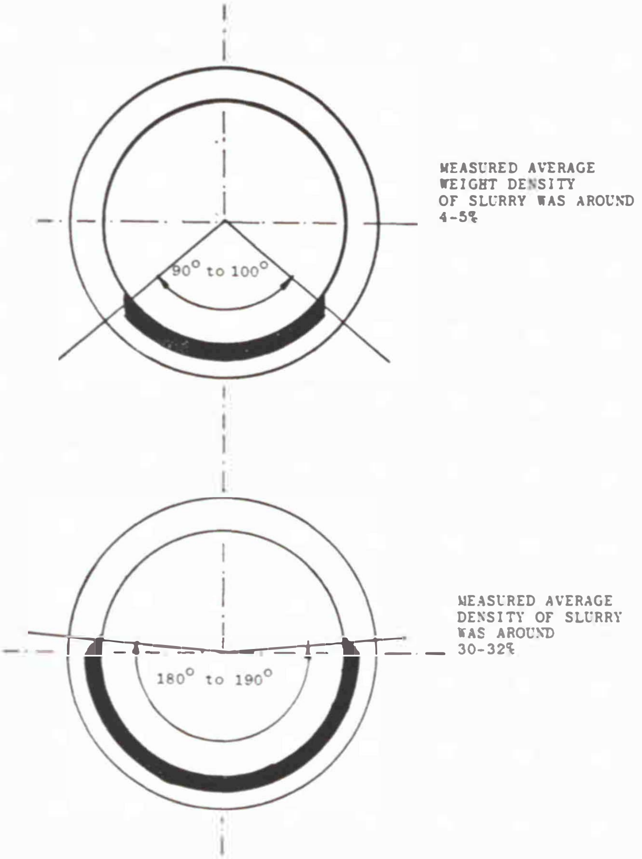

Fig. 12: Interrelation between the angle of wear and slurry density

The implications of the above findings and other factors were further explored by analyzing three popular mathematical formulae used for the computation of expected friction heads (Darcy, Hazen-Williams, and Schoder). A series of calculations was run by these formulae related to two different bottom ash slurry systems: one heavy duty, one light system. These calculations reveal the penalty in friction head when pipe surfaces become increasingly rough in slurry service. The tabulated figures in Fig. 13 also show that choosing the correct pump head requires sound engineering judgment.

5. Conclusions

This study shows that based on actual results and observations, service life, friction head, and maintenance cost require the same priority in pipe evaluation as the cost of the piping and its installation. Service life depends on the quality of bottom ash, slurry composition, average transport

Fig. 13: Summary of calculated friction head values (for 1 ft of pipe)

System A: Heavy Duty

Surface Condition	h_f	Schoder	Hazen-Williams	Darcy	Average
Extremely Smooth Pipe	ft	0.0384	0.0560	0.0619	0.0521
Fairly Smooth Pipe	ft	0.0692	0.0874	0.0728	0.0765
Extremely Rough Pipe	ft	0.1790	0.1270	0.0910	0.1323

Note: C_1 = 140, 110, and 90 were used in the Hazen-Williams Formula for the specified three cases.

System B: Light Duty

Surface Condition	h_f	Schoder	Hazen-Williams	Darcy	Average
Extremely Smooth Pipe	ft	0.0198	0.0285	0.0242	0.0242
Fairly Smooth Pipe	ft	0.0346	0.0446	0.0354	0.0382
Extremely Rough Pipe	ft	0.0867	0.0647	0.0466	0.0660

velocity, and the inherent capability of the piping material to resist erosive-corrosive attack.

The bottom ash in cyclone furnaces is more abrasive than the normal wet bottom ash. The major difficulty with ash quality is that it varies with individual boilers and is unknown when the slurry system is designed. It becomes a known quality only after the unit is in operation.

Two major factors may cause considerable maintenance efforts; replacement of leaking pipe sections and rotation of the pipe in order to extend service life. Rotation is usually an expensive and time consuming effort which may not be rewarded with the expected results. Unless it is done with geometric exactitude, which is rarely permitted by actual field conditions, double wear occurs, rendering the entire effort worthless. This was already illustrated in Fig. 6, and another case is shown in Fig. 14. In this light, the best rule is to try to select a pipe which requires no maintenance whatsoever; no rotation and no replacement for at least ten years, to be warranteed by the manufacturer.

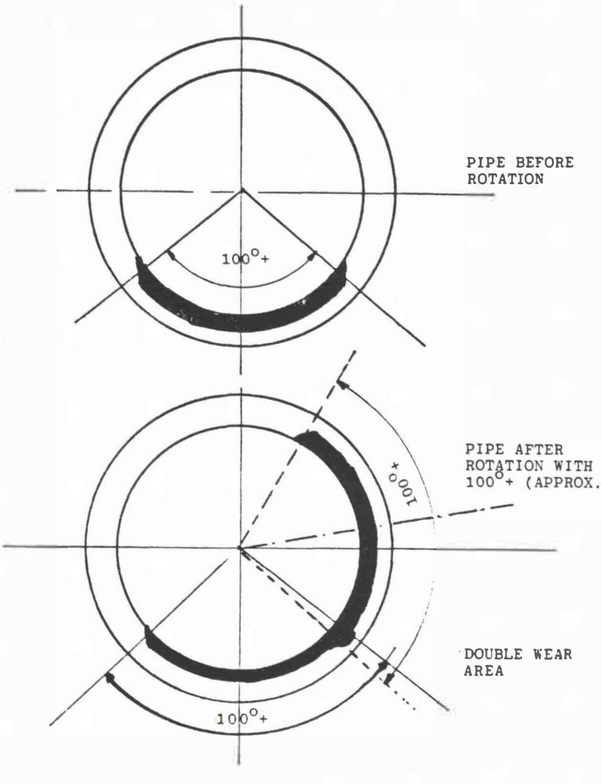

Fig. 14: Double wear caused by rotation at Deepwater Station

This study revealed that abrasion is a very complex process which, unfortunately, has remained a neglected field of research; however, instructive detailed data and observations about pipe behavior are embodied. Since the findings are tied to specific slurry conditions, this study does not intend to claim general validity.