HYDRAULIC ANALYSIS OF PIPE LINED WITH MADISON'S 100% SOLIDS STRUCTURAL POLYURETHANE COATINGS

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1. Introduction

The proper use of protective coatings is the extremely effective means of preventing pipeline deterioration and corrosion leaks in water and wastewater applications. In order to fulfill this function, however, a corrosion protective coating system has to be able to meet various combined requirements. These requirements include environmental and safety compliance such as volatile organic compound (VOC) content, cost-effectiveness, appearance, and high performance. The ideal corrosion protection coating system must be environmentally friendly, worker-safe, durable and able to expose little or no metal/substrate surface to the environment, while also being resistant to environmental, mechanical and chemical damage from the initial stage of handling and installation through its entire service life. It should also come at a reasonable cost in terms of materials, application, repair, and operation maintenance. Madison's 100% solids rigid and structural polyurethane coatings technology is regarded as one coatings solution that stacks up well against this long list of demands, and is becoming one of the main coating and lining choices of today's water and wastewater pipeline industry in North America and internationally.

When it comes to the true cost of any pipe coating system, it is not the 'cost per bucket' or even the applied cost per square feet or square meter. The true coating cost is the total sum of materials cost, application cost, maintenance cost, and hidden Cost. Comparing with other coating and lining systems available in the market, the application cost and maintenance cost of Madison's 100% solids structural polyurethane coating/lining systems is substantially lower due to many specific benefits associated with Madison's uniquely designed coating products. These unique benefits include not only the application cost savings due to some common natures of the 100% solids polyurethane technology (such as a cold/low temperature curing capability, fast or instant curing, one coat application, and unlimited build), but also the application cost savings in terms of time and equipment due to Madison's user-friendly design (such as 1:1 mixing ratio, much lower viscosity values (at around or less than 1,000 cps at 25^0C) than other competing products, and balanced viscosity between the two components), together with the maintenance cost savings due to superior performance properties associated with Madison's products such as excellent adhesion, cathodic disbondment resistance, low permeability, additional abrasion resistance due to ceramic modification, and the ability of incorporating anti-microbial additives.

An example of the hidden costs is the pump efficiency, which is related to the water/wastewater flow efficiency. Because Madison's 100% solids structural polyurethanes have better abrasive resistance and is smoother than cement-mortar and other lining materials, the pump efficiency of pipes lined with Madison's polyurethane coatings is significantly higher than the case of other lining materials.

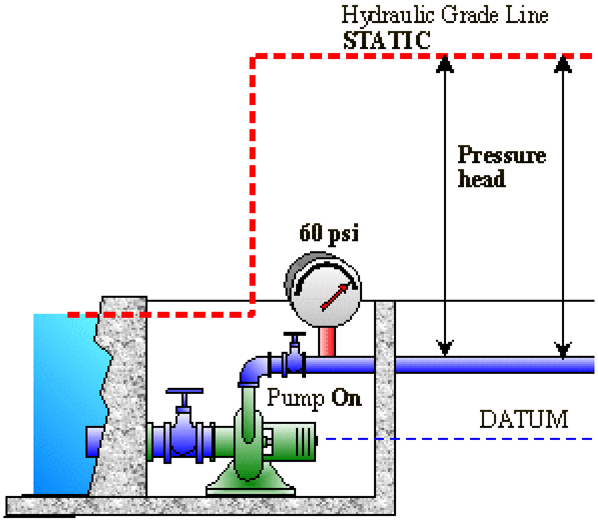
This paper gives out detailed hydraulic and friction analysis of various pipes lined with Madison's 100% solids structural polyurethane coatings.

2. Fundaments of hydraulic analysis

While conducting hydraulic analysis on pipes lined/coated with a coating, it is important to understand how water is going to flow through the piping and the loss associated with this flow. The primary loss of energy is due to the friction between the fluid and the pipe wall. The flow is converted to waste heat, drop in pressure in a pipeline is observed, and the energy is lost.

Illustrations made by Dan Lundy[1] are very helpful to help one understand the basic terminology of hydraulic analysis. Consider Figure 1 below. With the pump "on" but the hydrant valve closed, the pump simply produces pressure with no flow. The pressure all along the horizontal pipe is 60 psi. This is the "shutoff head" for this pump.

Figure 1. "Shutoff head", courtesy of Dan Lundy [1]



Consider then if the pump is "on" and the hydrant valve is open. As water flows through the pipe, valves and fittings, the interaction of the liquid with the pipe walls will produce turbulence and friction resistance, which results in the loss of energy or "head" (Figure 2). Water flowing through a closed pipe will experience irreversible loss of pressure or "headloss".

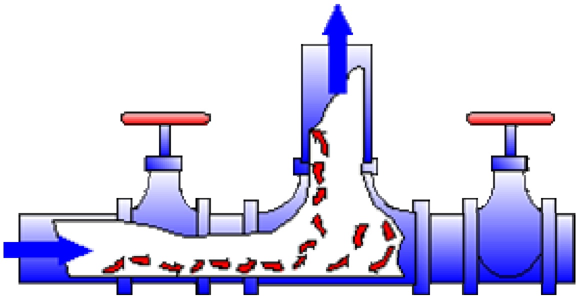


Figure 2. The turbulence that results as water flows along the pipe wall, through the valve opening and around the side-outlet TEE produces friction that results in the loss of pressure or “headloss”, courtesy of Dan Lundy [1]

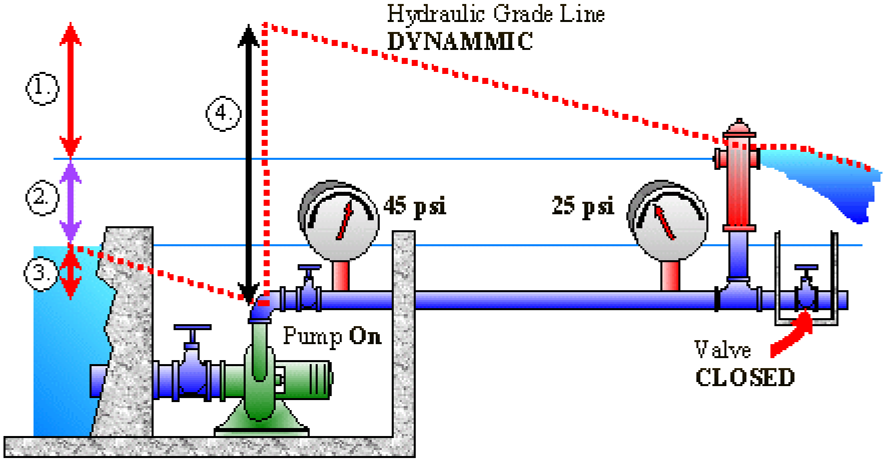


Figure 3. Illustration of headloss, courtesy of Dan Lundy [1]

Figure 3 illustrates various components of the “head loss”. Discharge Headloss is the loss of pressure that occurs in all of the piping, valves, and fittings on the discharge side of the pump. In Figure 3, the line sloping to the hydrant outlet represents the headloss in the discharge piping. Total Static Head is the distance from "water level to water level" or the vertical distance between the inlet water level and the discharge water level. In Figure 3, total static head is the distance from the top of the water surface in the reservoir at the left to the water level at the hydrant outlet. Suction Headloss is the loss in pressure that occurs in all of the pump suction piping, valves and fittings. In Figure 3, the sloped line from the reservoir to the pump inlet represents the suction headloss. Total Head is the sum of the total static head and the suction and discharge headloss. By adding ①, ②, and ③ together in Figure 3, total head is determined.

There are three methods that have been developed to determine the amount of friction “headloss”. The Darcy-Weisbach equation is probably the most well known, the Manning equation which was developed for open channels, and finally the Hazen-Williams equation which was developed from a purely empirical approach in 1905. The most commonly used headloss formula used in the waterworks industry today is the Hazen & Williams Headloss formula. This equation is expressed in a convenient form as follows:

$$\text{Headloss (feet)} = \frac{10.46\ L\ Q^{1.852}}{C^{1.852}\ \ D^{4.870}} \tag{1}$$

Where L = pipe length in feet, Q = flow rate in gpm, C = Hazen & Williams pipe roughness coefficient (C factor), and D = pipe inside diameter in inches; or

$$\text{Headloss (feet)} = \frac{54.90\ L\ V^{1.852}}{C^{1.852}\ \ D^{1.167}} \tag{2}$$

Where V = flow velocity in fps ($V=Q/2.448D^2$).

The Headloss in feet is correlated to pressure loss in psi as:

$$\text{Headloss (feet)} = \frac{2.307\ \text{Pressure loss (psi)}}{\text{Specific gravity of fluid}} \tag{3}$$

Thus for water, one feet of headloss is equal to 0.434 psi pressure loss.

The H & W headloss formula includes 4 variables that influence headloss. They are the length of pipe (distance the water travels), flow rate, roughness coefficient and pipe diameter. A variable that is not included directly are the various valves and fittings that the water passes through. The H & W formula treats valves and fittings as the equivalent of additional length of pipe. For instance a 10 inch globe valve adds the equivalent of 275 feet of straight 10 inch pipe (with a standard "C" value = 100).

The Manning equation for headloss can be written as:

$$\text{Headloss (feet)} = \frac{V^2 n^2 L}{2.22 R^{4/3}} \tag{4}$$

Where n is the roughness coefficient and R the hydraulic radius of the pipe.

The cost to pump through a given pipeline can be shown to be a function of headloss, pump efficiency, and power cost, as shown in the following equation: [2]

$$\text{Pumping Cost \$} = 1.65\ \text{Headloss}\ \ Q\ \ \frac{\text{Unit cost of electricity}}{\text{Pump efficiency \%}} \tag{5}$$

Where Pumping Cost is the dollar value per year based on 24-hr/day pump operation and Unit cost of electricity is $/KWH. As indicated from Equation (4), one way to realize the saving of operation is to reduce pumping cost of a pipeline through the use of a pipe material or a lined pipe which can produce the lower headloss.

3. Friction and hydraulic headloss of pipes lined with Madison's 100% solids structural polyurethane coatings

For any pipeline internal lining application, the lining must be able to withstand the constant flow of liquid and any particulates. Normal municipal pipeline velocities are in the range of 8 to 16 feet per second (2 to 4 meters per second) but these rates can increase in some cases to over 30 feet per second. The corrosion protection lining must be capable to withstand the constant abrasion caused by the passing water at the various velocities. Premature failure of the lining system can occur thereby exposing the steel substrate to the corrosion cycle.

ASTM D4060 is a commonly used testing method for measuring the abrasion resistance of a coating system. The Taber Abrasion Test (ASTM D4060) rotates a sample under a specific weight against a grinding wheel for a defined number of revolutions. The samples are evaluated by measuring the weight of the sample before and after the abrasion. The resulting weight loss indicates the comparative ability of the lining to resist abrasion and wear. The lower the reported weight loss, the more abrasion resistant the lining.

Table 1 summarizes the abrasion resistance testing results of a typical Madison's 100% solids structural polyurethane lining material, comparing with other solvent based or 100% solids epoxy linings as well as cement-mortar systems. The 100% solids polyurethane lining demonstrated superior abrasion resistance. This parallels what is already known in the industry that polyurethanes offer excellent abrasion resistance. The solvent based and 100% solids epoxy lining systems offered moderate abrasion resistance. The cement-mortar system samples illustrated the inherent nature of cement-based products to 'wear away' at an accelerated rate in environments that are subject to fast velocities. However, with cementitious linings, the abrasion resistance can vary widely depending on the type and amount of aggregate.

Table 1 Abrasion Resistance Results

Product Type	Solvent Amine Based Epoxy	100% Solids Epoxy	Madison's 100% Solids Polyurethane	Cement Mortar
Average Weight Loss	122 mg loss	183 mg loss	50 mg loss	1500 mg loss

For a pipe to have satisfactory flow characteristics, it initially must provide a high Hazen-Williams flow coefficient "C factor" and must be able to maintain a high flow coefficient through years of service. The capability of a lining system to maintain a high flow coefficient is correlated with its ability resisting to deterioration due to abrasion or other physical/chemical attack. The higher resistances to deterioration, the better the capability can a lining have to maintain the high flow coefficient.

Numerous flow tests have been conducted to demonstrate how well various pipe lining materials meet these requirements. The average value of “C factor” for new cement-mortar lined pipes was found to be 144, although some tests reported values from 150 to 157. For older systems, the average value of “C factor” was found to be 140. As a result, it is commonly accepted by the pipe industry that a “C factor” of 140 for cement-mortar linings is a realistic and long-term value.[2]

Tests have also been conducted and reported by third parties, including a world’s leading pipe manufacturer, on the abrasion resistance and flow coefficient of pipes lined with Madison’s 100% solids structural polyurethane coating systems[3]. It showed that the Madison’s linings will provide a tough abrasion resistant interior that will resist erosion from sand or grit particles being carried in suspension. Also the pipes and fittings lined with the Madison’s polyurethane materials can produce and maintain a smooth interior of pipe surface to which most materials will not adhere, having a Hazen-Williams “C factor” of 150. For a specific set of conditions, such a Hazen-Williams “C factor” of 150 is approximately equal to a Manning “n” coefficient of 0.010.

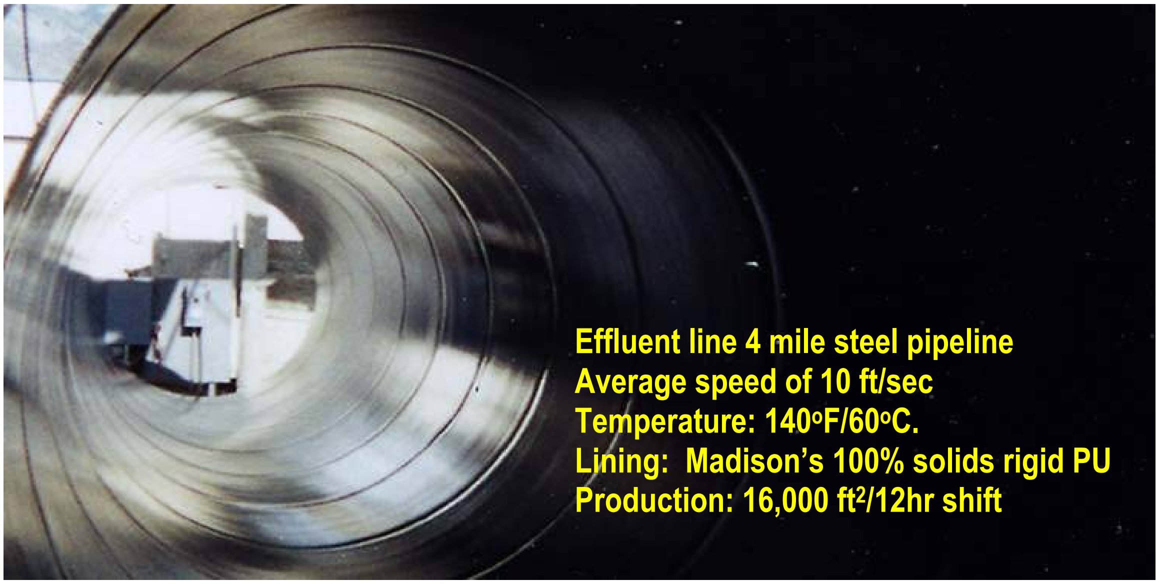


Figure 4 A smooth and abrasion resistant interior pipe surface for high aggressive and high slow rate applications with a Madison’s 100% solids structural polyurethane product

Typical minimum specified dry film coating thickness of Madison’s 100% solids structural polyurethane coatings for water/wastewater applications is given in Table 2, depending on the condition of substrate. In contrast, most other lining materials such as cement mortar, polyethylene, and/or 100% solids polyurea are applied at a much thicker dry film thickness than Madison’s 100% solids structural polyurethane products, hence the actual inside diameter of the pipes lined with theses other materials is much smaller. The combination of high flow coefficient with a larger inside diameter provides exceptionally high flow capacities of pipes lined with Madison's 100% solids structural polyurethane lining materials.

Table 2 Typical minimum specified dry film coating thickness of Madison's 100% solids structural polyurethane linings for water/wastewater interior applications

Substrate Type	Madison's 100% solids structural polyurethane linings	External Application
Steel	25 mils (625 microns) – normal	25 mils (625 microns) – normal 50 mils (1250 microns) - slip bore
Ductile iron	40 mils (1000 microns)	25 mils (625 microns) 50 mils (1250 microns) – slip bore
Reinforced concrete	60 mils (1500 microns)	40 mils (1000 microns)
Pre-stressed concrete cylinder	25 mils (625 microns)	30 mils (750 microns)

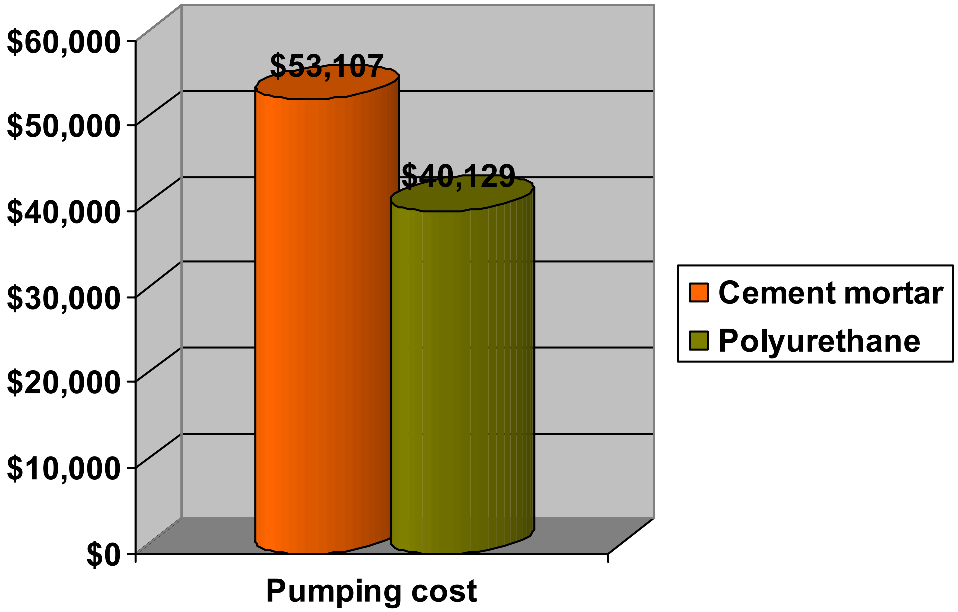


Figure 5 Significant annual pumping cost with a Madison's polyurethane lining vs. cement-mortar for a 30,000 ft normal 24 inch size pipe

Figure 5 illustrates that significant pumping cost savings of about $12,978.00 US dollars could be achieved by simply the use of a Madison's 100% solids rigid polyurethane lining rather than a cement-mortar lining for a 30,000 feet length 24 inch normal size steel pipe. This saving is estimated assuming: 6,000 gpm design flow, 70% pumping efficiency, $0.06 dollar KWH unit power cost, a 140 Hazen-Williams C factor for a 375 mils thick cement-mortar lining and 150 for a 25 mils thick polyurethane lining. This represents the total pumping cost savings of over $648,900 dollars during the pipeline operation period of a 50-year design life (assuming zero inflation).

Pipe manufacturers can also save money from the use of Madison's 100% solids rigid polyurethane lining. The estimation in Figure 5 assumes a 24 inch normal size of steel pipe. About 2.83% pipe material cost could be saved if a Madison's polyurethane lining rather than a cement-mortar lining is used. For the 30,000 feet length pipeline, it means a pipe material cost saving of $68,000 US dollars assuming a unit cost of $80 per feet of steel.

Furthermore, the above estimation assumes that Madison's 100% solids rigid polyurethane performs equally as cement-mortar. However, both laboratory and field experience and testing results have proved that the polyurethane would outperform the cement-mortar.

4. Summary

Madison's 100% solids structural polyurethanes have better abrasive resistance and is smoother than cement-mortar and other lining materials, the pump efficiency of pipes lined with Madison's polyurethane coatings would be significantly higher than the case of other lining materials.

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[1] Dan Lundy, Water & Environmental Technology, Course Notes, Clackamas Community College, Oregon City, Oregon, USA, 2003

[2] DIPRA, "Hydraulic Analysis of Ductile Iron Pipe", 2002

[3] U.S. Pipe, "Polyurethane Lined Ductile Iron Pipe and Fittings For Force Mains and Gravity Sewer Lines", 1993