PIPELINE PROTECTION AND EXTENSION OF INTERNAL COATING LIFE

Dr J Sargison

INTRODUCTION

Pipelines form a significant part of the asset base for any hydro-electric power scheme, and as an example, in Hydro Tasmania's infrastructure in Tasmania, there are currently 66 pipelines with a combined length of approximately 105 km. They vary in length from 49m to 8.93 km and in diameter between 1.2 m and 9.1 m. Coal tar products have been extensively used to coat the internal surface of steel pipelines and penstocks, to provide corrosion protection [1]. One product, used in many installations in Tasmania, is coal tar enamel [2], which is applied hot to the steel surface and spun to produce a good surface finish. Hot applied coal tar enamel is produced by dissolving coking coal in pitch, made from horizontal, or coke oven tar at an elevated temperature, to form a coal digestion pitch. The coal digestion pitch is hard and brittle and requires the addition of a filler (talc) and fluxing oils to produce a coating having the desired toughness and film thickness to withstand impact and flexing loads to which pipe sections are commonly subjected. The hot applied coal tar enamel provides an excellent corrosion protection, but it has two weaknesses [3,4]:

- Its mechanical properties vary considerably with service temperature. When heated it flows under relatively little stress, and when cold it has poor resistance to impact
- When subjected to prolonged heating the low boiling point tar oils (volatiles added to the coal digestion pitch to soften it after the digestion process) are lost, resulting in a loss of elastic properties and a tendency to crack.

EFFECT OF LINING DEGRADATION

Figures 1 and 2 show the typical degradation of the coal tar enamel coating. Once cracks are initiated in the lining, water is able to penetrate the lining and significantly increase the rate of failure of the coating. The initial cracking stage is hydraulically undesirable because it causes an increase in effective roughness of the pipe surface and therefore friction and hence headloss in the pipe are increased significantly. Further degradation due to ingress of water causes coating failure due to sections of coating losing adhesion to the pipe wall. This becomes a significant problem, not only for hydraulic performance,but also for pipe corrosion.

Typical headloss increase due to poor coating condition has been measured to be of the order of a 55% increase.

MEASUREMENT OF PIPE SURFACE TEMPERATURES IN SUMMER CONDITIONS

Test pipe section overview

A four metre section of pipe removed from site and replaced as a result of an upgrade, was installed in a sunny location on the University of Tasmania campus. This provided an opportunity to measure the typical internal pipe temperatures that would be developed when the pipe was dewatered on a sunny day. The pipe is shown in Figure 3. The internal and external coatings were not modified and as shown in Figure 1, the internal lining already showed significant signs of deterioration. The crown of the pipe was exposed to afternoon sun, and both ends of the pipe were open. This would be expected to reduce the pipe internal surface temperature compared with a normal installation of hundreds of metres because of increased ventilation of the pipe.

All steel pipelines owned by Hydro Tasmania are treated with an external coating for corrosion protection, which was designed to limit radiant heating of the pipe. These coatings are typically pale grey or silver in colour. A new alternative, externally applied heat reflective coating was also trialed in a one square metre sample on this pipe. This coating (designation NMP 1120) was supplied by National Maintenance Products. The sample area is white in Figure 3. This sample was thought to typify the best heat reflective coating currently available although it could not be discounted that other highly reflective conventional coatings might provide comparable performance. As the external coating was deemed to be in good condition, the trial area was simply cleaned and the trial coating applied by brush over a 90 degree sector from the apex to the front of the pipe.

The pipe was instrumented with K-Type Thermocouples in order to measure internal surface temperatures. These thermocouples can be expected to have an accuracy of ±2 °C. The thermocouple signals (μV) were conditioned using a National Instruments NI4351 for PCI card. This conditioned and amplified the signals to voltages in the range 0-10V. These signals were then acquired to PC using a National Instruments PCI 6025E card at 15 minute intervals. The indicated

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Figure 1: *Distribution of internal pipe lining cracking over the crown of the pipe*

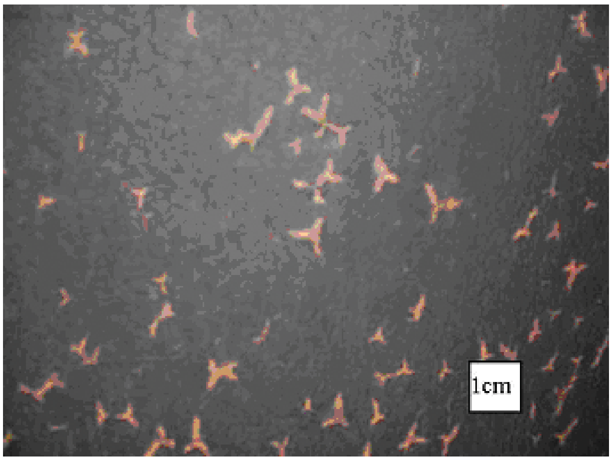

Figure 2: *Close inage of corrosion behind cracks in internal lining*

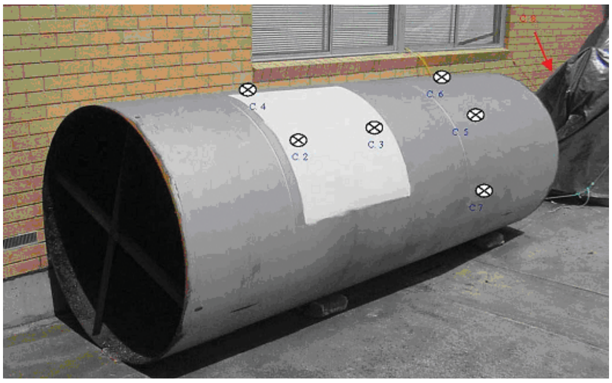

Figure 3: *Pipe section in car park. Thermocouple locations indicated.*

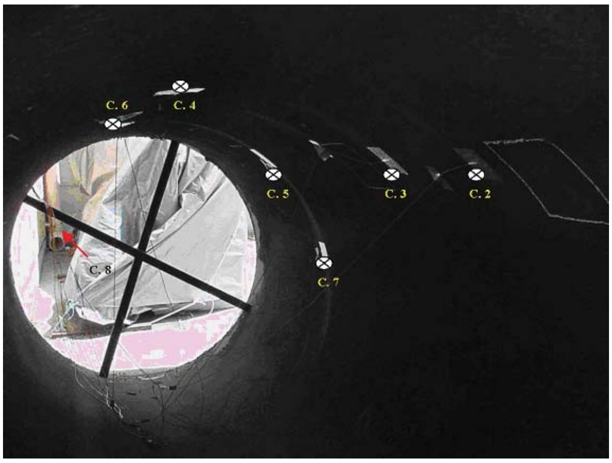

Figure 4: *Pipe interior showing thermocouple locations.*

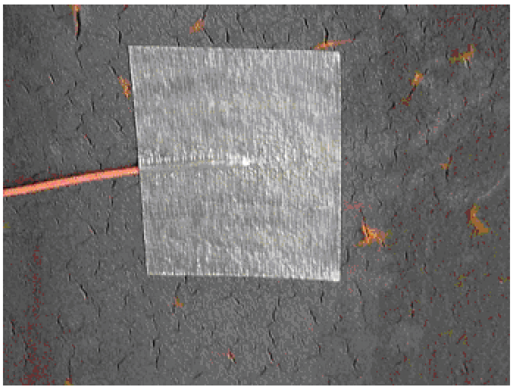

Figure 5: *Thermocouple attached to interior pipe wall using tape.*

temperatures were compared with a handheld thermocouple reader and found to agree to within 1°C.

The thermocouples were located in the arrangement shown in Figures 3 and 4 behind the heat reflective coating and behind the existing coatings across the crown of the pipe. The local ambient temperature was also monitored away from the pipe in a shady, well ventilated region. Figure 5 shows the thermocouple attached to the wall using tape. The thermocouples behind the reflective paint were located 260 mm (channel 2) and 390 mm (channel 3) from the edge of the painted section. It is likely that due to the conduction of heat in the pipe wall, there may be some edge effect, causing the measured temperature to be higher than would be the case if the entire pipe section in direct sunlight were coated with the reflective paint. This is demonstrated by the experimental results in Figures 6-7, where the channel 3 thermocouple, located further from the edge of the painted section, records a measurably lower temperature (1-2°C) than the channel 2 thermocouple, located closer to the edge of the painted section. Thermocouple channels 2-4 monitored temperatures behind the heat reflective paint, channels 5-7 monitored temperatures inside the unmodified pipe section and channel 8 monitored the ambient temperature in the shade

Temperature results

The temperature measurements are shown in Figures 6 and 7. The typical diurnal temperature variation is visible, and results are shown for a sunny day (Figure 6) and a cloudy day (Figure 7). All samples

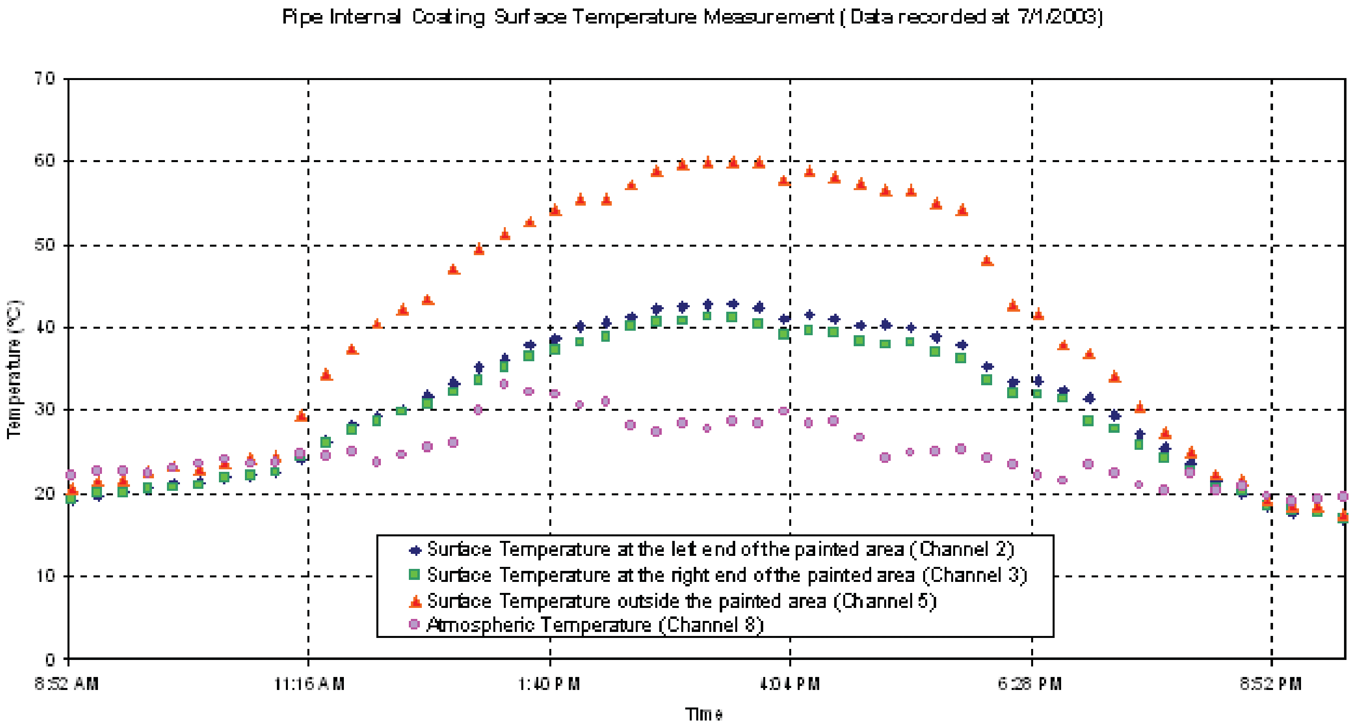

Figure 6: Recorded Temperatures 7/1/2003 (Hot, Sunny Day)

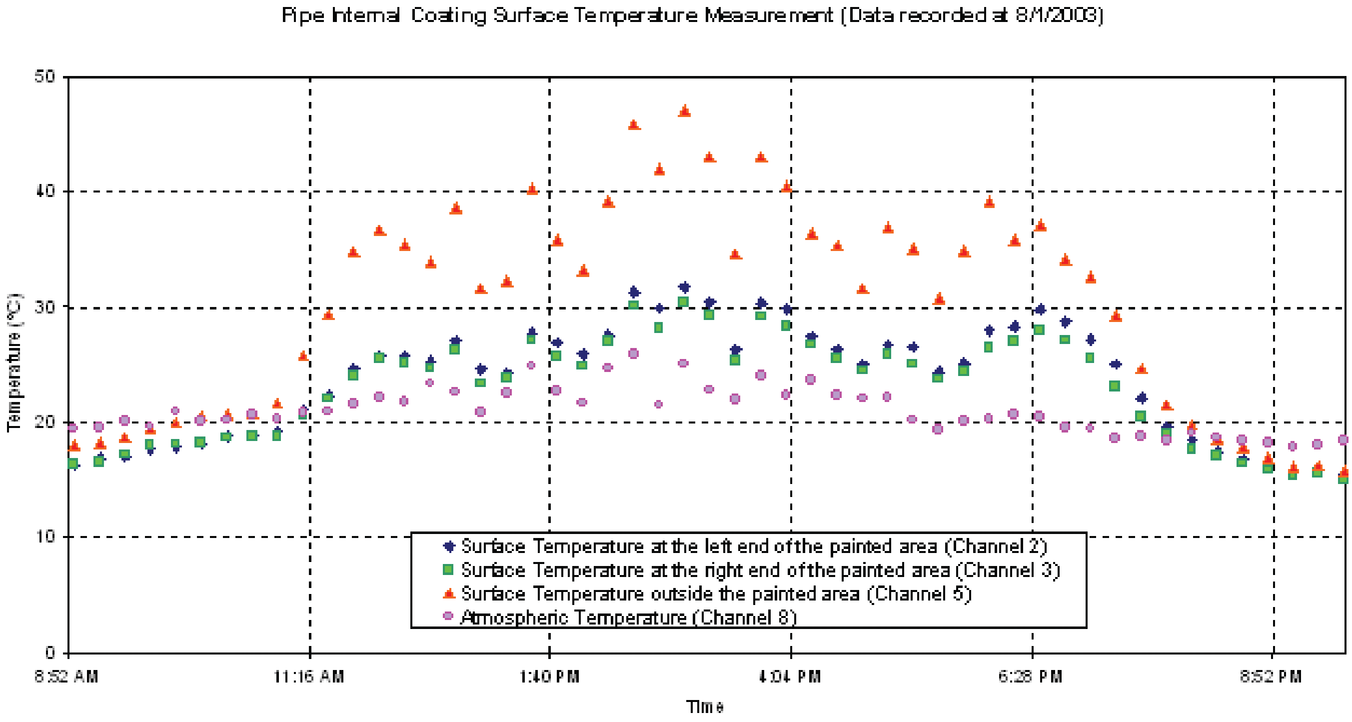

Figure 7: Recorded Temperatures 8/1/2003 (Some Cloud)

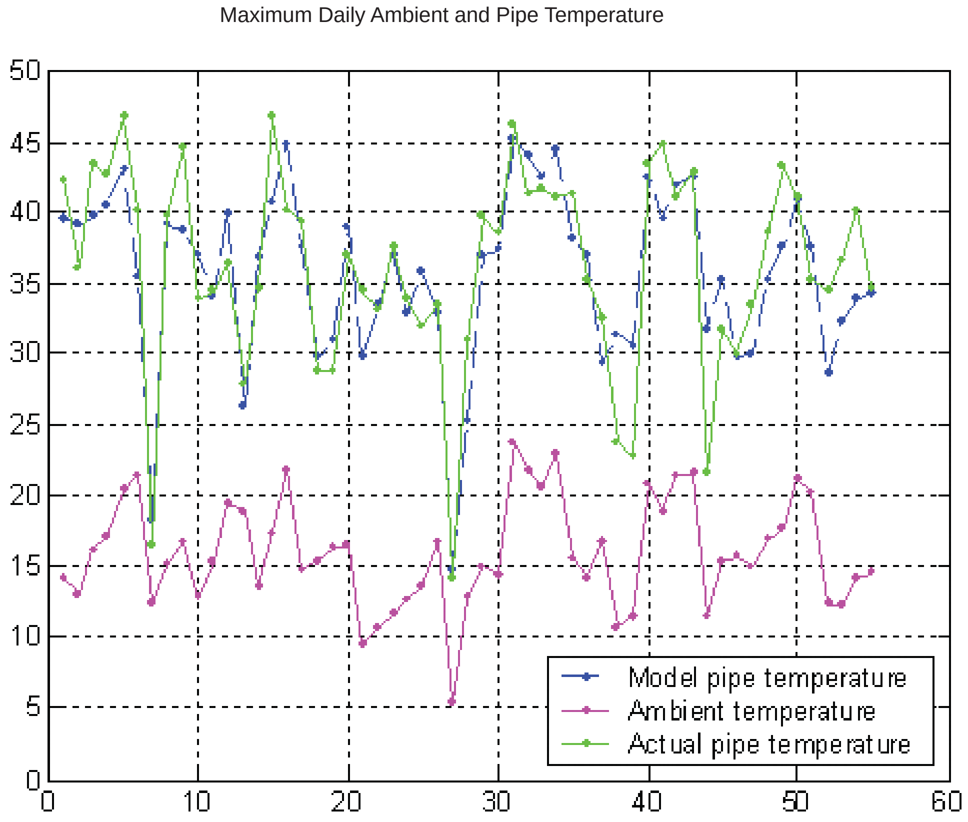

***Figure 8**: Comparison of measured results with thermal model prediction*

were taken within a week in January and daily temperatures were in the typical (for Tasmania) summer range of 20 – 30 °C.

The key observation is the increase in the pipe internal temperature of up to 30°C above local, ambient temperature when exposed to direct sunlight. This significant temperature increase would expose the internal lining to temperatures well above the normal operating range (when filled) of 5-10°C. The performance of the section covered with the new heat reflective coating exhibits a markedly reduced temperature increase of 10-12 °C above ambient temperature. This level of performance has been recorded by other studies, for example Moujaes and Brickman [5], which review the cooling advantages of using these coatings to reduce heating load on buildings. This demonstrates that by correct selection of material used in the management of pipelines, the problem of extreme temperature can be mitigated.

THERMAL MODEL

In the investigation of previous internal lining failures, the ambient temperature and solar radiation data from local weather stations was generally available, but of course the internal temperature of the pipe was not known. In order to determine the likely internal pipeline temperatures a model was developed to predict the temperature of the pipe based on direct solar radiation, ambient temperature and local convective heat transfer at the pipe surface.

A thermal balance equation [6] for the system was developed assuming that:

$$\boxed{\begin{array}{l}\text{Solar radiation}\\ \text{input to the surface}\end{array}} - \boxed{\begin{array}{l}\text{Convective heat transfer}\\ \text{from the surface}\end{array}} - \boxed{\begin{array}{l}\text{Radiation heat transfer}\\ \text{from the surface}\end{array}} = \boxed{0}$$

This can be written:

$\text{Solar rad} - h(T_p - T_a) - \varepsilon\,\sigma\,(T_p^4 - T_a^4) = 0$

Where:

h= convective heat transfer coefficient (45 W/m^{2}K for cylinder in still air)

T_p , T_a = Temperature of pipe, ambient air respectively

ε = emissivity of the surface (assumed to be 0.1 for silver surface)

σ = Stefan-Boltzmann Constant (5.670 x 10^{-8} W/m^{2}K^4)

Using measured values for solar radiation and ambient temperature (from weather station data), a Newton Raphson iteration technique [6] was used to determine the correct pipe temperature to balance this equation. Very good results were obtained with this simple model. A comparison of predicted maximum daily pipe temperature with data measured in the field in a long pipe section is shown in Figure 8. In this situation an increase in pipe temperature of 25°C above ambient temperature was typical.

CONCLUSIONS

Measurements and a thermal model of the temperatures of an out of service (empty) steel pipe have demonstrated that on a sunny day, the pipe surfaces can reach temperatures of 25 – 30 °C above ambient temperature. This is particularly significant for situations where the normal pipe working temperature is 5 - 12 °C such as the cool area hydroelectric power schemes in central Tasmania. During out of service times, pipe temperatures could rise to more than 60°C.

Traditionally, coal tar enamel products were used to coat the internal surfaces of these pipelines to provide corrosion protection and hydraulically smooth surfaces. Whilst these coatings have performed well where the pipe has been maintained at or near the working temperature, in situations where there has been a significant out of service interval during summer months, the lining has significantly deteriorated. The coating has typically become embrittled due to loss of volatile components caused by overheating of the lining. Subsequent thermal cycling of the pipe during out of service operation has resulted in cracking and deterioration of the lining.

Whilst damaged lining requires upgrade or replacement, the findings of this work can be used to determine an operating plan for such infrastructure. Dewatering of the pipelines should be avoided during warm, sunny weather. Where internal linings are replaced, the replacement coating should be able to withstand temperatures of at least 60°C (or the relevant maximum temperature for solar radiation in the area). In addition to this, modern heat reflective coatings have been shown to provide a reduction of solar heating by 15°C compared with the weathered silver grey surface.

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