Water Pipeline Final Report

Reference QUT-140930-0004-65

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Temperature increases in water pipes
Client: Country Energy

Report: Prediction of temperature increases in a water pipeline, with experimental validation of the mathematical model used.

Introduction.

The increase in water temperature has been modelled for a 50 km length of above ground pipeline for a range of environmental conditions, and comparisons made between an existing unpainted pipe and a pipe painted with heat reflecting paint.

Experimental results of water temperature increase have been obtained for 200 m lengths of painted and unpainted pipe. These results have been used to validate the model, and to obtain an estimate of the solar absorptivity of the painted surfaces.

For the most extreme conditions examined for the 50 km pipeline (a low water flow rate with high surrounding temperatures) with an inlet water temperature of 25°C, the predicted water temperature reaches 54°C for the current unpainted pipe, and 37°C for the painted pipe.

The reduction in water temperature increase achieved by painting the pipe reduces as the water flow rate increases, and as the surrounding environmental conditions become cooler. For the least extreme conditions examined (a high water flow rate with cooler surrounding temperatures) with an inlet water temperature of 25°C, the predicted water temperature reaches 31°C for the current unpainted pipe, and 27°C for the painted pipe.

The overall results obtained by modelling the pipeline under different conditions suggests that painting the pipe with heat reflecting paint should result in significant reductions in the maximum water temperature. For the range of conditions examined, the maximum water temperature remained below 40°C after the pipe was painted.

Analysis.

A mathematical model of the water pipeline and the surrounding environment was developed as outlined in the stage 1 report.

An experimental rig consisting of two 200 metre long water pipes (nominal size 1″) was constructed to test the model, with one of the pipes painted with heat reflective paint. The pipes were laid out on a black tarmac surface, slightly off the ground.

A series of experiments was conducted with water continuously recirculating through each of the two pipes, to allow the water to reach an equilibrium temperature equivalent to that attained at the end of an extremely long pipe. The results of these experiments are estimates of the solar absorptivity of 0.8 for the unpainted pipe, and 0.225 for the painted pipe.

A second series of experiments was conducted with a single pass of the water through each pipe. The measured water temperatures after 100 m and 200 m in both pipes was in reasonable agreement with the predicted water temperature increase obtained from

the mathematical model, providing added confidence in the model predictions for the 50 km pipeline.

The final model for the pipeline, using the measured solar absorptivities, was used to plot the water temperature increase in both the current pipe and a painted pipe, for a range of flow rates and surrounding conditions.

Experimental Results.

Series One: Final equilibrium water temperature (end of a long pipe) under a range of surrounding environmental conditions.

Test Number	Solar Rad. W/m2	Air Temp. °C	Ground T. °C	Unpainted Water °C	Painted Water °C
1	509	29	44	40.9	32.3
2	563	30	46	43.2	33.5
3	632	31	49	44.9	35.2
4	681	31	50	45.2	35.3
5	751	33	52	47.8	37.1
6	838	34	52	49.9	38.3
7	889	34	53	50.5	39.6
8	945	35	53	52.1	40.8

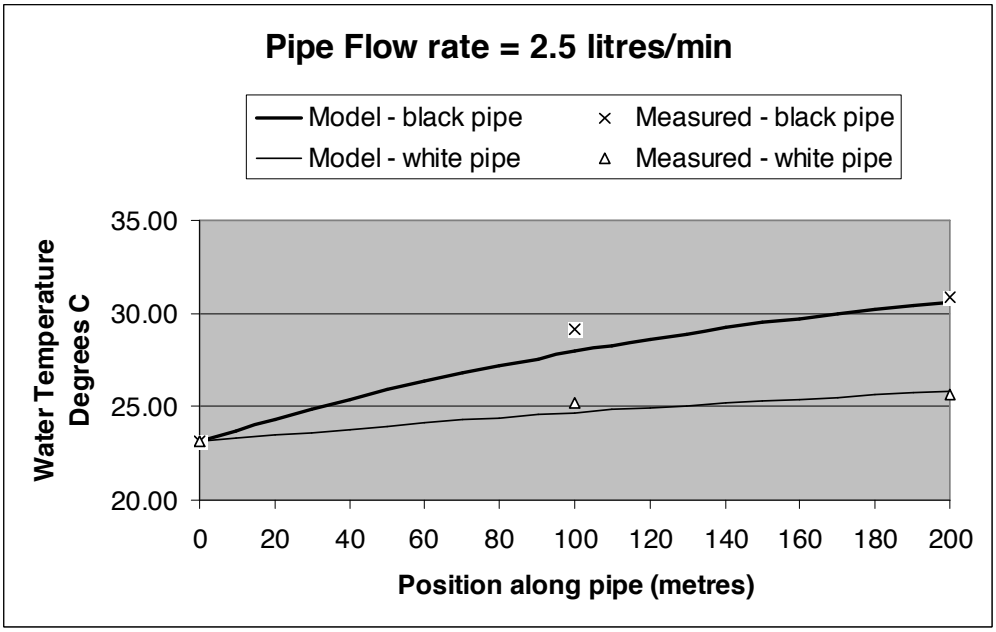
The unknown solar absorptivity of each pipe surface was determined for each final equilibrium water temperature by applying the pipeline model to the smaller scale experimental water pipes, providing the following data.

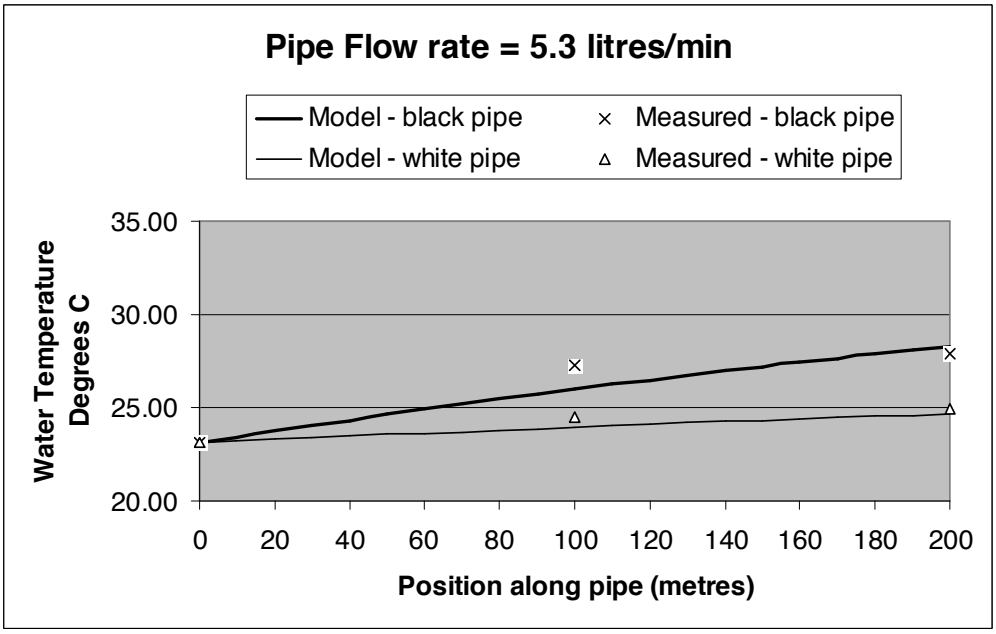
Test Number	Unpainted Pipe Solar Absorptivity	Painted Pipe Solar Absorptivity
1	0.80	0.23
2	0.81	0.22
3	0.81	0.22
4	0.80	0.23
5	0.79	0.22
6	0.81	0.22
7	0.80	0.23
8	0.80	0.23

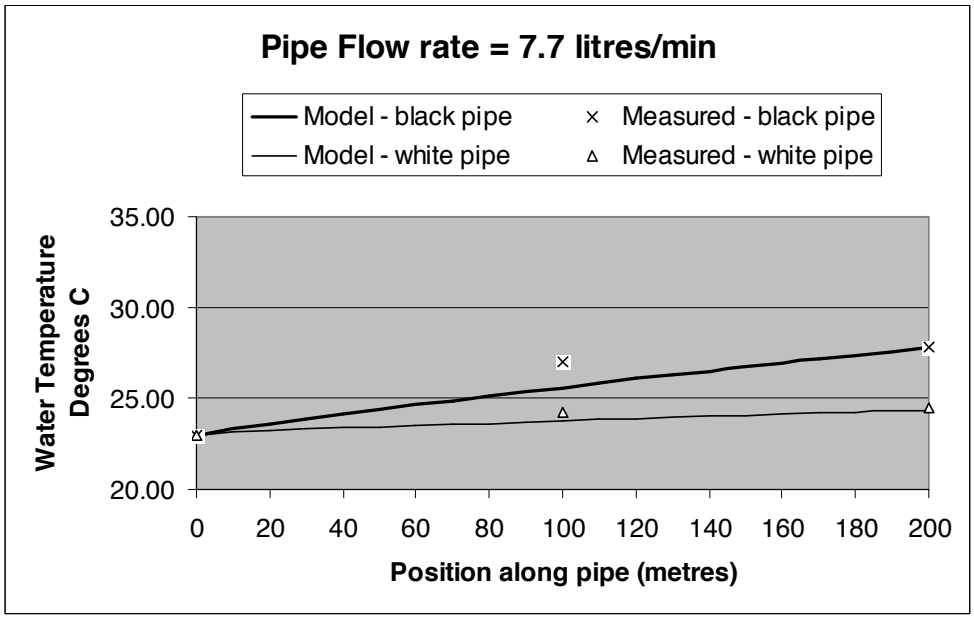
From these results the solar absorptivity was estimated to be **0.8** for the unpainted pipe, and **0.225** for the painted pipe.

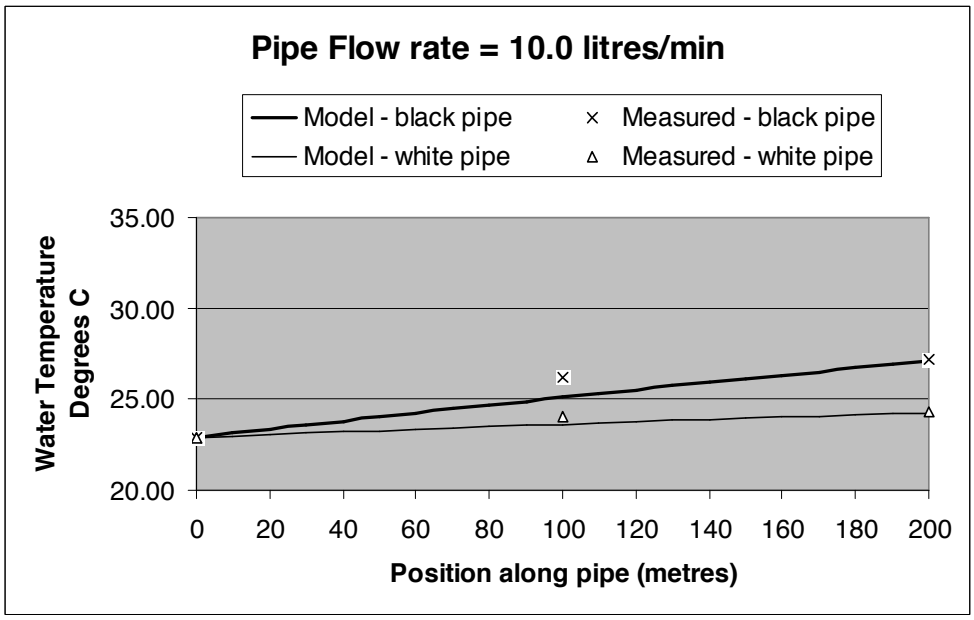
Series Two: Measured water temperatures at inlet, 100 m and 200 m in both painted and unpainted pipes, with comparison to model predictions.

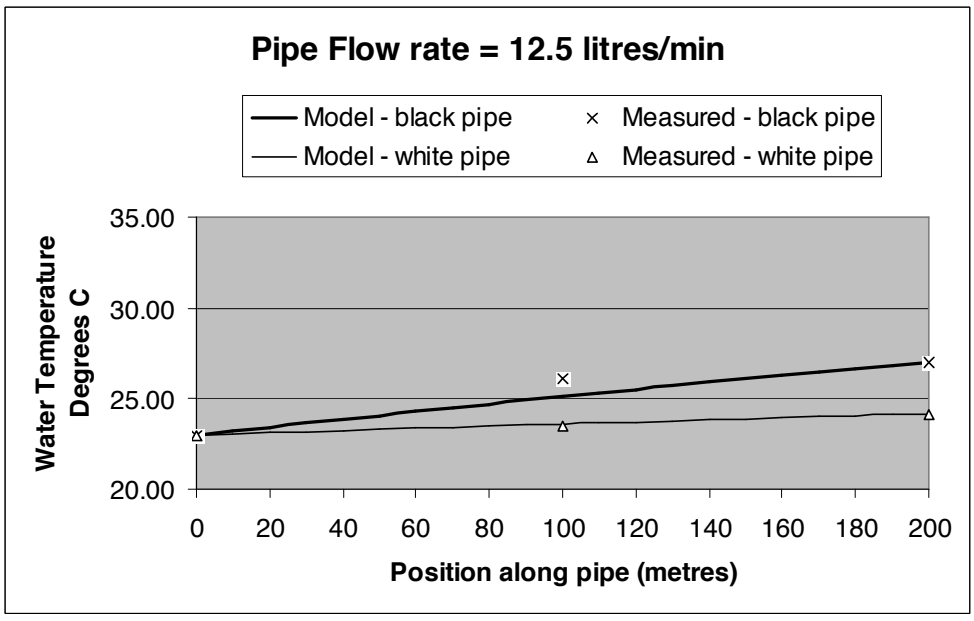
Test	Flow Rate	Solar	Water	Unpainted Pipe		Painted Pipe	
Number	Litres/min	W/m2	Inlet °C	100 m °C	200 m °C	100 m °C	200 m °C
1	2.5	720	23.1	29.2	30.9	25.2	25.7
2	5.3	760	23.1	27.3	27.9	24.5	24.9
3	7.7	800	23.0	27.0	27.8	24.2	24.5
4	10.0	720	22.9	26.2	27.2	24	24.3
5	12.5	820	23.0	26.1	27.0	23.5	24.1






Pipe Flow rate = 7.7 litres/min
Model - black pipe
Measured - black pipe
Model - white pipe
Measured - white pipe
Water Temperature Degrees C
35.00
30.00
25.00
20.00
0
20
40
60
80
100
120
140
160
180
200
Position along pipe (metres)

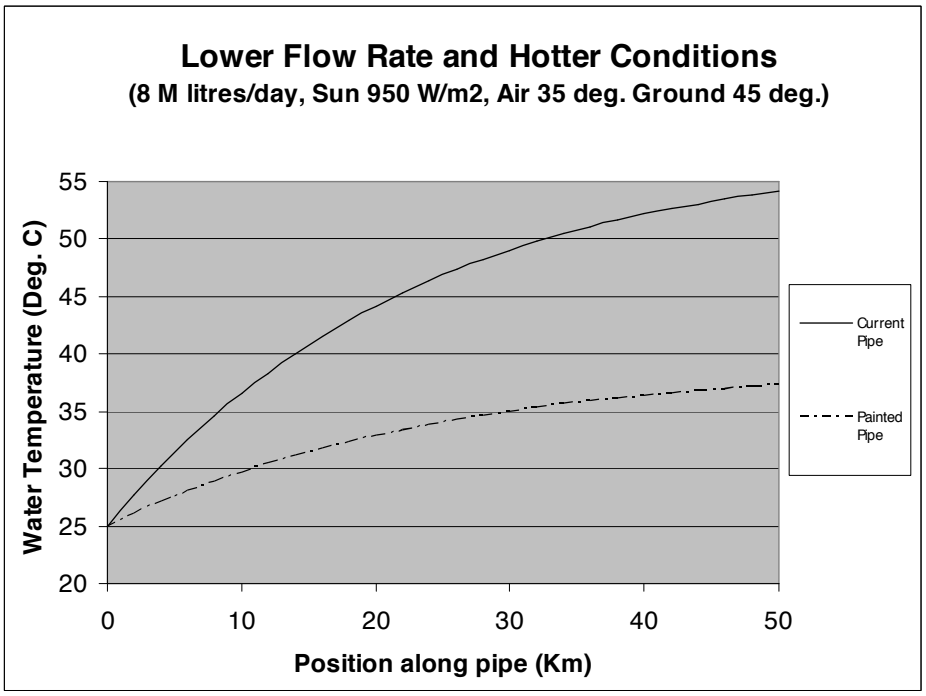

Pipe Flow rate = 10.0 litres/min
Model - black pipe
Measured - black pipe
Model - white pipe
Measured - white pipe
Water Temperature Degrees C
35.00
30.00
25.00
20.00
0
20
40
60
80
100
120
140
160
180
200
Position along pipe (metres)

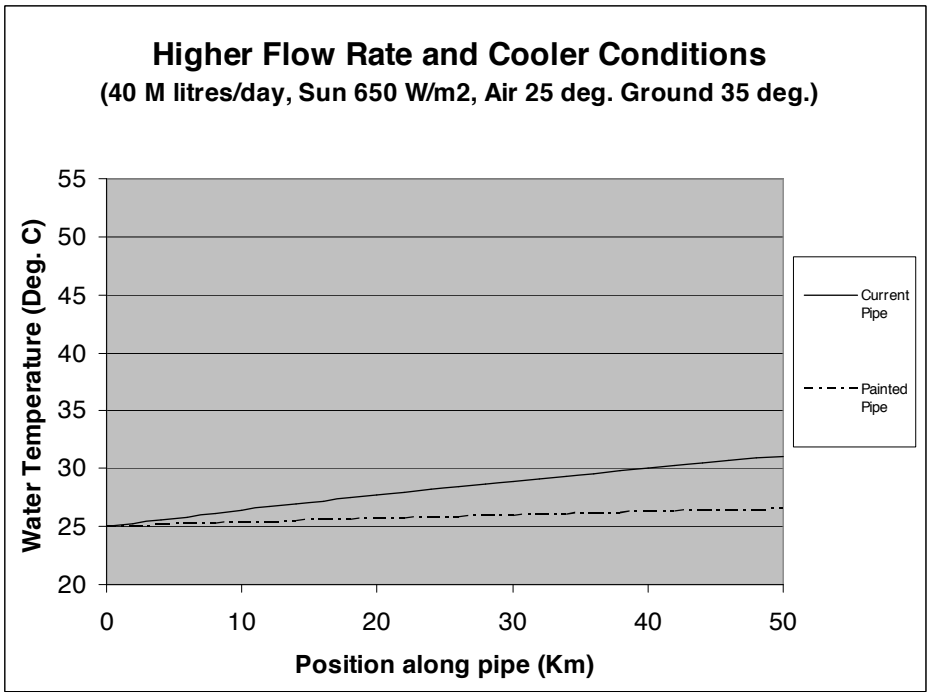

Pipe Flow rate = 12.5 litres/min
Model - black pipe
Measured - black pipe
Model - white pipe
Measured - white pipe
Water Temperature Degrees C
35.00
30.00
25.00
20.00
0
20
40
60
80
100
120
140
160
180
200
Position along pipe (metres)

From these results the mathematical model is shown to accurately predict the water temperature at the pipe exit for the experimental arrangement, and thus is expected to predict the water temperature increase along the pipeline with some confidence.

Mathematical Model Results.

The water temperature increase over a 50 km length of a 640mm diameter, concrete lined, steel pipe was determined for a range of flow rates and surrounding conditions for both a painted and an unpainted pipe. The results for the greatest and least effect of painting the pipe are shown in the following two graphs respectively.





Examination of the results obtained by modelling the pipeline in average, cooler and hotter conditions, and for flow rates between 8 M litres/day and 40 M litres/day, show that the greatest reductions in water temperature achieved by painting the pipe occur at the lowest flow rates in combination with the hotter conditions. The first of the two graphs above provides a direct comparison between the painted and unpainted pipes under these conditions. From an initial inlet temperature of 25°C the water temperature rises to 54°C in the unpainted pipe over the 50 km pipeline length. This very high water temperature is predicted to be reduced to 37°C by painting the outer surface of the pipeline with a heat reflective paint.

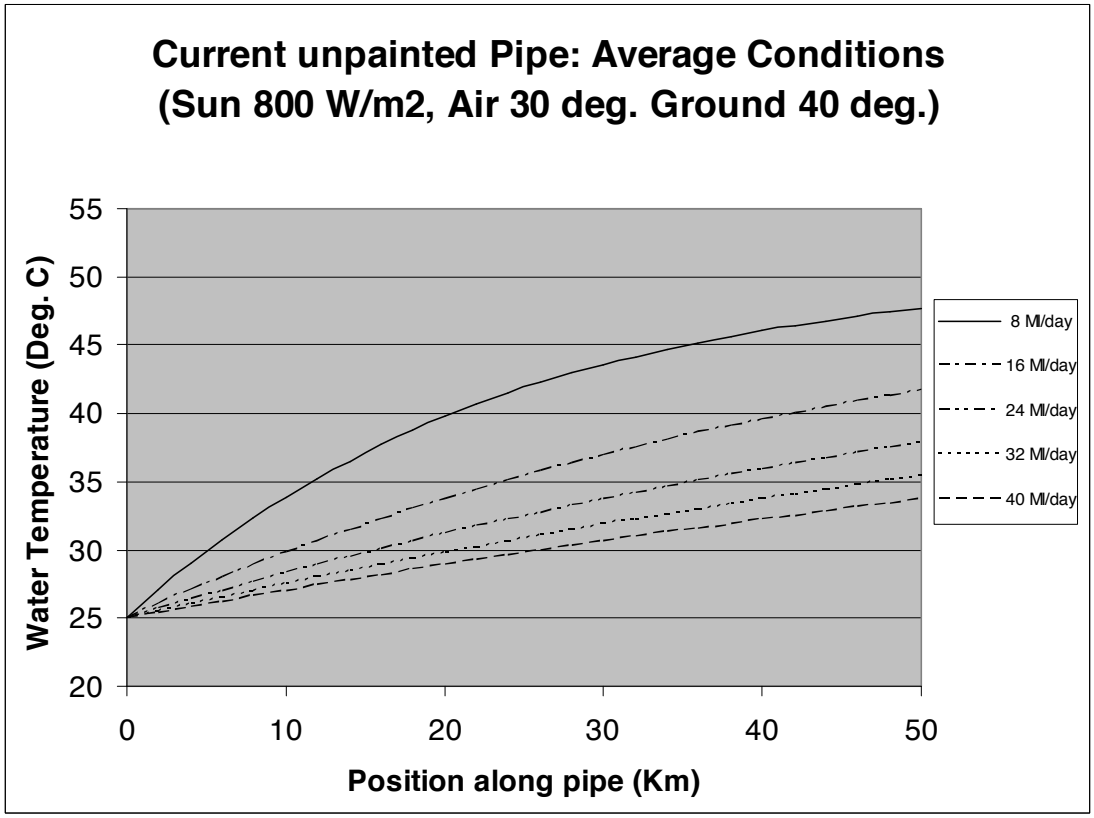
The extent of the predicted reduction in water temperature is seen to be reduced at higher flow rates and in cooler conditions. The second of the two graphs above illustrates the more limited effect of painting the pipe at a flow rate of 40 M litres/day in cooler conditions. For an inlet water temperature of 25°C, the predicted water temperature reaches 31°C for the current unpainted pipe, and 27°C for the painted pipe.

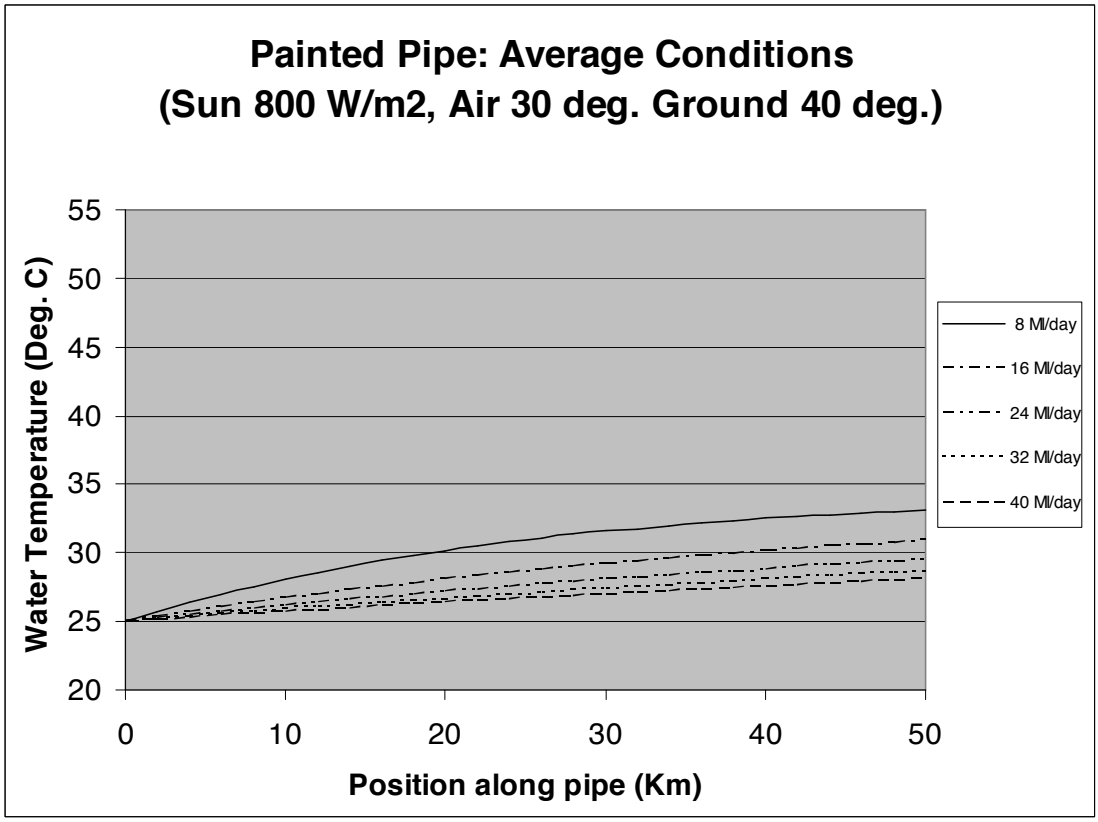
Results for five flow rates (8,16,24,32 and 40 M litres/day) are provided in the Appendix for both the unpainted and the painted pipe, for average, hotter and cooler conditions.

Conclusions.

The application of heat reflective paint is expected to significantly reduce the higher temperatures reached in water flowing through long above ground pipelines in hot surrounding conditions. For the range of conditions examined in this report, for water entering a 50 km pipeline at 25°C, the maximum water temperature is predicted to remain below 40°C if the pipe is painted with heat reflective paint.

Appendix:
Heat Transfer Model Results, 50 km pipeline





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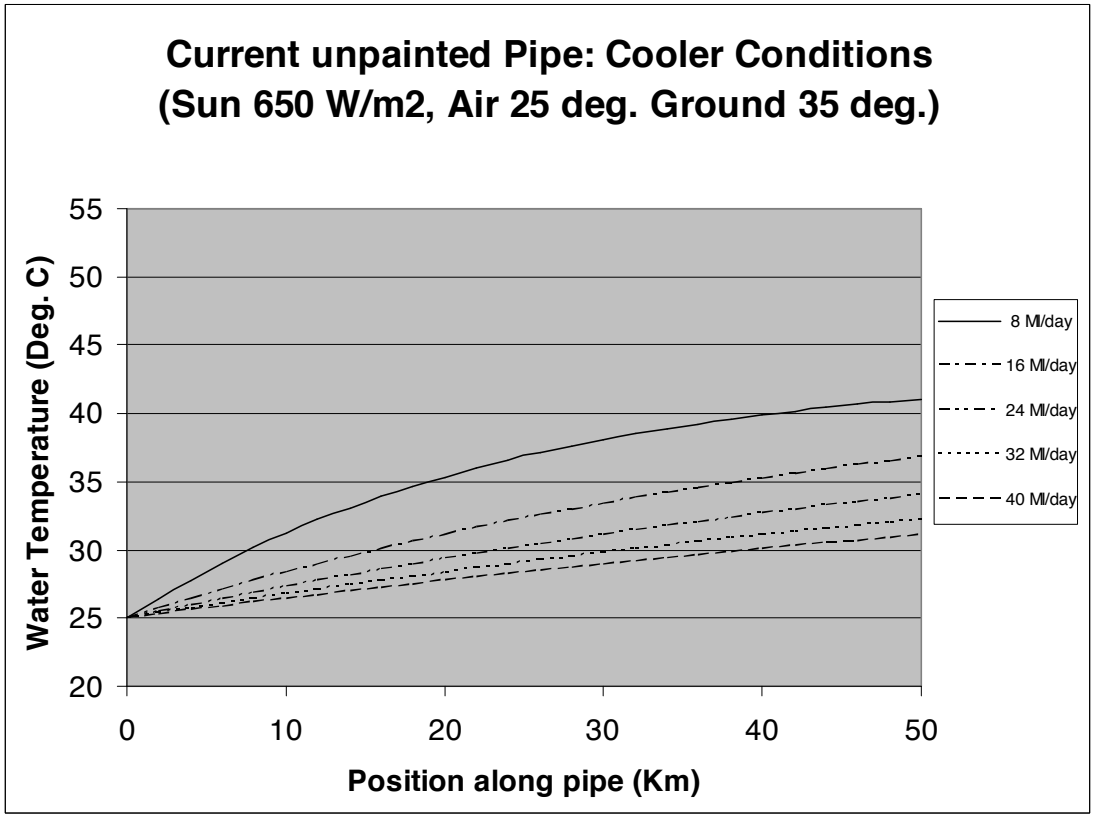

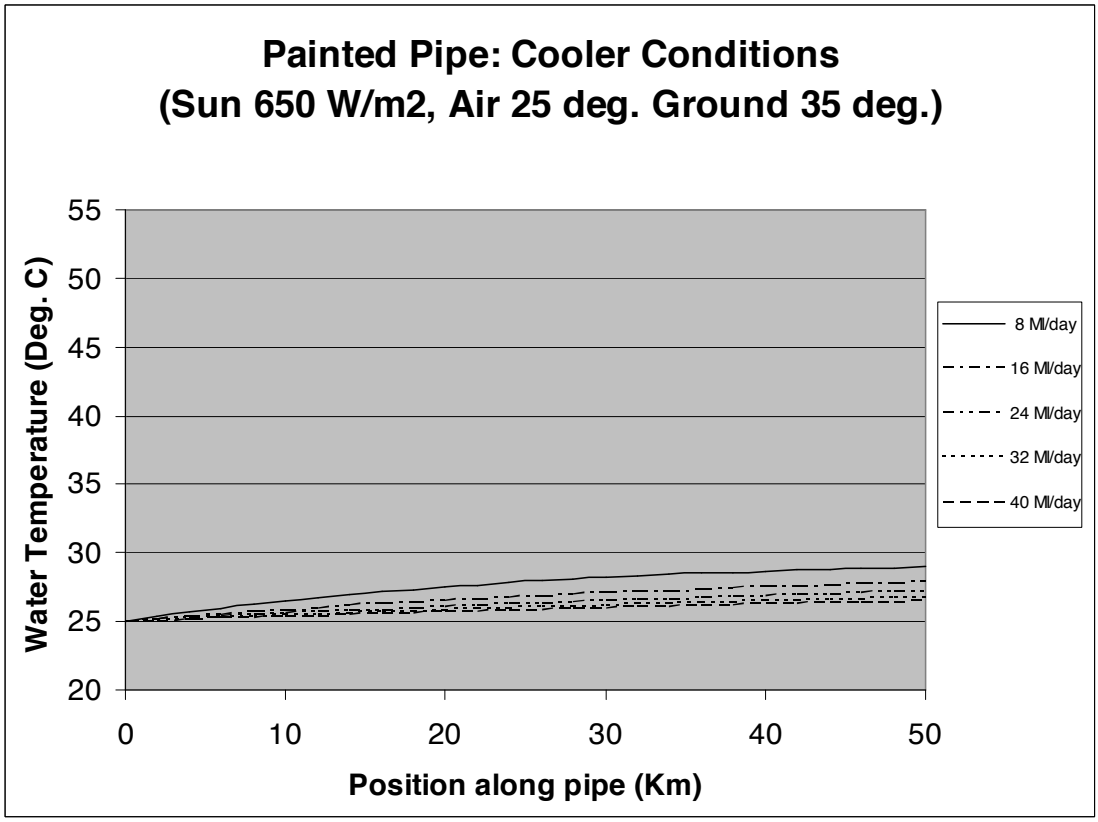

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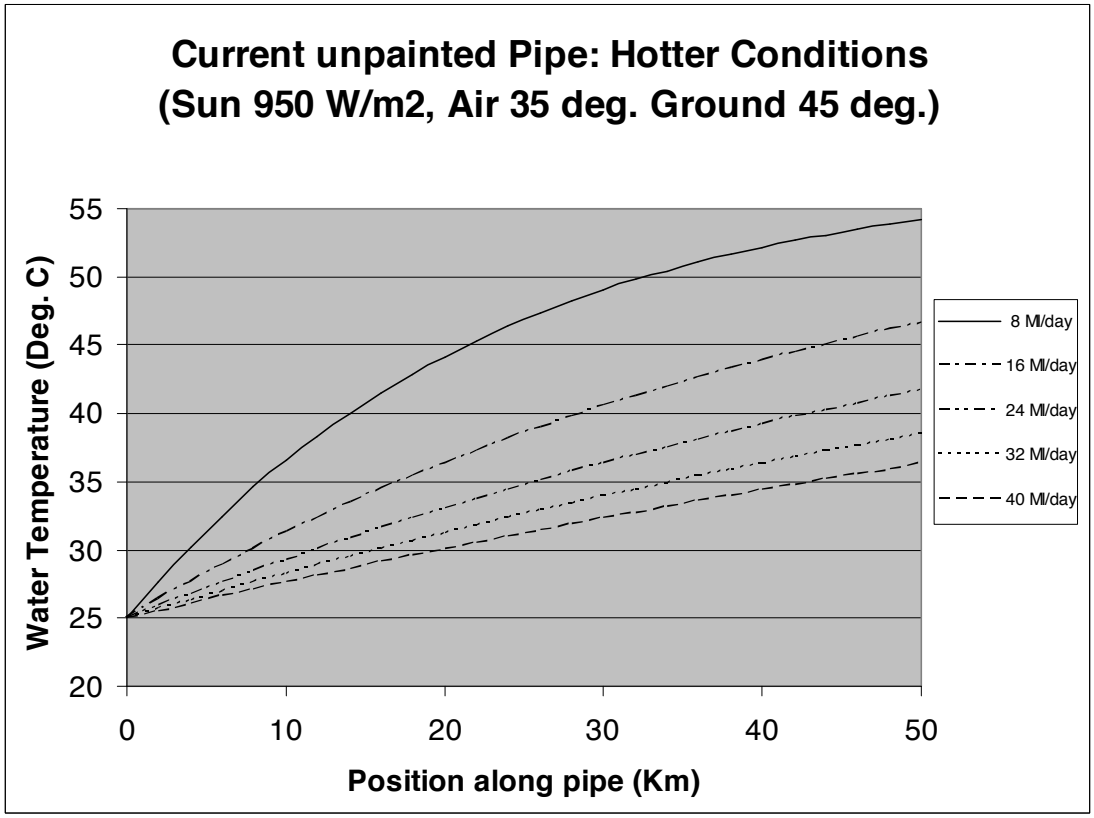

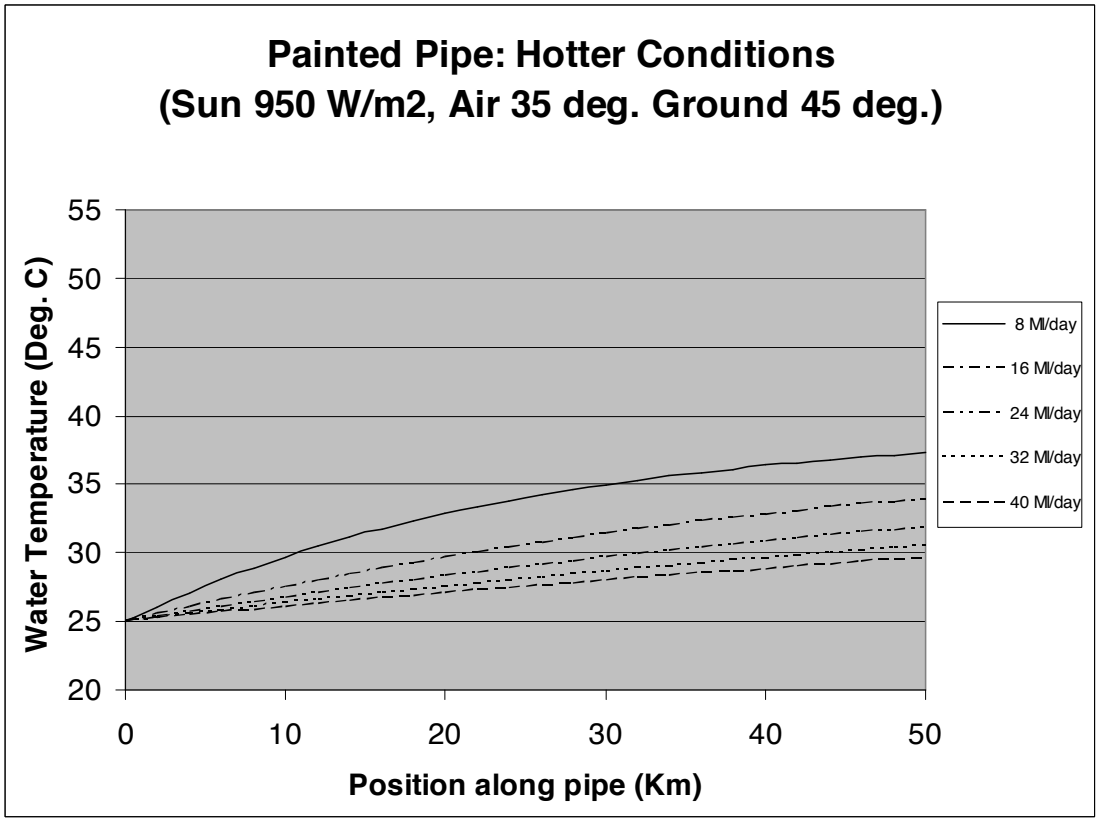

Appendix:
Heat Transfer Model Results, 50 km pipeline

Predicted Water Temperatures										
Average Conditions: Solar Radiation 800 W/m2, Air 30 deg,., Ground 40 deg. Water inlet 25 deg.										
Flow Rate	8 M litres/Day		16 M litres/Day		24 M litres/Day		32 M litres/Day		40 M litres/Day	
x (km)	Current	Painted	Current	Painted	Current	Painted	Current	Painted	Current	Painted
0	25.00	25.00	25.00	25.00	25.00	25.00	25.00	25.00	25.00	25.00
2	27.07	25.72	26.04	25.36	25.69	25.24	25.52	25.18	25.42	25.15
4	28.99	26.39	27.04	25.71	26.37	25.48	26.03	25.36	25.83	25.29
6	30.75	27.01	28.00	26.05	27.03	25.71	26.53	25.53	26.23	25.43
8	32.38	27.57	28.93	26.37	27.67	25.93	27.03	25.71	26.63	25.57
10	33.88	28.10	29.81	26.68	28.30	26.15	27.51	25.87	27.02	25.70
12	35.26	28.59	30.67	26.98	28.91	26.36	27.98	26.04	27.41	25.84
14	36.53	29.04	31.49	27.26	29.50	26.57	28.44	26.20	27.79	25.97
16	37.69	29.45	32.28	27.54	30.08	26.77	28.90	26.36	28.16	26.10
18	38.77	29.83	33.03	27.81	30.64	26.97	29.34	26.51	28.53	26.23
20	39.75	30.18	33.76	28.06	31.19	27.16	29.78	26.67	28.89	26.36
22	40.66	30.51	34.46	28.31	31.72	27.35	30.21	26.82	29.25	26.48
24	41.49	30.81	35.13	28.54	32.24	27.53	30.63	26.96	29.60	26.60
26	42.25	31.09	35.77	28.77	32.75	27.71	31.04	27.11	29.95	26.72
28	42.95	31.34	36.39	28.99	33.24	27.88	31.45	27.25	30.29	26.84
30	43.59	31.58	36.98	29.20	33.72	28.05	31.84	27.39	30.62	26.96
32	44.18	31.80	37.54	29.40	34.19	28.21	32.23	27.52	30.95	27.08
34	44.72	32.00	38.09	29.59	34.64	28.37	32.61	27.66	31.28	27.19
36	45.21	32.18	38.61	29.78	35.08	28.53	32.98	27.79	31.60	27.30
38	45.66	32.35	39.11	29.96	35.51	28.68	33.35	27.92	31.91	27.41
40	46.08	32.51	39.59	30.13	35.93	28.83	33.70	28.04	32.22	27.52
42	46.46	32.65	40.05	30.30	36.34	28.97	34.05	28.16	32.52	27.63
44	46.81	32.79	40.50	30.45	36.74	29.11	34.40	28.29	32.82	27.73
46	47.12	32.91	40.92	30.61	37.12	29.25	34.73	28.40	33.12	27.84
48	47.41	33.02	41.33	30.75	37.50	29.38	35.06	28.52	33.41	27.94
50	47.68	33.13	41.72	30.90	37.86	29.51	35.39	28.63	33.69	28.04

Appendix:
Heat Transfer Model Results, 50 km pipeline

Predicted Water Temperatures										
Cooler Conditions: Solar Radiation 650 W/m2, Air 25 deg,., Ground 35 deg. Water inlet 25 deg.										
Flow Rate	8 M litres/Day		16 M litres/Day		24 M litres/Day		32 M litres/Day		40 M litres/Day	
x (km)	Current	Painted	Current	Painted	Current	Painted	Current	Painted	Current	Painted
0	25.00	25.00	25.00	25.00	25.00	25.00	25.00	25.00	25.00	25.00
2	26.45	25.35	25.73	25.18	25.49	25.12	25.36	25.09	25.29	25.07
4	27.79	25.67	26.43	25.35	25.96	25.23	25.72	25.17	25.58	25.14
6	29.02	25.97	27.10	25.51	26.42	25.34	26.07	25.26	25.86	25.21
8	30.16	26.25	27.75	25.66	26.87	25.45	26.42	25.34	26.14	25.28
10	31.22	26.51	28.37	25.82	27.31	25.56	26.75	25.42	26.41	25.34
12	32.19	26.74	28.97	25.96	27.73	25.66	27.08	25.50	26.68	25.41
14	33.08	26.96	29.54	26.10	28.15	25.76	27.41	25.58	26.95	25.47
16	33.90	27.17	30.09	26.23	28.55	25.86	27.73	25.66	27.21	25.54
18	34.66	27.35	30.62	26.36	28.95	25.96	28.04	25.74	27.47	25.60
20	35.36	27.52	31.13	26.49	29.33	26.05	28.34	25.81	27.72	25.66
22	36.00	27.68	31.62	26.61	29.71	26.14	28.65	25.88	27.97	25.72
24	36.59	27.83	32.09	26.72	30.07	26.23	28.94	25.95	28.22	25.78
26	37.14	27.97	32.55	26.83	30.43	26.32	29.23	26.02	28.46	25.84
28	37.64	28.09	32.98	26.94	30.77	26.40	29.51	26.09	28.70	25.90
30	38.10	28.21	33.40	27.04	31.11	26.48	29.79	26.16	28.93	25.95
32	38.52	28.32	33.80	27.14	31.44	26.56	30.06	26.23	29.17	26.01
34	38.91	28.42	34.18	27.23	31.76	26.64	30.33	26.29	29.39	26.06
36	39.27	28.51	34.55	27.33	32.07	26.72	30.59	26.35	29.62	26.12
38	39.59	28.59	34.91	27.41	32.37	26.79	30.84	26.42	29.84	26.17
40	39.90	28.67	35.25	27.50	32.66	26.86	31.10	26.48	30.05	26.22
42	40.17	28.74	35.58	27.58	32.95	26.93	31.34	26.54	30.27	26.28
44	40.43	28.81	35.89	27.66	33.23	27.00	31.58	26.60	30.48	26.33
46	40.66	28.87	36.19	27.73	33.50	27.07	31.82	26.66	30.68	26.38
48	40.87	28.93	36.48	27.80	33.77	27.13	32.05	26.71	30.89	26.43
50	41.07	28.98	36.76	27.87	34.02	27.20	32.28	26.77	31.09	26.48

Appendix:
Heat Transfer Model Results, 50 km pipeline

Predicted Water Temperatures										
Hotter Conditions: Solar Radiation 950 W/m2, Air 35 deg,., Ground 45 deg. Water inlet 25 deg.										
Flow Rate	8 M litres/Day		16 M litres/Day		24 M litres/Day		32 M litres/Day		40 M litres/Day	
x (km)	Current	Painted	Current	Painted	Current	Painted	Current	Painted	Current	Painted
0	25.00	25.00	25.00	25.00	25.00	25.00	25.00	25.00	25.00	25.00
2	27.70	26.10	26.36	25.55	25.91	25.37	25.68	25.28	25.54	25.22
4	30.20	27.11	27.66	26.08	26.79	25.73	26.35	25.55	26.08	25.44
6	32.49	28.05	28.91	26.59	27.65	26.08	27.00	25.81	26.61	25.65
8	34.61	28.92	30.12	27.08	28.48	26.42	27.64	26.07	27.13	25.86
10	36.56	29.72	31.27	27.56	29.30	26.75	28.27	26.33	27.64	26.07
12	38.35	30.46	32.38	28.01	30.09	27.07	28.88	26.58	28.14	26.28
14	39.99	31.14	33.45	28.45	30.87	27.39	29.49	26.83	28.63	26.48
16	41.50	31.76	34.47	28.87	31.62	27.70	30.08	27.07	29.12	26.68
18	42.88	32.34	35.46	29.27	32.35	28.00	30.66	27.31	29.60	26.87
20	44.15	32.88	36.40	29.66	33.06	28.29	31.23	27.54	30.07	27.07
22	45.31	33.37	37.30	30.03	33.76	28.57	31.79	27.77	30.54	27.26
24	46.37	33.82	38.17	30.39	34.43	28.85	32.33	27.99	31.00	27.44
26	47.35	34.24	39.00	30.73	35.09	29.12	32.87	28.21	31.45	27.63
28	48.24	34.62	39.80	31.06	35.73	29.38	33.39	28.42	31.89	27.81
30	49.05	34.98	40.57	31.38	36.35	29.64	33.91	28.63	32.32	27.99
32	49.80	35.30	41.30	31.69	36.96	29.89	34.41	28.84	32.75	28.16
34	50.48	35.60	42.00	31.98	37.55	30.13	34.91	29.04	33.17	28.33
36	51.10	35.88	42.68	32.26	38.12	30.37	35.39	29.24	33.59	28.50
38	51.67	36.13	43.32	32.53	38.67	30.60	35.86	29.44	34.00	28.67
40	52.19	36.36	43.94	32.79	39.22	30.82	36.33	29.63	34.40	28.84
42	52.66	36.58	44.53	33.04	39.74	31.04	36.78	29.81	34.80	29.00
44	53.09	36.78	45.10	33.28	40.26	31.25	37.23	30.00	35.18	29.16
46	53.48	36.96	45.64	33.51	40.75	31.46	37.66	30.18	35.57	29.31
48	53.84	37.13	46.16	33.73	41.24	31.66	38.09	30.36	35.94	29.47
50	54.17	37.28	46.66	33.95	41.71	31.86	38.51	30.53	36.31	29.62