INVESTIGATION INTO BITUMEN HEATING

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Technic Roading and Civil Engineering Companies, the NZ Bitumen Contractors' Association Inc. (BCA), and Transit New Zealand.

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EXECUTIVE SUMMARY

In 1990 the New Zealand Bitumen Contractors' Association Inc. (BCA) developed a Code of Practice, "*The Safe Handling of Bituminous Materials Used in Roading*", which includes safety guidelines for tank heating. Technic Roading and Civil Engineering Companies (TRACE) and the BCA undertook research to verify if the limits used in Clauses 3.8.1 and 3.8.4 of the Code were in fact appropriate and achievable.

1991 Testing Programme

- To establish the temperature distribution along a typical flame tube.

- To determine the effects that different types and sizes of burners, nozzles, and different fuels have on temperature gradients along flame tubes.

1. Boral Nu-Way NOL6, Riello Mectron 20M, Boral Nu-Way NG7, Technic, and Matthews burners were tested and performed satisfactorily.

2. Different diesel burner nozzles showed minimal differences, although 30° nozzles appeared to have an improved flame pattern and reduced impingement on the flame shield wall compared to 45° nozzles.

3. The average heating rate was below the recommended maximum of $17kW/m^2$.

4. The maximum temperature of 250°C was exceeded in all tests, with the first five metres of the flame tube subjected to temperatures in excess of the recommended temperature, and the bitumen subjected to localised heating at temperatures up to 347°C.

1992 Testing Programme

- To test the effects of different operating conditions while using the same heating equipment.

1. Smaller nozzles resulted in decreases of all parameters measured.

2. Lower fuel pressure resulted in decreases of all parameters measured.

3. Maximum air flow gave a large drop in the maximum flame tube temperature but reduced the heating rate by up to 2°C/h or approximately 20%.

4. When bitumen is heated up from cold, rapid heating to high temperatures of trapped bitumen occurred (up to 243°C in bitumen at 100mm above the flame tube). Slow heating is necessary until all the bitumen is fluid (110°C).

5. Recirculation appeared to have little effect in reducing flame tube temperatures.

6. Flame tube temperatures in the combustion area were reduced when a flame shield was used.

7. The temperature peak at the end of the 1200mm flame shield was eliminated and a smaller temperature peak was observed at the end of the 5m flame shield.

8. Insulation with KAO wool reduced the flame tube temperatures where it was present but a high temperature peak was observed beyond the end of the KAO wool.

9. Insulation combined with longer flame tube, if combined with an enlarged combustion zone, may possibly keep maximum temperatures below 250°C.

10. Secondary (induced) air reduced the temperatures in the combustion zone, but resulted in a higher flue gas temperature and a decrease in thermal efficiency.

11. A minimum level of bitumen above the flame tube, for safe heating, was 200mm.

12. The time needed to allow the flame tube to cool before safely moving the tanker was 15 minutes.

- To monitor the rate of bitumen hardening as heating cycles continued.

The bitumen hardened as the tests progressed, with the penetration value decreasing from 181 to 121 over 21 heating/cooling cycles. This is an average decrease of 3dmm per heating cycle.

1993 Testing Programme

- To determine the rate of hardening of bitumen that has been held at spraying temperature for a prolonged period of time, in a full tank and in a half-full tank.

Tests revealed that the tank should be kept full to prevent excessive hardening of the bitumen.

The rate of hardening of bitumen in the half full tank is double that of bitumen in a full tank (i.e. 2.6dmm per 24 hour period as against 1.25dmm per 24 hour period).

Note: These results are only directly applicable to the tanker/flame tube/burner configuration used for the tests, and other designs may give different results.

ABSTRACT

When the New Zealand Bitumen Contractors' Association Inc. (BCA) developed a Code of Practice, *"The Safe Handling of Bituminous Materials Used in Roading"*, which includes safety guidelines for tank heating, research was carried out to verify if the limits used in Clauses 3.8.1 and 3.8.4 of the Code were in fact appropriate and achievable.

To provide the necessary information, temperature distribution along a typical flame tube were established; the effects of different heating equipment and different operating conditions were determined; and effects of heating/cooling cycles on hardening of the bitumen in a tank were measured, by carrying out a testing programme spread over three winters (1991 to 1993).

1. INTRODUCTION

The New Zealand road industry consumes approximately 120,000 tonnes of hot bitumen annually. Much of this bitumen is held at pumping and application temperatures of up to 190°C, in tanks fitted with flame tube heaters. Many of these tanks are prone to coke and carbon build-up on the walls and baffles.

In the late 1970s the then National Roads Board (NRB) of New Zealand (now Transit New Zealand) required all bitumen distributors to comply with the NRB E/2 Specification (which later became TNZ E/2 1987) for *"Performance of Bitumen Distributors"*. Incorporated in the specification were the following requirements:

- *That the distributor shall be provided with heating tubes capable of raising the temperature of the bitumen from 135°C to 175°C in not more than two hours when fully laden.*
- *That the flame tubes were required to have a minimum cover of 150mm of bitumen before heating was applied.*

Introduction of the NRB E/2 specification in the 1970s heralded a new era in the technological development of bitumen distributors which included upgrading the heating equipment to meet the new requirements. It also became evident that, in the quest for high heating performance while at the same time economising on size and weight of the heating equipment, many distributors were operating with dangerously high rates of heat transfer into the bitumen.

The New Zealand Bitumen Contractors' Association Inc. (BCA) was formed in 1989, and its first major assignment undertaken was to develop a Code of Practice, published in 1991 as *"The Safe Handling of Bituminous Materials Used in Roading"*.

As the Code needed a section incorporating safety guidelines for bitumen heating, the technical committee preparing the Code needed to establish:

a. Maximum allowable surface temperature at the flame tube/bitumen interface to safeguard against possible degradation of the bitumen.

b. Minimum level of bitumen above the flame tube necessary to safeguard against the risk of fire/explosion during heating operations.

2. BCA CODE OF PRACTICE REQUIREMENTS

In preparing the safety guidelines, the absence of available technical data on bitumen heating was noted and a survey was carried out on current overseas and New Zealand practices (Appendix 2).

The survey failed to identify any definitive information so the following provisional criteria were adopted in the Code:

Clause 3.8.1 *The minimum heating level set for the tank contents shall ensure that every part of the heat transfer surface inside the tank is covered with at least 200mm of binder.*

Clause 3.8.4 *Flame Tubes*

(a) *The heat rating with the burner at maximum firing shall not exceed 17kW (61MJ/hour) per square metre of external tube surface.*

(b) *Alternatively, the maximum heating rate may be established ... by measuring the temperature with thermocouples bonded to the external heating surface. In no position at maximum firing may the surface temperature exceed 250°C.*

In July 1991 Transit New Zealand transferred the administration of Bitumen Distributor Certification to the BCA, who also undertook to review the E/2 specification. The heating criteria in the Code of Practice were adopted in the interim, pending availability of more definitive data. A joint BCA / Technic Roading and Civil Engineering (TRACE) / Transit New Zealand research project on bitumen flame tube heating was commissioned in 1991 to supply the necessary information, and the testing programme was carried out by TRACE. This work was funded by Transit New Zealand, BCA, and TRACE.

The programme was extended over 1992 and 1993 to gather additional information. Details of testing procedure and equipment are given in Appendices 3 and 4 .

3. OBJECTIVES

3.1 1991 Testing Programme

Tests with a bitumen tanker were set up with the following objectives:

- To establish the temperature distribution along a typical flame tube by measuring surface temperatures along the length of the tube at the bitumen/tube interface.

- To determine the effects that different types and sizes of burners, nozzles, and different fuels have on temperature gradients along flame tubes.

3.2 1992 Testing Programme

Tests set up in 1992 to continue the programme had the following objectives:

- To test the effects of different operating conditions while using the same heating equipment.

1. To decide on a nozzle size that gives low temperatures on the flame tube surface, but still maintains an adequate heating rate.

2. To decide on a fuel pressure setting that gives low temperatures on the flame tube surface, but still maintains an adequate heating rate.

3. To confirm the observation, made in 1991, of the effect of maximum air flow through the flame tube.

4. To observe the effect of heating up from cold.

5. To determine the effect of recirculation (tank agitation) on heating rates, on temperatures of flame tube surfaces, and on thermal efficiency.

6. To observe the effect of the flame shield on temperature gradients along the flame tube.

7. To observe the effect on temperature gradients along the flame tube by lengthening the flame shield.

8. To investigate the effect of insulation (KAO wool) on temperature gradients along the flame tube.

9. To investigate the combined effect of insulation and longer flame shield on temperature gradients along the flame tube.

10. To investigate the effect of secondary (induced) air on reducing the excessive temperatures in the combustion zone and on distributing the heat more evenly along the length of the flame tube.

11. To determine if the minimum level of bitumen above the flame tube, for safe heating, specified as 200mm in Clause 3.8.1 of the provisional BCA Code of Practice, is sufficient.

12. To determine the time taken, after the burner is extinguished, before the flame tube surface temperature drops below 255°C, and therefore to determine the time delay before the tanker can be safely moved.

- To monitor the rate of bitumen hardening as heating cycles continued.

3.3 1993 Testing Programme

Further tests were carried out in 1993:

- To determine the rate of hardening of bitumen being held at spraying temperature for a prolonged period of time, in a full tank and in a half full tank.

3.4 Further Use for the Data

The data obtained from the 3-year testing programme will be supplied to the Technical Committee of the BCA for further consideration of Objective 3, which is:

- To verify that the requirements of Clauses 3.8.1. and 3.8.4 of the Code of Practice are relevant and practical, and would produce "safe" heating.

(This objective is not discussed further in this report.)

Note: These results are only directly applicable to the tanker/flame tube/burner configuration used for the tests, and other designs may give different results.

4. 1991 TESTING PROGRAMME

4.1 Introduction

The bitumen tanker used had 38 temperature probes attached for the series of tests undertaken in 1991. Of these probes, 34 were attached to the flame tube, one was in the flue, one was in the tank to measure the temperatures of the bitumen contents, one was in the drain filter to measure the pump suction temperature, and one was on the outside of the tank to measure the ambient air temperature. Probe locations are illustrated in Appendix 4 "Thermocouple Location and Identification (1991 Tests)".

The probes on the flame tube were 200mm to 400mm apart in the combustion zone (the first 2 metres) and then at 1m spacings along the balance of its length.

Four probes were positioned circumferentially on the flame tube at four points along the tube, at 200mm, 900mm, 1450mm and 2850mm distance from the burner end.

Different models and types of burners and nozzles were tested, each being attached to the open end of the flame tube in turn to determine the temperature gradients and fuel consumptions they produced. Three fuels, diesel, LPG and natural gas, were tested as well. Details of burners, nozzles and fuels used for the tests are given in Appendix 4.

4.2 Results

These results were developed using the tests set up to answer the objectives listed in Section 3.1. The details of the test results are summarised in Section 4.2.3. All graphs have been plotted using measurements taken from probes located on top of the flame tube.

4.2.1 Temperature Distribution along Flame Tubes

- *To establish the temperature distribution along a typical flame tube by measuring surface temperatures along the length of the tube at the bitumen/tube interface.*

4.2.1.1 Temperature distribution along the flame tube

The temperature gradient along the flame tube follows a similar pattern irrespective of which burner or fuel is used.

Figure 1 shows temperature gradients obtained from three different fuels: Diesel, LPG, and Natural Gas. The Diesel and Natural Gas readings were taken just before the burner turned off (by thermostatic control) after reaching normal spraying temperature (165°C).

The LPG readings were taken just after a new LPG bottle had been installed. At this time, a more representative comparison can be made between the three fuels. As the

LPG bottles became empty, they tended to ice up and the gas supply to the burner decreased. Full bottles give better pressures and higher temperatures, and gave a more accurate picture of the maximum temperatures to which the bitumen was subjected.

The graphs in Figure 1 show similar shapes, with high temperatures at the wall of the tank, a drop in temperature at about 0.5m from the wall, followed by a rise in temperature to a maximum (approximately 325°C) at about 1.2m where the flame shield ends, then a steady temperature decrease to approximately 210°C - 230°C at the exit of the tube.

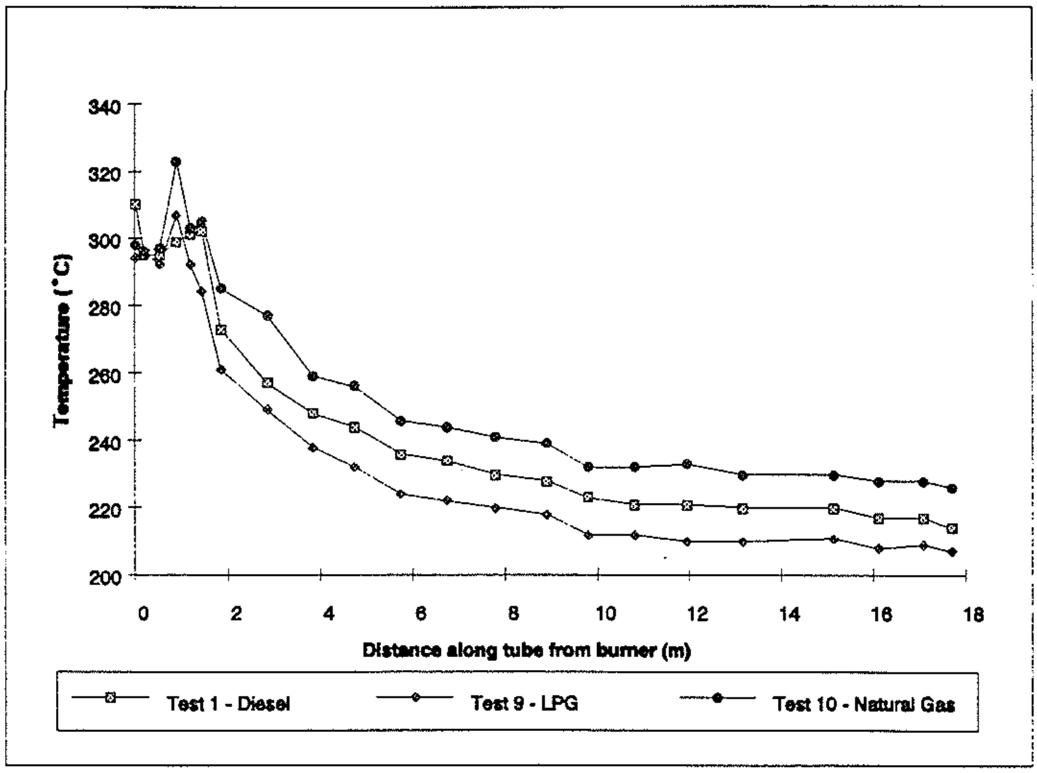


Figure 1. Effect of diesel, LPG and natural gas fuels on temperature gradient of the flame tube.

The high temperature at the tank wall, where the flame tube enters the tank, could be caused by the position of the burner, which could be too far from the tank wall. To remedy this a modification was made for the 1992 series of tests (see Section 5 for details of modification).

In all the 1991 tests with the burner nozzle positioned 300mm from the tank wall, probe 1 (0.02m from tank wall) always gave a higher reading than probe 2 (0.2m from tank wall). The results obtained with the burner nozzle only 150mm from the tank wall are considered in Section 5.

4.2.1.2 Maximum temperatures on the flame tube

Maximum temperatures obtained on the flame tube are listed in Tables 1 and 2.

Table 1. Distance (metres) from burner end of flame tube beyond which the tube has a temperature lower than 250°C throughout the test.

Test No.	1	2	3	4	5	6	7	8	9	10	11
Probe No.	19	20	20	19	19	17	20	9	19	21	15
Distance (m)	2.85	3.85	3.85	2.85	2.85	2.85	3.85	0.90	2.85	4.75	1.85

As the probes were not closer than one metre apart, a change of 1°C (say from 249°C to 250°C) could appear as a variation of one metre and is not significant.

Table 2. Maximum tube temperatures (°C) and the distance (m) of the probe which recorded them from the burner end of the flame tube.

Test No.	1	2	3	4	5	6	7	8	9	10	11
Probe No.	9	7	9	4	4	4	4	9	7	9	9
Distance(m)	0.9	0.9	0.9	0.2	0.2	0.2	0.2	0.9	0.9	0.9	0.9
Temp. (°C)	338	338	334	331	340	320	335	252	327	347	304

An external flame tube temperature of less than 250°C is not achievable with the configurations of the flame tubes and burners that were tested. In some cases 250°C has been exceeded by up to 97°C.

Similar flame tube temperatures were produced by all burners, except the Boral Nu-Way NG5 and Matthews (tests 8 and 11 respectively). Both of these gave much lower firing rates than the other burners.

The Technic (test 7) and Matthews (test 11) are non fan-assisted vaporising type LPG burners. These types of burners did not produce significantly different flame tube temperatures to either the fan-assisted or pressure-jet burners.

4.2.1.3 Temperature variation on circumference of the flame tube

The temperature gradient on the circumference of the flame tube was investigated. Figure 2 shows the temperatures recorded at the time just before the burner turned off, at probes 6, 7, 8, and 9 (0.9 metres from the burner) and in Figure 3 at probes 16, 17, 18, and 19 (2.85 metres from the burner).

At 0.9 metres distance the bottom of the tube was much colder, with the sides hotter than the top. At 2.85 metres away from the burner all parts of the tube were at approximately the same temperature.

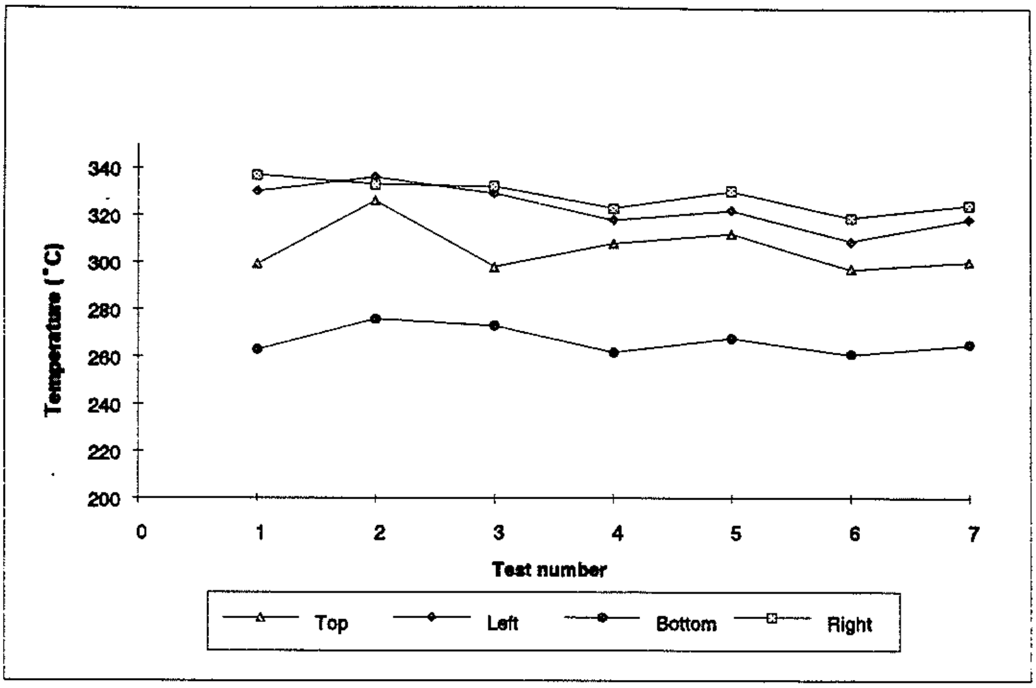


Figure 2. Variation in temperatures around the circumference of the flame tube at 0.9m distance from the burner, for seven tests (using different burners and fuels).

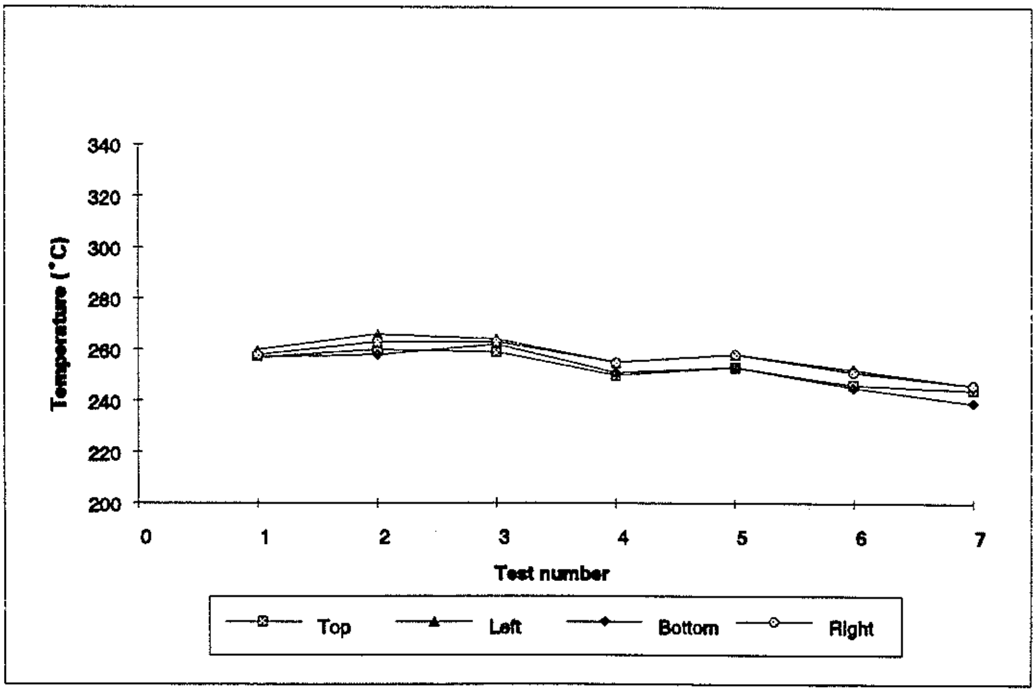


Figure 3. Variation in temperatures around the circumference of the flame tube at 2.85m distance from the burner, for seven tests (using different burners and fuels).

4.2.2 Effects of Heating Equipment

- *To determine the effects that different types and sizes of burners, nozzles, and different fuels have on temperature gradients along flame tubes.*

4.2.2.1 Effect of burner type

The burners used the following fuels (Appendix 4 for further information):

DIESEL: Boral Nu-Way NOL5, Boral Nu-Way NOL6,
Riello Mectron 20M
LPG: Boral Nu-Way NG5, Boral Nu-Way NG7,
Technic (non-fan assisted), Matthews (non-fan assisted)
NATURAL GAS: Boral Nu-Way NG7

• **Diesel burner** Comparison of Boral Nu-Way NOL6 and Riello Mectron 20M diesel burners in tests 1 and 2 showed no significant difference in the performance of these burners.

• **LPG burner** Comparison of different LPG burners in tests 7, 8, 9 and 11 indicated that the Boral Nu-Way NG7 (Test 9) was more efficient than the Technic burner (Test 7). Only these two burners had sufficient capacity to give an adequate firing rate for the test tanker.

The Boral Nu-Way NG7 gave a lower temperature in the first metre of flame tube than the Technic burner (possibly because of its mounting position and fan). Similar temperature increases per hour were recorded but the Boral Nu-Way NG7 had a lower fuel consumption and lower firing rate than the Technic burner.

Heating occurred rapidly at the beginning of heating using LPG, then heating decreased for much of the heating time. This decrease was caused by the gas regulator icing up, reducing the gas supply pressure. Icing up occurred on all burners using LPG, although it was more pronounced in the Technic burner which has a larger nozzle. Peaks in temperature recorded in the course of some tests using LPG were caused when LPG bottles were changed. Full bottles gave an initial temperature increase.

The Matthews burner (test 11) had a very low initial temperature compared to the other burners using LPG, and the tube was not hot at the tank wall probably because of the burner position. The burner had a low fuel consumption rate, with a correspondingly low firing rate and temperature rise of the bitumen. The Matthews burner had a smaller nozzle than the other burners using LPG that were tested, and the fuel supply pressure was set at a lower level. (Set-up parameters were obtained from the supplier and from Fulton Hogan personnel.)

The fan on the Boral Nu-Way NG5 burner used in test 8 appeared unable to overcome back pressure generated in the flame tube, so the burner was adjusted to match the air available (otherwise the mixture became too rich and "popping" occurred). This gave insufficient fuel to produce an adequate firing rate. As a result the temperature rise was only 6.6°C/h.

• **Natural gas burner** Boral Nu-Way NG7 performed satisfactorily.

4.2.2.2 Effect of burner size

- **Diesel burner** Comparisons between Boral Nu-Way NOL5 and Boral Nu-Way NOL6 (test 1 v 4, test 3 v 5) showed no significant differences in performance between the different sized burners. Temperature rise, fuel consumption and firing rates were similar in tests 1 and 4. Test 3 with the Boral Nu-Way NOL6 burner had a greater temperature rise, fuel consumption and firing rate than test 5.

Burners designed for flame tube heating require fans that have sufficient capacity to overcome the tube resistance (back pressure). If burners are not specifically designed for flame tube heating, a larger size of burner is usually used to ensure sufficient fan size. The minimum acceptable sizes of burner were based on the capacity of their fan to overcome tube resistance and to supply adequate excess air.

As the Boral Nu-Way NOL5 had no spare fan capacity, it was capable of stoichiometric combustion only. The Boral Nu-Way NOL6 did have spare fan capacity which was utilised when tests with excess (secondary) air were carried out in 1992 (Section 5.2.1.10).

The oxygen content of the exit gas was measured using a Combustion Analyser mounted in the exit flue of the flame tube.

The Boral Nu-Way NOL6 or the Riello Mectron 20M diesel burners are the minimum acceptable size for this kind of application.

- **LPG burner** The Boral Nu-Way NG5 was unacceptably small, and the Matthews burner was barely sufficient, although it could have been easily modified.

The Boral Nu-Way NG7 and the Technic were adequate for the heating required.

- **Natural gas burner** The Boral Nu-Way NG7 was adequate for the heating required.

4.2.2.3 Effect of burner nozzles (for diesel burners only)

Comparisons between spray angles of the Danfoss S 30° and Monarch AR 45° nozzles (test 1 v 3, test 4 v 5) showed no overall difference between nozzle types or configurations. No significant differences in flue gas temperatures were noted.

The Danfoss S 30° nozzles gave a longer flame, that impinged less on the flame shield surface, and required less air for stoichiometric combustion, than did the Monarch AR 45° nozzles.

Overall, no measurable differences were apparent between the nozzles, but the lower capacity of the Delevan B nozzle resulted in lower values for all parameters.

4.2.2.4 Effect of burner fuels

Diesel, LPG and natural gas fuels were used in the tests.

- **Temperature** All three fuels gave similar temperatures in the combustion zone. Further along the flame tube, LPG gave the lowest flame tube temperatures, and natural gas the highest (Figure 1).

- **Pressure** LPG fuel pressure could not be held constant throughout a test because the regulators iced up. Although LPG gave the lowest temperatures at the end of the test (and other fuels gave the maximum temperatures), immediately after a change to a full LPG bottle, the temperatures in the combustion zone of the flame tube were similar to those recorded using natural gas and diesel.

The second temperature peak for LPG burners in tests 7, 8, 9 and 11 was not as high as for diesel or natural gas, possibly related to different flame characteristics. Beyond one metre tube temperatures were lower for LPG than those in all diesel tests at the time the temperatures were recorded.

Table 3. Comparison of energy inputs and resulting maximum temperatures between LPG and natural gas.

Test No.	Fuel	Rate of energy input	Max.Temp. (°C)
9	LPG	9.2 kg/h x 49.7 MJ/kg = 457 MJ/h	327
10	Natural Gas	10 m^3/h x 40.5 MJ/m^3 = 405 MJ/h	347

The comparison between LPG and natural gas in tests 9 v 10 (Table 3) showed that natural gas had a lower rate of energy input, but increased temperature rise and higher maximum temperature. The natural gas test (10) gave temperatures that were approximately 20°C hotter along the entire length of the tube, and the highest maximum tube temperature recorded, of 347°C.

- **Efficiency** Comparing the efficiency of the fuels on the energy (MJ) required to raise the temperature by 1°C basis, diesel (33.4MJ) and LPG (32.4MJ) gave similar rates while natural gas (24.5MJ) appeared more efficient.

Fuel	Energy (MJ)/°C
Diesel	33.4
LPG	32.4
Natural gas	24.5

4.2.2.5 Effect of fan capacity on air flow

Before beginning the testing programme, the fan-assisted diesel and LPG burners were adjusted for maximum efficiency, with the air damper adjusted for minimum excess air (thus allowing stoichiometric combustion, explained in Appendix 4.5).

4.2.3 Summary of 1991 Heating Test Results

TEST No.	BURNER MAKE & MODEL	NOZZLE MAKE, SIZE & CONFIG	FUEL	FUEL PRESSURE	FUEL CONSUMP	FIRING RATE *	HEATING RATE *	BITUMEN TEMP RISE +	MAX TUBE TEMP
1	Boral Nu-way NOL6	Danfoss S 30° 8kg/h @ 6.9bar	Diesel	12.4bar	10.0kg/h	10.2kW/m^2	7.1kW/m^2	13.7°C/h	338°C
2	Riello Mectron 20M	Danfoss S 30° 8kg/h @ 6.9bar	Diesel	12.4bar	10.4kg/h	10.6kW/m^2	7.4kW/m^2	13.7°C/h	338°C
3	Boral Nu-way NOL6	Monarch AR 45° 8kg/h @ 6.9bar	Diesel	12.4bar	12.2kg/h	12.4kW/m^2	8.7kW/m^2	15.2°C/h	334°C
4	Boral Nu-way NOL5	Danfoss S 30° 8kg/h @ 6.9bar	Diesel	12.4bar	9.8kg/h	10.0kW/m^2	7.0kW/m^2	14.1C/h	331°C
5	Boral Nu-way NOL5	Monarch AR 45° 8kg/h @ 6.9bar	Diesel	12.4bar	10.1kg/h	10.3kW/m^2	7.2kW/m^2	13.4°C/h	340°C
6	Boral Nu-way NOL5	Delavan B 30° 6.3kg/h @ 6.9bar	Diesel	12.4bar	9.0kg/h	9.1kW/m^2	6.4kW/m^2	11.6°C/h	320°C
7	Technic Gas	LPG Nozzle	LPG	Not Recorded	11.7kg/h	12.9kW/m^2	9.0kW/m^2	14.3°C/h	335°C
8#	Boral Nu-way NG5	LPG Nozzle	LPG	Not Recorded	5.5kg/h	6.1kW/m^2	4.3kW/m^2	6.6°C/h	252°C
9	Boral Nu-way NG7	LPG Nozzle	LPG	Not Recorded	9.2kg/h	10.2kW/m^2	7.1kW/m^2	14.1°C/h	327°C
10	Boral Nu-way NG7	Natural Gas Nozzle	Natura Gas	Not Recorded	10.0m3/h	9.0kW/m^2	6.3kW/m^2	16.5°C/h	347°C
11	Matthews Gas	LPG Nozzle	LPG	1.5bar	6.5kg/h	7.2kW/m^2	5.0kW/m^2	8.2°C/h	304°C

\# This burner was unable to be fired at a higher rate as the tube back pressure prevented sufficient air entering for stoichiometric combustion.

* The Firing Rate and Heating Rate are values averaged over the entire heating tube surface. The Heating Rate is equal to 70% of the Firing Rate, as specified in the Code of Practice.

\+ The calculation of bitumen temperature rise assumes a constant temperature throughout the tank before and after each test. As only two probes were positioned in the bitumen in 1991, this figure will only be approximate.

The importance of fan capacity was visually confirmed in a test using the air damper on the burner fully opened, so that more oxygen than was required for stoichiometric combustion entered the combustion zone.

With maximum air, the flame appeared to be "freed up" and thrown further down the flame tube, and it impinged less on the flame shield, perhaps reducing the temperature at the beginning of the flame tube and spreading heat more evenly. The oxidising flame resulting from maximum air could also be more corrosive and less stable. This was further investigated in 1992 (Section 5.2.1.3).

4.3 Conclusions

- The temperature distribution along a typical flame tube has been established.

1. The temperature gradients along a typical flame tube showed that the first five metres may be subjected to temperatures in excess of 250°C, the temperature specified in the provisional BCA Code of Practice.

   Moving the mounting position of the burner nozzle further into the flame tube was investigated further in 1992.

- The effects of different heating equipment and fuels on temperature gradients along flame tubes have been determined as follows:

1. The Boral Nu-Way NOL6 and the Riello Mectron 20M diesel burners have sufficient fan capacity.

   The Boral Nu-Way NG7 and the Technic are satisfactory LPG burners but the Matthews burner was barely sufficient, and the Boral Nu-Way NG5 LPG burner was too small.

2. No measured temperature difference was recorded between the different angled nozzles. The 30° nozzle appears to have an improved flame pattern and reduced impingement on flame tube walls compared to the 45° nozzle.

3. The average heating rate obtained in the tests was below the recommended maximum (17kW/m^2) in the Code of Practice. As this is an average, it is possible that the maximum heating rate exceeded 17kW/m^2 in the combustion zone.

4. The maximum temperature of 250°C was exceeded in all tests. The bitumen was subjected to localised heating with temperatures up to 347°C.

5. Firing rate and heating rate based on external tube surface areas are not good criteria for defining a safe flame tube. Although average heating rates may be acceptable, heating rates in the first few metres may be too high.

5. 1992 TESTING PROGRAMME

5.1 Introduction

Testing was continued in 1992 using the same tanker. This time, the fuel and type of burner were kept constant while other conditions of heating were changed. The fuel was diesel, and the burner was a Boral Nu-Way NOL6 with a Danfoss S 30° nozzle. Modifications to the equipment were made before these tests were begun.

- A pipe was added along the bottom of the tank to improve recirculation, details of which are in Appendix 4 (Figure A4.1).

- The position of the burner was moved by reducing the length of flame tube protruding from the tank wall by 150mm (Figure 4). This modification was made to move the source of high temperature, shown in the 1991 results, away from the tank wall. The first test carried out in 1992 confirmed that the aim of moving the temperature peak away from the tank wall had been achieved.

- Fewer probes were attached to the flame tube, and more were placed through the bitumen, at 100mm intervals between the bottom and top of the tank, above and below the hottest part of the flame tube, and at the surface of the bitumen. This arrangement was to measure more accurately the rise in bitumen temperature and hence to calculate the thermal efficiency more accurately, as well as to measure the temperature gradient of the bitumen in the tank.

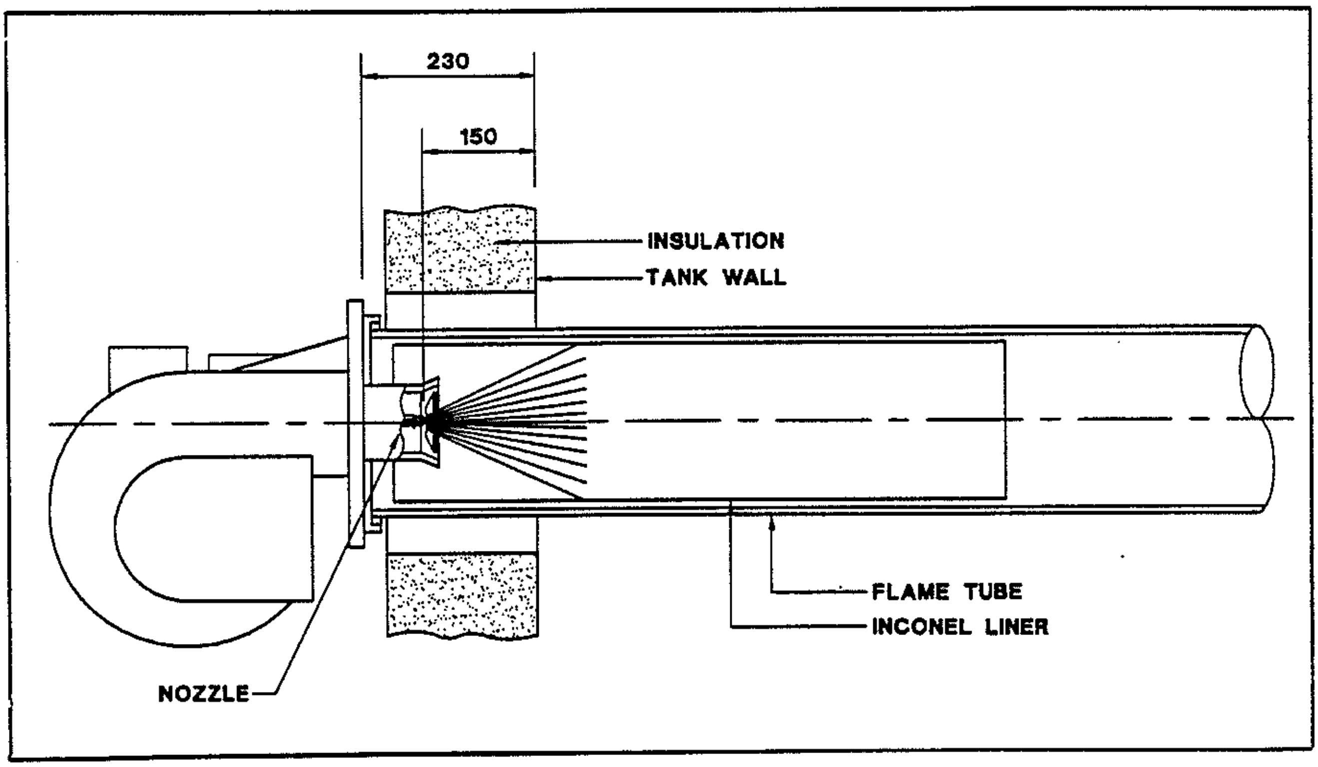


Figure 4. Burner position after modification.

At 900mm and 1450mm distance from the burner, probes were positioned circumferentially on the flame tube. At 900mm (probes 4 - 7) the hottest temperatures had been recorded in 1991, and at 1450mm (probes 9 - 12) the flame tube diameter reduces to 200mm NB (nominal bore).

Five probes measured temperatures in the bitumen, with one probe attached to each of the baffles separating the six compartments (probes 28 - 32).

The hottest point on the flame tube, shown in the 1991 results, was at 900mm. Thus a row of probes was positioned from the bottom of the tank, with probe 33 beneath the tube, and probes 34 - 40 spaced at 100mm intervals above it. Probes 38, 39 and 40 were above the bitumen surface. In this series of tests, they measured the temperature of the air in the vapour space above the bitumen. These locations are illustrated in Appendix 4 "Thermocouple Location and Identification (1992 Tests)".

5.2 Results

The results were developed in a consecutive manner by comparing the tests listed in Section 3.2. The details of the test results are summarised in Section 5.2.3. All graphs have been plotted using measurements taken from probes located on top of the flame tube.

5.2.1 Effects of Different Operating Conditions

- *To test the effects of different operating conditions while using the same heating equipment.*

Parameters of operating conditions measured in all these tests included:
fuel pressure (bar); fuel consumption (kg/h); firing rate (kW/m^2);bitumen temperature rise (°C); maximum tube temperature (°C); thermal efficiency (%).

5.2.1.1 Effect of nozzle size

. *To decide on a nozzle size that gives low temperatures on the flame tube surface but still maintains an adequate heating rate.*

The nozzle used was a Danfoss S 30°. Comparisons were made between tests 12 v 16, 13 v 17 (plotted in Figure 5), 14 v 18, 15 v 19. Tests 12 - 15 used a 8kg/h nozzle size and tests 16 - 19 used a 6.3kg/h nozzle.

Tests 12 v 16 - thermal efficiency was about the same (3% increase), maximum tube temperature decreased by 13°C, fuel consumption, firing rate and bitumen temperature rise decreased.

Tests 13 v 17 - efficiency was about the same (4% decrease), maximum temperature decreased by 25°C, fuel consumption, firing rate and bitumen temperature rise decreased.

Tests 14 v 18 - efficiency decreased (11%), maximum temperature decreased by 31°C, fuel consumption, firing rate and bitumen temperature rise decreased.

Tests 15 v 19 - efficiency decreased (11%), maximum temperature decreased by 40°C, fuel consumption, firing rate and bitumen temperature rise decreased.

This pattern indicates that smaller nozzles resulted in decreases of all the parameters measured, with a more marked amount of change with lower fuel pressures (8kg/h v 6.3kg/h).

Nozzle size **8kg/h v 6.3kg/h**	**Change Thermal Efficiency %**	**Change Max.Tube Temp.°C**	**Air Flow; Fuel pressure**
Test no.			
12 v 16	+3	-13	Stoich. ; 12.4bar
13 v 17	-4	-25	Max.Air; 12.4bar
14 v 18	-11	-31	Max.Air; 10.3bar
15 v 19	-11	-40	Max.Air; 8.3bar

Abbreviations used in all tables: max. maximum; stoich. stoichiometric; temp. temperature; h hour

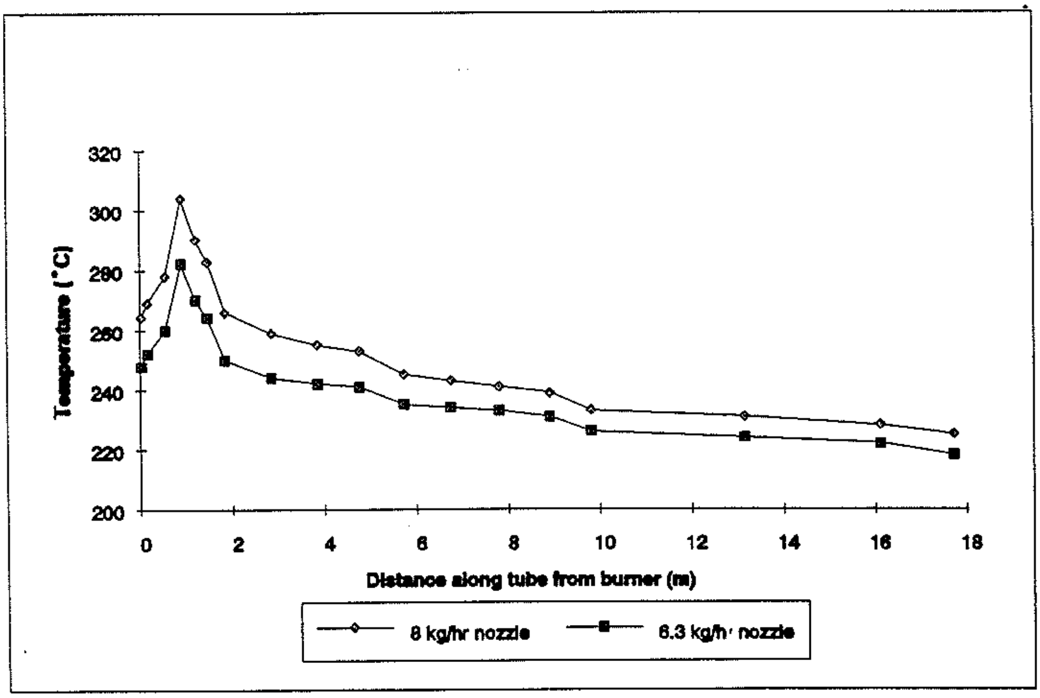


Figure 5. Effect of nozzle size on temperature gradient of the flame tube, for tests 13 and 17.

5.2.1.2 Effect of fuel pressure

. To decide on a fuel pressure setting that gives low temperatures on the flame tube surface, but still maintains an adequate heating rate.

Comparisons between tests 13, 14, 15 using 8kg/h nozzle size and 17, 18, 19 using 6.3kg/h nozzle size were made (Figure 6). In each of these sets of tests the fuel pressure was decreased, from 12.4 bar to 10.3 bar to 8.3 bar.

As the fuel pressure decreased, the parameters of fuel consumption, bitumen temperature rise per hour, maximum temperature, and firing rate all decreased. In general the thermal efficiency also decreased because at lower fuel pressure, atomisation of the fuel is not as complete. Larger droplets remain and complete combustion is difficult with the lower surface area available.

Tests 13, 14 and 15 took similar times to complete. Tests 17, 18 and 19 took progressively more time to complete, as more time was required to reach spraying temperature (165°C) with the smaller nozzle and lower fuel pressure.

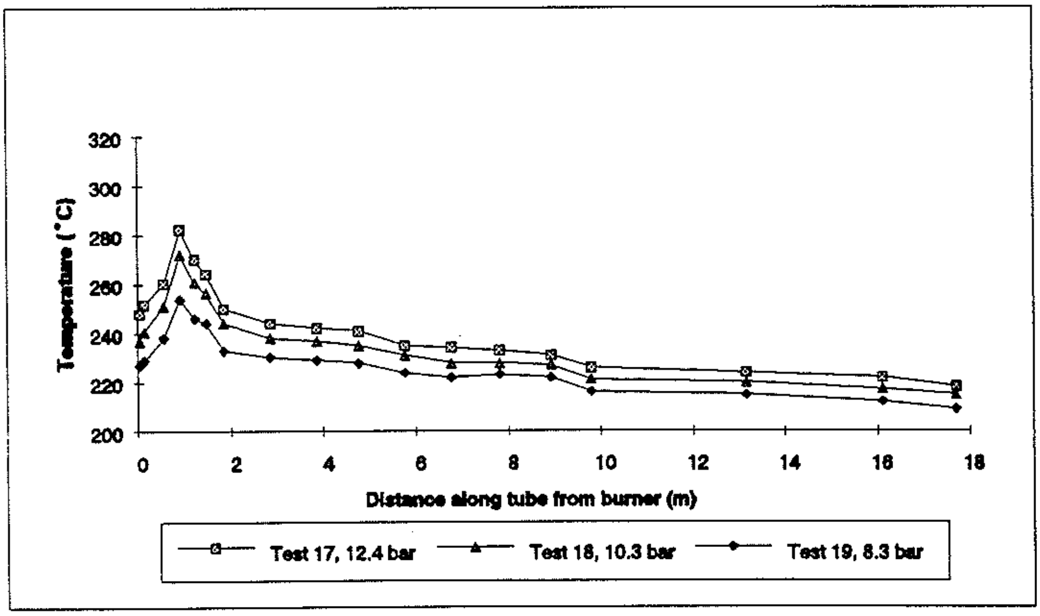


Figure 6. Effect of fuel pressures on temperature gradients of the flame tube, for tests 17 - 19.

5.2.1.3 Effect of air flow

. To confirm the observation, made in 1991, of the effect of maximum air flow through the flame tube.

Comparisons were made between tests 12 v 13, and tests 16 v 17, for effect of varying the air flows only. Tests 12 and 16 were run with stoichiometric air, tests 13 and 17 with maximum air. Results are shown in Figures 7 and 8.

Both sets of tests showed similar fuel and firing rates, with stoichiometric air giving a higher temperature rise per hour and higher heating efficiency.

The temperature rise at the wall was reduced even more when maximum rather than stoichiometric air flow was used.

Maximum air flow lowered the maximum temperature by 31°C with an 8kg/h nozzle, and 43°C with a 6.3kg/h nozzle, as tabulated below.

Test No.	**Stoich.Air Max.Temp.(°C)**	**Test No.**	**Max.Air Max.Temp.(°C)**	**Temp.reduction (°C)**
12	350	13	319	31
16	337	17	294	43

The flue exit gas temperature was approximately 70°C higher throughout the test with maximum air flow. Both maximum air flow tests took longer than the stoichiometric tests, although heating commenced with the bitumen at similar temperatures.

Overall, the change from stoichiometric to maximum air flow meant a decrease in the heating rate of up to 2°C/h or approximately 20%. A large drop in the maximum temperature was also recorded.

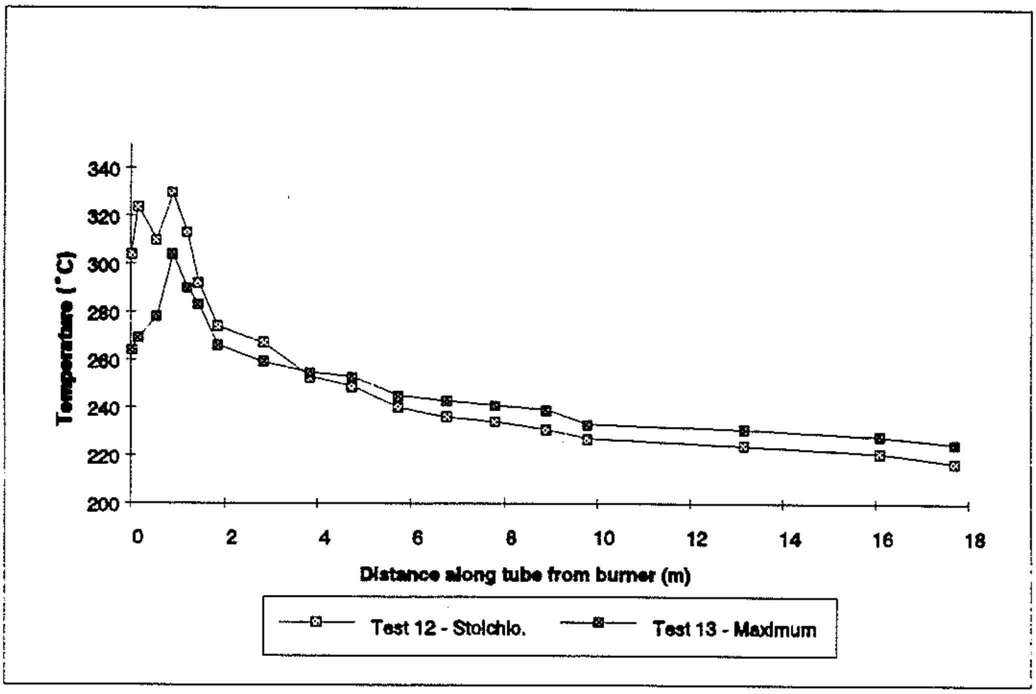


Figure 7. Effect of stoichiometric and maximum air flows on temperature gradients of flame tube using 8kg/h nozzle.

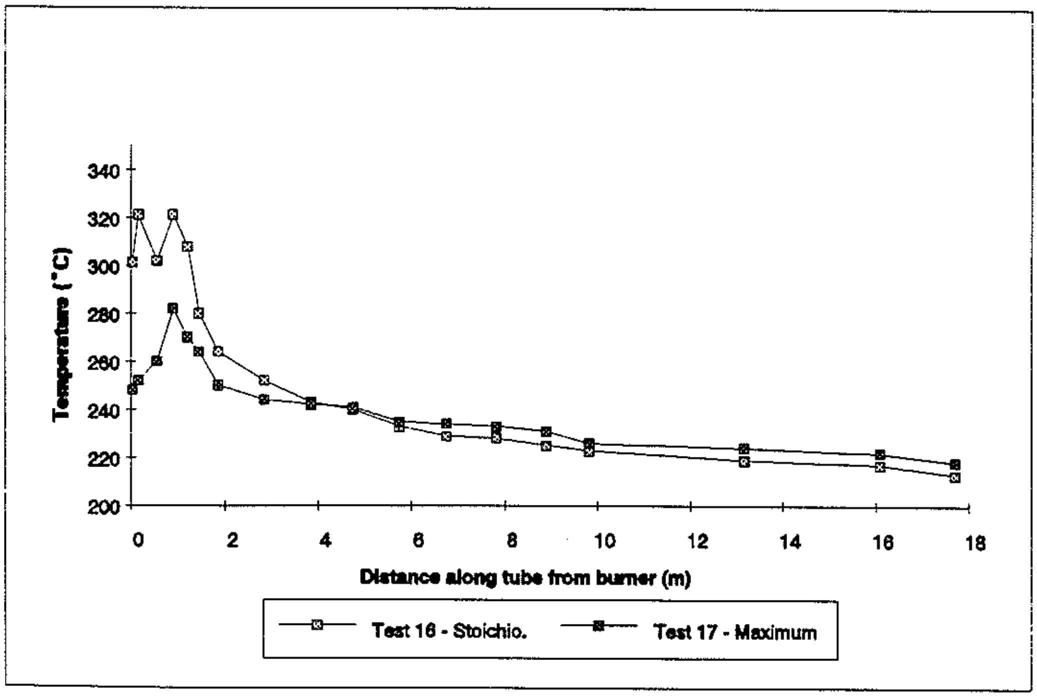


Figure 8. Effect of stoichiometric and maximum air flows on temperature gradients of flame tube using 6.3kg/h nozzle.

5.2.1.4 Effect of heating up from cold

. To observe the effect of heating up from cold.

The entire tank contents were allowed to cool to a temperature of approximately 15°C before the test began. The resulting data (test 20) were compared with test 14 for which, under similar burner conditions, the bitumen was heated from approximately 100°C.

The firing rate, temperature rise, heating efficiency and maximum temperature parameters all increased for bitumen heated from 15°C in test 20.

The temperatures recorded at the baffles and at the different levels in the bitumen showed surprising jumps in temperature (Figure 9). Probes 34 to 40 were placed in the tank at 100mm intervals above the heating tube, 0.9m from the tank wall, so that probe 34 is 100mm above the tube, 35 is 200mm above, and so on. The distance 0.9m is the approximate location of the hottest point along the flame tube.

A sudden change in temperature 25 minutes after the burner started was recorded at probe 34, when it rose from 34°C to 240°C over a 5 minute period. This high temperature is held for about 30 minutes, then drops to a low of 20°C. This pattern is repeated, after a time lag of 5 to 10 minutes, by probes 35 and 36 (Figure 9).

This heating pattern could be caused by the cold semi-solid bitumen surrounding the tube being heated rapidly, initially by flame tube temperatures of approximately 300°C (measured by probes 5 - 8 on the tube). The bitumen is trapped around the flame tube and unable to escape to the surface because of the solid cold material above it. The high temperature migrates through the bitumen at a rate of about 100mm over 10 minutes, indicated by sudden jumps in temperature recorded by consecutive probes. Once the bitumen has heated through to the surface, natural convection starts, and cold bitumen slumps around the probes above the flame tube.

When bitumen is heated up from cold, very rapid heating to high temperatures of trapped bitumen occurs (up to 243°C in bitumen approximately 100mm above the flame tube). This heating pattern justifies the use of a burner with high and low firing settings, when bitumen is to be heated up from cold. The burner can be fitted with thermostatic control which prevents high firing until all the bitumen is fluid.

Figure 10 compares temperatures from test 14, plotted at the end of the test (the time at which bitumen was usually at its hottest), with temperatures from test 20, plotted 40 minutes after the beginning of heating. Temperatures on the flame tube in test 20 (of trapped bitumen) at 40 minutes were not significantly higher than temperatures on the flame tube in test 14 (when all the bitumen was fluid). This indicates that the trapped bitumen did not raise temperatures of the flame tube excessively.

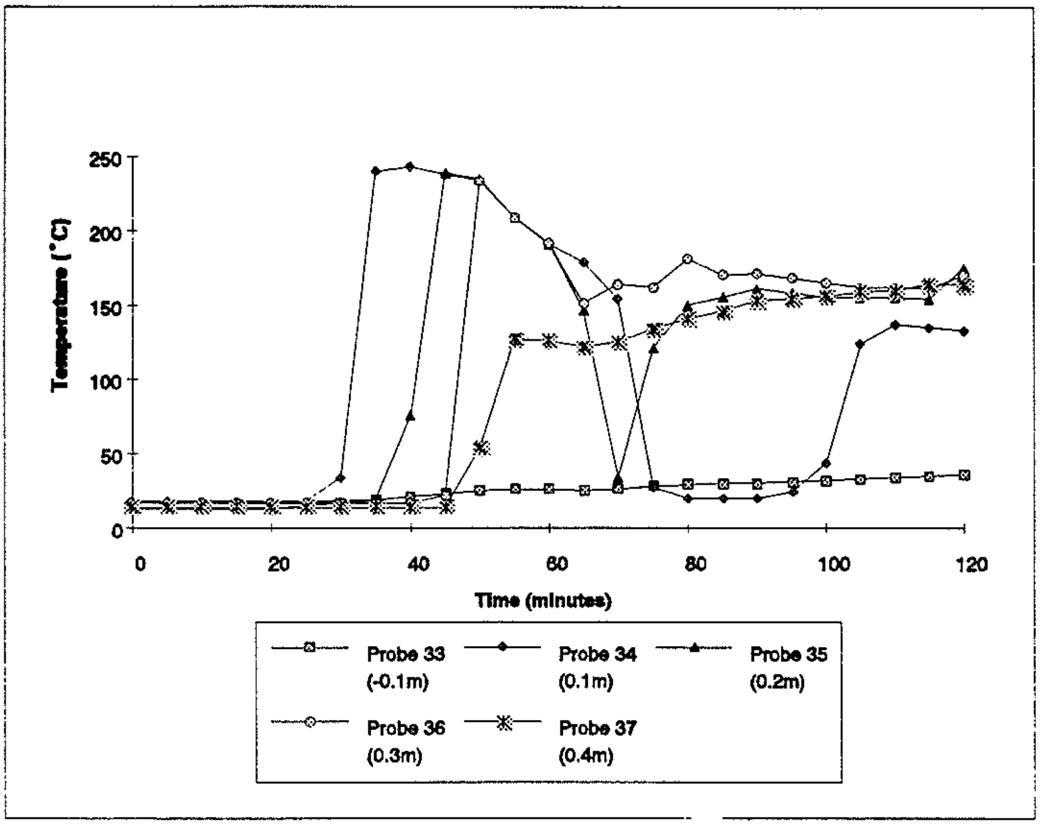


Figure 9. Changes with time in temperature of bitumen in the tank when heating up from cold (15°C) (Test 20).

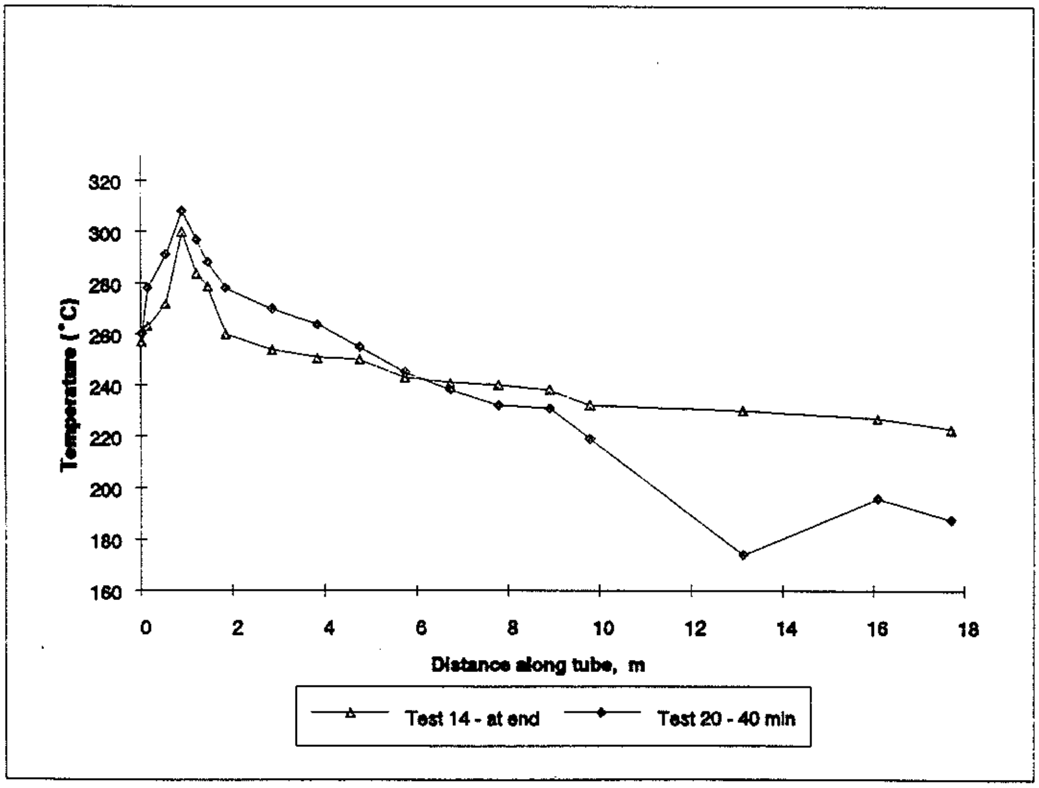


Figure 10. Maximum temperatures on the flame tube when heating the bitumen in the tank. Test 14 at 165°C compared with Test 20 at 40 minutes (with trapped bitumen at its highest temperature).

5.2.1.5 Effect of recirculation

. To determine the effect of recirculation (tank agitation) on heating rates, on temperatures of flame tube surfaces, and on thermal efficiency.

To determine the effect of recirculating continuously throughout heating, comparisons between the results of tests 14 v 21, and tests 22 v 23 were made. Bitumen was recirculated during heating in Tests 21 and 23, and in tests 14 and 22 the bitumen was recirculated for the standard fifteen minutes after the burner had turned off. All the parameters were similar.

The bitumen remained colder beneath the flame tube when the tank was not being recirculated. Probe 33, located between the tank base and the underside of the flame tube, read significantly lower temperatures than other probes when bitumen was not recirculating.

Probes 38 - 40 gave similar readings for both sets of tests as they were above the bitumen. These readings showed the vapour temperature above the bitumen, for which up to 170°C was recorded. Probe 37 on the bitumen surface was always slightly hotter.

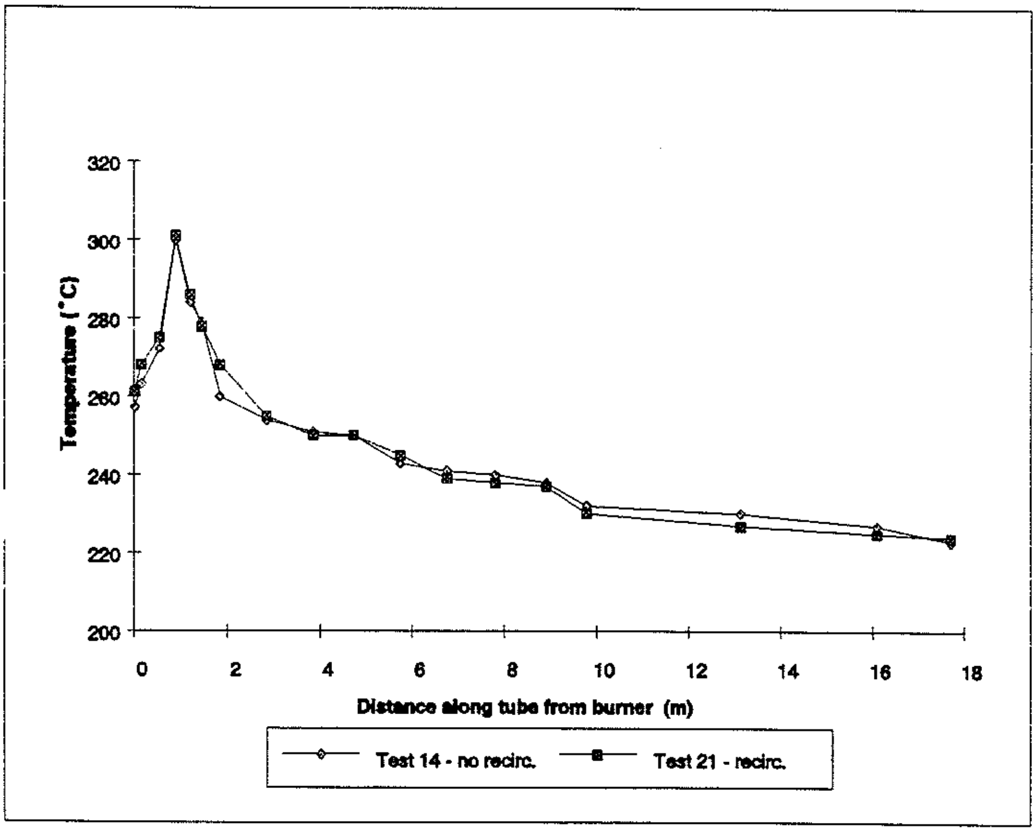


Figure 11. Effect of recirculation on temperature gradients of flame tube.

Comparing the temperatures across the baffles and through the bitumen at different points in time:

> Probe 33 (below the flame tube) recorded a more uniform temperature with the rest of the tank once recirculation had started.
>
> At the completion of the tests the temperatures were similar for both continuous recirculation and 15 minute-only recirculation. 15 minutes appeared to be sufficient time for recirculation to bring the tank contents to an approximately uniform temperature.

Figure 11, for tests 14 and 21, shows the temperature gradient along the flame tube just before the burner turned off at spraying temperature. The gradients are almost identical, indicating that recirculation did not reduce the temperature along the flame tube.

5.2.1.6 Effect of flame shield

. *To observe the effect of the flame shield on temperature gradients along the flame tube.*

By comparing tests 14 v 22, 21 v 23, and 27 v 28, the effect of removing the Inconel flame shield can be observed. In tests 22, 23 and 28, the shield was removed, with the flame directed down the enlarged combustion zone section.

The heating parameters were similar. Without the shield the maximum temperature was slightly lower. The decreases were 18°C (comparing tests 22 with 14), 14°C (tests 23 and 21), and 9°C (tests 28 and 27), as shown below.

With Flame Shield		**Without flame shield**		**Temp.reduction (°C)**
Test No.	**Max.Temp.(°C)**	**Test No.**	**Max.Temp.(°C)**	
14	313	22	295	18
21	315	23	301	14
27	289	28	280	9

The effect of the flame shield appeared to have shifted the temperature peak away from the tank wall to beyond the end of the flame shield (Figure 12).

Two possible reasons for this shift when the flame tube has no shield were: the flame "looks" directly at the flame tube wall, which could account for the higher temperatures; the combustion area has increased by 56%, and this greater available volume gave improved combustion conditions, and combustion occurred earlier.

With a flame shield, temperatures of the flame tube behind the flame shield are lower, but the peak beyond the flame shield is higher.

Without a flame shield, temperatures in the combustion zone are much higher and no peak was recorded.

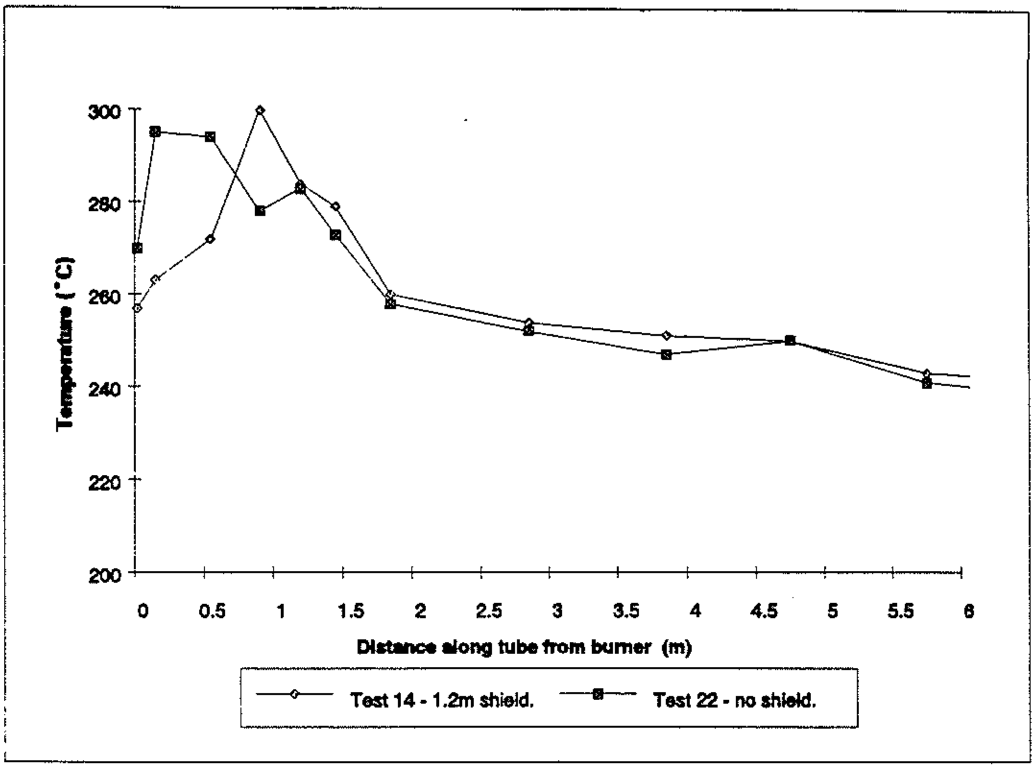


Figure 12. Effect of the flame shield on temperature gradients of the flame tube.

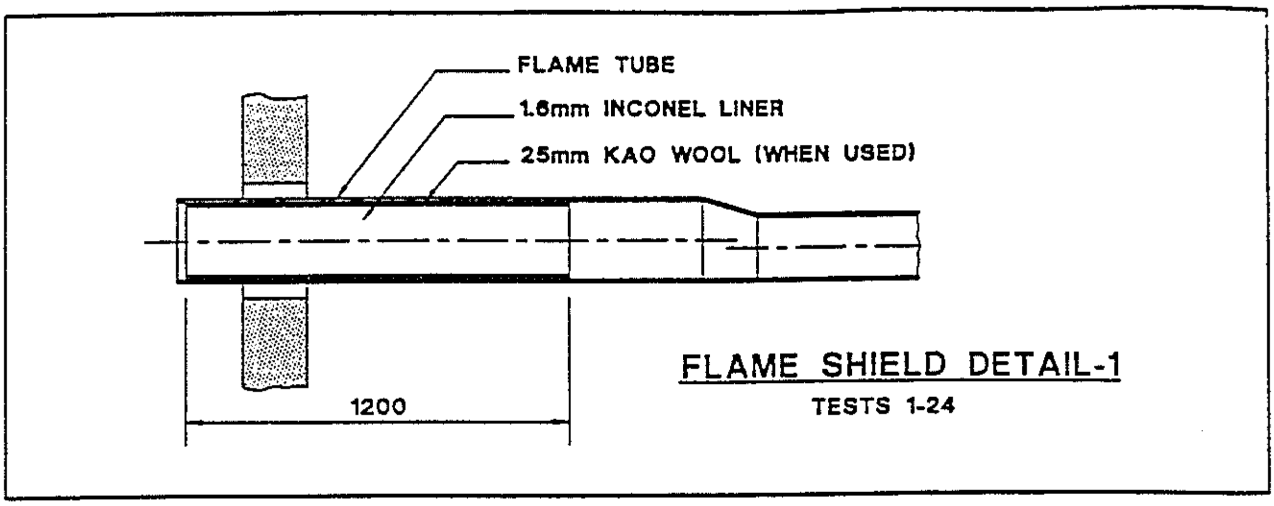
5.2.1.7 Effect of longer flame shield

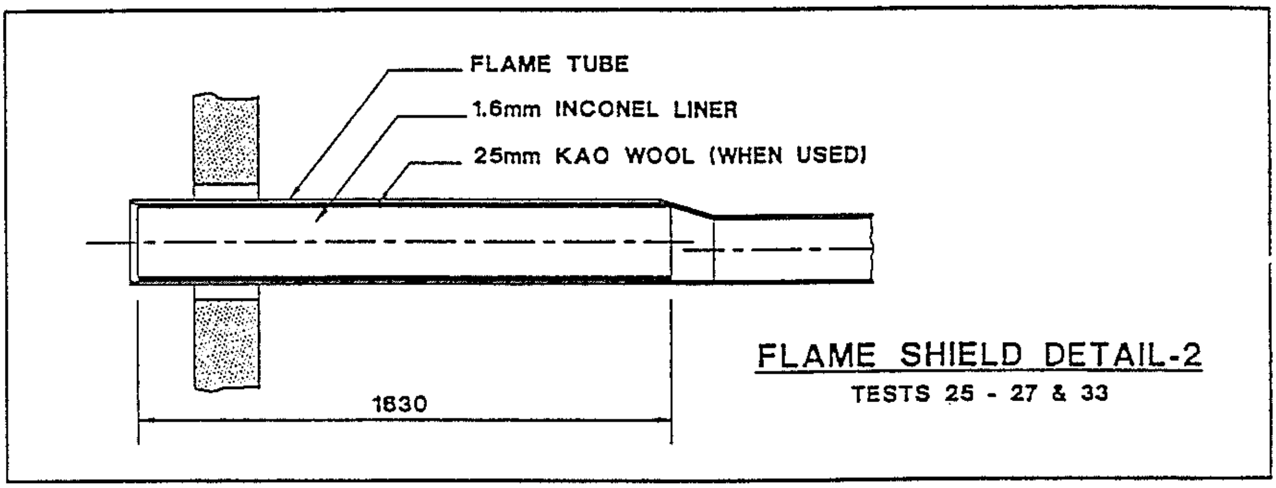
. To observe the effect on temperature gradients along the flame tube by lengthening the flame shield.

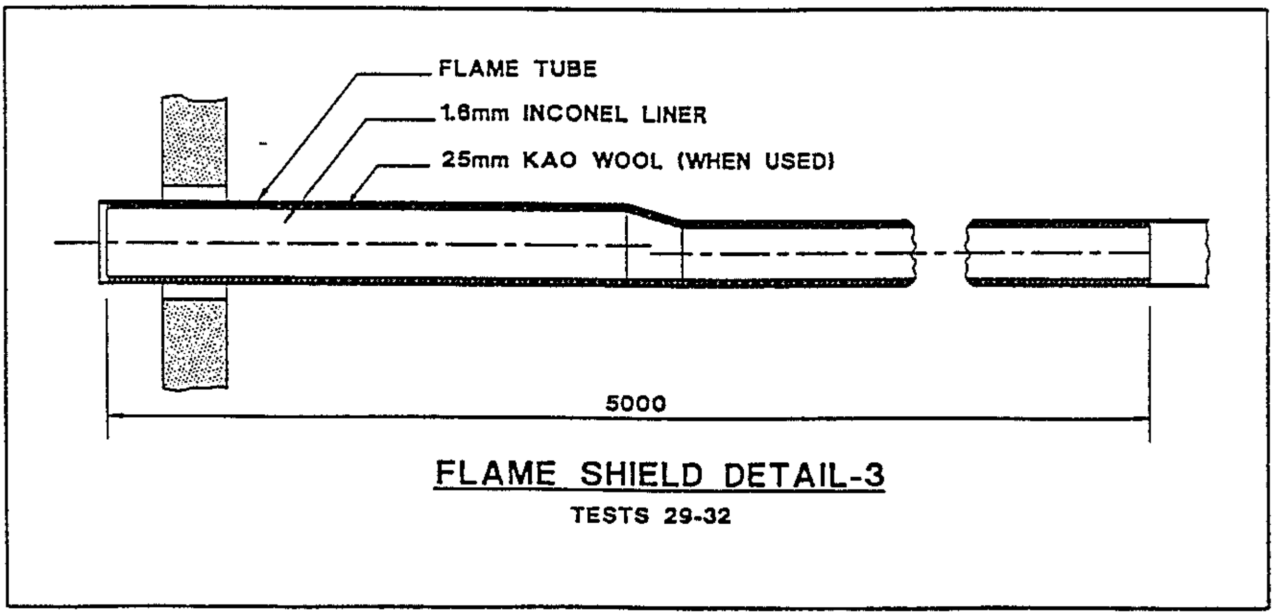
The flame shield was extended for test 29 to 5 metres in length. This distance is the position (of probe 16) where temperatures at the flame tube appeared to drop below the BCA maximum limit of 250°C. Figure 13 shows details of flame shields used for the tests, and also that the section of the shield extending beyond the enlarged combustion zone area was of a smaller diameter than the first section.

The temperature peak at the end of the 1200mm flame shield was eliminated, and a smaller temperature peak was observed at the end of the 5m flame shield. Overall, this modification resulted in a maximum tube temperature reduction of 39°C when compared with test 14.

Figure 13. Details of the flame shields used for the tests.







5.2.1.8 Effect of insulation (KAO wool)

. *To investigate the effect of insulation (KAO wool) on temperature gradients along the flame tube.*

The flame shield used in tests 1 to 24 was 1.2m long (Figure 13). There was an air gap of 25mm between the shield and tube wall, the shield diameter was 200mm, and the tube diameter was 250mm (see Appendix 3, photograph). In test 24 the air gap between the shield and the flame tube wall was filled with insulation using KAO wool, to investigate the effect of insulation on the high temperatures recorded on that part of the flame tube.

Comparing test 24 with test 14 indicated that using the KAO wool gives a higher maximum temperature, up 23°C from 313° to 336°C. Other parameters and the flue exit gas temperatures were similar.

Probes 1, 2 and 3 were cooler when KAO wool was used, whereas probe 8 located at the end of the flame shield was hotter.

Figure 14 shows the difference in temperature gradients (from probes on top of the flame tube) in a test with a shield without KAO wool (test 14), and in tests with a shield and KAO wool (tests 24, 25). In test 25 the shield was also longer. Only the first 10 metres of the flame tube were plotted as the graphs were very similar after this point.

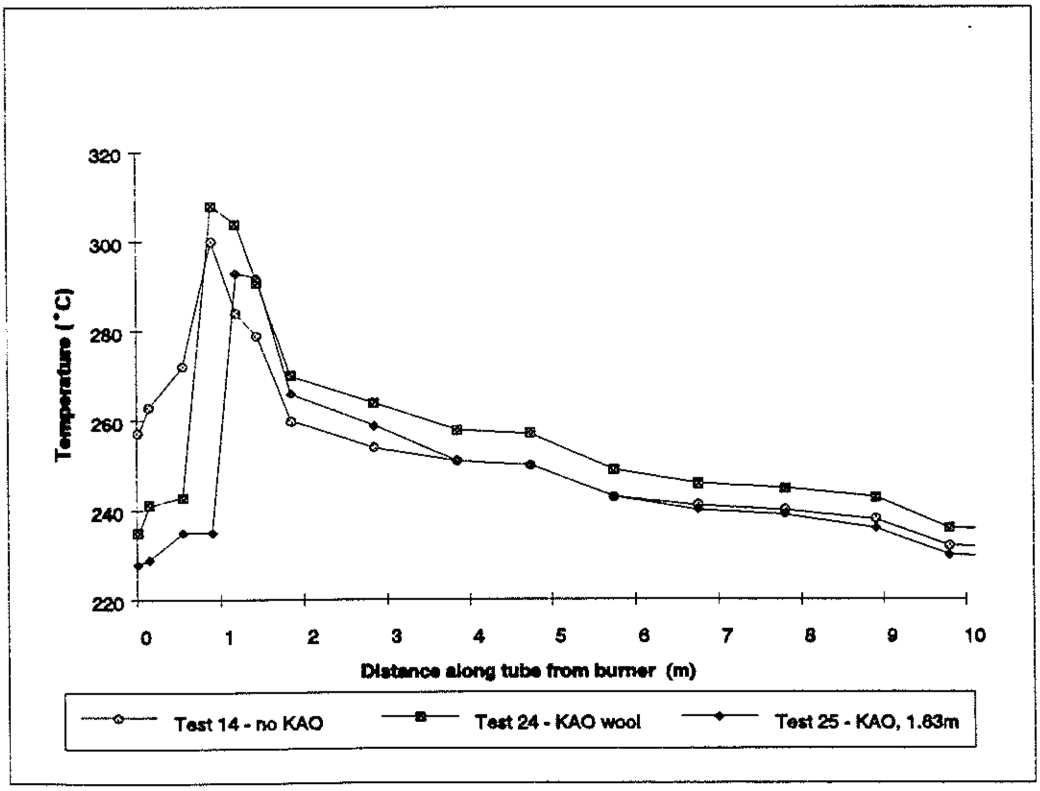


Figure 14. Effect of insulation (KAO wool) on temperature gradients of the flame tube.

In test 25 the length of the flame shield was increased from 1.2m to 1.63m, so that the entire enlarged combustion zone area was lined. KAO wool was placed in the 25mm gap for the 1.63m length.

Increasing the shield length and adding KAO wool decreased the maximum temperature, which then occurred further down the tube (at 1.45m or probe 10 for test 25 compared to 0.9m or probe 7 in test 24). The temperature between 0.9m to 1.2m distance (i.e. probe 7 to probe 8), increased rapidly by 60 or 70°C.

Using KAO wool can reduce the temperatures on the flame tube, and temperatures lower than 250°C were recorded. Where the KAO wool and shield ended, a high temperature peak was recorded (up to 336°C).

5.2.1.9 Effect of insulation and longer flame shield

. To determine the combined effect of insulation and longer flame shield on temperature gradients along the flame tube.

Tests 24 and 25 indicated that KAO wool was useful but, because the temperature peaked where the KAO wool ends, a longer shield with KAO wool insulation was tested.

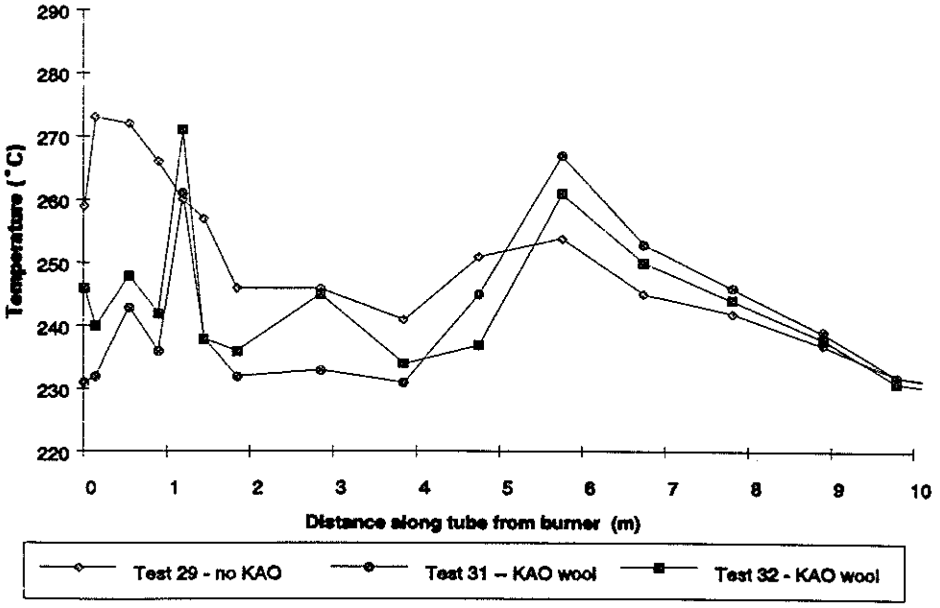


Figure 15. Effect of insulation in a longer (5m) flame shield on temperature gradients in the flame tube.

In tests 31 and 32 KAO wool was placed in the air gap surrounding the 5m shield. For test 31, KAO wool was placed evenly around the entire circumference of the shield. The results showed some fluctuations in temperature along the shield, and in test 32 the KAO wool was repositioned to try to even out the fluctuations and to bring the tube to a uniform temperature of approximately 250°C. The KAO wool was thinned in cooler areas (below 250°C) and thickened in hotter areas (above 250°C) around the tube.

Figure 15 shows the difference between a 5m shield without KAO wool (test 29), and those with it (tests 31, 32). Only the first 10m of the flame tube were plotted as the gradients were very similar after this distance.

In tests 31 and 32 an increase in temperature was recorded where the flame shield ended. Both tests 31 and 32 had a temperature peak at approximately 1.5m, where the profile of the flame tube reduced from a nominal bore of 250mm to 200mm. The flame may have been impinging on the wall at this point.

The rearranging of the KAO wool in test 32 gave some change in temperatures, but did not significantly smooth out the temperature fluctuations that had been noted in test 31.

Over the first five metres of the flame tube the temperatures were below 250°C, except where the diameter of the tube reduced, a point about 1.5m out from the tank wall. If the enlarged combustion zone was 5m long and incorporated a full length insulated flame shield, it may be possible to keep temperatures below 250°C along the entire length.

5.2.1.10 Effect of secondary (induced) air

. *To investigate the effect of secondary (induced) air on reducing the excessive temperatures in the combustion zone and on distributing the heat more evenly along the length of the flame tube.*

A fan was mounted on the exit flue of the tanker to suck air out of the flame tube. Its size was the same as that in the Boral Nu-Way NOL6 burner. A series of fifteen 12mm holes were drilled in the flame tube end cap so that additional cool air could be induced between the flame shield and the flame tube.

Comparisons were made between tests 14 and 27, 22 and 28, 29 and 30 to indicate effects of this additional fan.

Cooler temperatures were recorded at the beginning of the flame tube when induced air was used; cooler to 0.9m (probe 7) in test 27, and to 0.55m (probe 3) in test 30. In test 27 the flue exit gas temperatures were about 20°C higher than those in test 14.

Tests 26 and 27 also compared the effects of stoichiometric air flow and maximum air flow at the burner, with the induced air fan operating at the maximum flow.

With stoichiometric air flow (test 26) the temperature rise per hour was greater, but also reached a greater maximum temperature. The flue exit gas is cooler by approximately 55°C in the stoichiometric air conditions. These observations correspond with those made when induced air was not used.

Overall induced air appeared to reduce the temperatures recorded in the combustion area of the flame tube, but removal of heat from this area resulted in a higher exit (flue) gas temperature and therefore a decrease in thermal efficiency.

The amount of induced secondary air in this test did not appear to be very large as only a small negative pressure could be felt at the holes in the flame tube end cap. The reduced temperatures in the combustion area could have been caused by the flame being sucked further down the tube, and not by the induced air actually cooling the flame tube.

5.2.1.11 Effect of minimum heating level

. *To determine if the minimum level of bitumen above the flame tube, for safe heating, specified as 200mm in Clause 3.8.1 in the provisional BCA Code of Practice, is sufficient.*

Test 33 was designed to observe the characteristics of heating when the bitumen covering the flame tube was either 200mm or 100mm, using the probes positioned in the tank and adjacent to the hottest part of the flame tube.

The results were not conclusive and the recommended minimum level of bitumen above the flame tube, for safe heating, remains as 200mm.

5.2.1.12 Effect of cooling period

. *To determine the time taken after the burner is extinguished, before the flame tube surface temperature drops below 255°C, and therefore to determine the time delay before the tanker can be safely moved.*

The flame tube surface has to be at a temperature below the auto-ignition temperature of kerosine (255°C) before the tanker is moved, which could cause the flame tube to become exposed and cause a tank explosion.

In test 33 with 200mm cover of bitumen, the flame tube temperature had dropped below 255°C after 10 minutes, and below 200°C after 15 minutes.

Such cooling was also shown in test 4, where a half-full tank of bitumen was heated. Ten minutes after the burner was turned off, all the probes on the flame tube registered temperatures below 255°C.

5.2.2 Rate of Hardening of Bitumen

- *To monitor the rate of bitumen hardening as heating cycles continued.*

The bitumen was sampled between each of the heating tests 12-33, over a total of 86 days. The Labtech results are recorded in Lab Report No. 1000-10, Appendix 5.3. These results are discussed in detail in Appendix 5.2, and they showed that hardening had taken place at an average rate of 3dmm per heating cycle.

5.2.3 Summary of 1992 Heating Test Results

All tests use a Boral Nu-Way NOL6 burner, Danfoss S 30° nozzle, and diesel as fuel

TEST No.	NOZZLE SIZE (at 6.9 bar)	FUEL PRESSURE	AIR SUPPLY	FUEL CONSUMP	FIRING RATE	BITUMEN TEMP RISE	MAX TUBE TEMP	THERMAL EFF.	COMMENTS
12	8.0 kg/h	12.4bar	Stoichiometric	10.5kg/h	10.7kW/m²	14.4°C/h	350°C	77%	
13	8.0 kg/h	12.4bar	Maximum	10.0kg/h	10.1kW/m²	12.5°C/h.	319°C	71%	
14	8.0 kg/h	10.3bar	Maximum	9.6kg/h.	9.7kW/m²	12.1°C/h	313°C	72%	
15	8.0 kg/h	8.3bar	Maximum	8.8kg/h	9.0kW/m²	9.7°C/h	301°C	62%	
16	6.3 kg/h	12.4bar	Stoichiometric	8.3kg/h	8.4kW/m²	11.8°C/h	337°C	80%	
17	6.3 kg/h	12.4bar	Maximum	8.3kg/h	8.4kW/m²	9.9°C/h	294°C	67%	
18	6.3 kg/h	10.3bar	Maximum	7.7kg/h	7.8kW/m²	8.3°C/h.	282°C	61%	
19	6.3 kg/h	8.3bar	Maximum	7.2kg/h	7.3kW/m²	6.6°C/h	261°C	51%	
20	8.0 kg/h	10.3bar	Maximum	10.2kg/h	10.4kW/m²	17.1°C/h	323°C	95%	Heat up from cold
21	8.0 kg/h	10.3bar	Maximum	10.0kg/h	10.2kW/m²	11.3°C/h	315°C	64%	Recirculate continuously
22	8.0 kg/h	10.3bar	Maximum	9.9kg/h	10.1kW/m²	12.1°C/h	295°C	69%	Flame tube shield removed
23	8.0 kg/h	10.3bar	Maximum	9.7kg/h	9.9kW/m²	11.7°C/h	301°C	68%	Recirculate and flame shield removed
24	8.0 kg/h	10.3bar	Maximum	10.0kg/h	10.2kW/m²	12.0°C/h	336°C	67%	KAO wool around shield
25	8.0 kg/h	10.3bar	Maximum	9.5kg/h	9.7kW/m²	10.9°C/h	308°C	65%	Shield extended to 1.63m and KAO wool
26	8.0 kg/h	10.3bar	Stoichiometric			13.4°C/h	308°C		Induced air, Shield at 1.63m
27	8.0 kg/h	10.3bar	Maximum			9.5°C/h.	289°C		Induced air, Shield at 1.63m
28	8.0 kg/h	10.3bar	Maximum				280°C		Induced air, flame tube shield removed
29	8.0 kg/h	10.3bar	Maximum	9.34kg/h	9.5kW/m²	11.7°C/h	274°C	71%	Shield extended to 5m
30	8.0 kg/h	10.3bar	Maximum				302°C		Induced air, shield extended to 5m.
31	8.0 kg/h	10.3bar	Maximum			12.5°C/h	317°C		Shield extended to 5m, KAO wool
32	8.0 kg/h	10.3bar	Maximum	9.0kg/h	9.2kW/m²	11.5°C/h	303°C	72%	Shield extended to 5m, spaced KAO wool
33	8.0 kg/h	10.3bar	Maximum				337°C		Shield at to 1.63m, only 200mm bitumen

5.3 Conclusions

- The effects of different operating conditions were tested.

1. Smaller nozzles resulted in decreases of all parameters measured, with the amount of change becoming more marked as the fuel pressure decreases.

2. Lower fuel pressure resulted in decreases of all heating parameters measured.

3. Maximum air flow gave a large drop in the maximum flame tube temperature but reduced the heating rate by up to 2C°/h or approximately 20%.

4. When bitumen is heated up from cold, rapid heating to high temperatures of trapped bitumen occurred. Slow heating is necessary until all the bitumen is fluid (110°C).

5. Recirculation appeared to have little effect in reducing flame tube temperatures.

6. Flame tube temperatures in the combustion area were reduced when a flame shield was used. Maximum temperatures increased marginally when a flame shield was used; the temperature peak occurred at the point where the flame shield ended.

7. The temperature peak at the end of the 1200mm flame shield was eliminated and a smaller temperature peak was observed at the end of the 5m flame shield.

8. Insulation with KAO wool reduced the flame tube temperatures where it was present but a high temperature peak was observed beyond the end of the KAO wool.

9. Insulation combined with longer flame shield, if combined with an enlarged combustion zone, may possibly keep maximum temperatures below 250°C.

10. Secondary (induced) air reduced the temperatures in the combustion zone, but resulted in a higher flue gas temperature and a decrease in thermal efficiency.

11. A minimum level of bitumen above the flame tube, for safe heating, was 200mm

12. The time needed to allow the flame tube to cool before safely moving the tank was 15 minutes.

- The rate of bitumen hardening as heating cycles continued was monitored.

The bitumen hardened as the tests progressed, with the penetration value decreasing from 181 to 121 over 21 heating/cooling cycles, an average decrease of 3dmm per heating cycle. This hardening is probably related to reaction with atmospheric oxygen, rather than the result of exposure to high flame tube temperatures.

6. 1993 TESTING PROGRAMME

6.1 Introduction

Further tests were carried out in 1993 to determine the rate of hardening of bitumen using the same testing conditions as those in 1992, with a Boral Nu-Way NOL6 diesel burner, a Danfoss S 8kg/h 30° nozzle and a fuel supply pressure of 10.3 bar.

For both tests the burner thermostat cut-out temperature was set at 170°C and the unit was left to run for 16 and 17 days respectively. The bitumen was sampled daily after the tank contents had been recirculated for 15 minutes. The penetration values of the samples were determined by Labtech Services Ltd.

6.2 Results

6.2.1 Rate of Hardening of Bitumen

- *To determine the rate of hardening of bitumen that has been held at spraying temperature for a prolonged period of time,*

- in a full tank (test tanker 95% full (19920 kg) of 180/200 bitumen), and
- in a half full tank (test tanker 46% full (9560 kg) of 180/200 bitumen).

6.2.1.1 Effect of 95% full tank

The results of this test are recorded in Labtech Services Ltd report "*Effects of Heating on 180/200 Bitumen*", number 1036-1 (Appendix 5.3).

Over the 16 days the penetration dropped from 184dmm to 164dmm, or an average of 1.25dmm per 24 hour period.

The burner ran intermittently to maintain the temperature at 170°C. To achieve this temperature it had an average operating time of 2 hours 45 minutes per 24 hour period.

6.2.1.2 Effect of 46% full tank

The results of this test, and comparison of them with the results of the 95% full tank are recorded in Labtech Services Ltd report "*Effects of Heating on 180/200 Bitumen*", number 1256-1 (Appendix 5.3).

Over the 17 days the penetration dropped from 180dmm to 135dmm, or an average of 2.6dmm per 24 hour period. The burner run time was not recorded.

6.3 Conclusion

- When maintaining bitumen at elevated temperatures for prolonged periods, tanks should be kept full to prevent excessive hardening of the bitumen.

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Boral Nu-Way Ltd;
NZ Industrial Gases

APPENDIX 1

BCA Code of Practice Requirements for Tank Heating

3.8 TANK HEATING

3.8.1 Minimum Heating Level. The minimum heating level set for the tank contents shall ensure that every part of the heat transfer surface inside the tank is covered with at least 200mm of binder.

* Designers must note the risk of auto-ignition of carbonaceous deposits on exposed tube surfaces (stated to be as low as 250°C) or of kerosine drippings (255°C).

3.8.2 Electric Elements. The element rating shall not exceed 9.5 kilowatts (34 MJ/hour) per square metre of external tube surface.

* The Oil Industry figure for bitumen heating is 6 Watts per square inch (9.3 kW per square metre.)

3.8.3 Liquid Heat Transfer Systems. (Usually hot oil.) The temperature of the heat transfer liquid entering a natural convection tank heater shall not exceed 250°C.

* This aims at keeping the maximum temperature of the pipe surface in contact with binder low enough to avoid undue risk of thermal decomposition. (Section 2.3 notes that even the hardest grades of bitumen do not require a processing temperature in excess of 190°C. Section 6.8 adopts this as the normal upper heating limit. It may also be noted that the Institute of Petroleum, London, sets an upper limit of 220°C for grades down to 15 penetration.)

The limit for a hot oil system applies only to bitumen heated by natural convection. Forced convection totally enclosed heaters such as fin-tube heat exchangers or tank suction heaters reduce the risk of overheating bitumen at the tube surface. Moreover the bitumen is fully confined so that an unduly hot surface does not tend to boil off flux or cutter. In such instances the temperature of the heat transfer medium may be taken above 250°C. Oil company practice limits the transfer medium temperature to 70°C above the binder temperature. Designers should note that the bitumen currently available in New Zealand begins to degrade at temperatures in excess of 220°C. The auto-ignition temperature of straight-run bitumen is 500°C.

3.8.4 Flame Tubes.

(a) The heat rating with the burner at maximum firing shall not exceed 17 kilowatts (61MJ/hour) per square metre of external tube surface. (It should be noted that this value is under investigation and is liable to be reduced.)

* Designers should note that the radiant heat transfer from an unshielded flame, particularly an oil flame, can lead to an excessive heat input to tube surfaces which "look" at the flame.

* So far as can be ascertained no codes set a limit on flame heating rates. The value temporarily set in (a) above is based on limited unpublished New Zealand work on a "normal" tanker design. However 17 kW/M^2 is grossly in excess of the 9.5 kW/M^2 required for electric heaters. At a thermal efficiency of say 70%, it is equivalent to a firing rate of 24kW (86 MJ/hour) per square metre of external surface. Such rates are not uncommon in New Zealand systems intended for the rapid reheating of tank contents in the field. The consequences of a high input rate from a burner system with an adequate flame shield are less drastic than those from an electric element. In both cases an excessive rate of heat flow will lead to a high temperature on the bitumen side of the tube. This will produce binder degradation which is usually accompanied by an increasing resistance to the flow of heat. When the heat transfer is from combustion products to the metal wall, the increased resistance results in a rise in the flue gas temperature. In the case of an electric element there is no flow of gas to carry off the excess heat. Instead the element and its surrounding sheath grow hotter and hotter, the degraded bitumen on the outside chars and cokes, the resistance to heat flow from the element becomes ever greater; eventually the temperature rises so high that the element burns out.

Recent New Zealand trials have shown that even with a flame shield to reduce radiant heating in the vicinity of the burner flame, firing rates currently accepted are producing very hot bitumen side surfaces. Work is continuing to establish rates and configurations which will not result in the risk of binder degradation through excessively hot transfer surfaces.

(b) Alternatively, the maximum heating rate may be established for a prototype system by measuring the temperature with thermocouples bonded to the external heating surface. In no position at maximum firing may the surface temperature exceed 250°C.

(c) Flame tubes shall be designed so that either the tube or a flame tube insert is readily removable for replacement or service.

(d) No flame tube inlet or external flue may be closer than 2 metres via the vapour path to any hatch or vent pipe exit.

3.8.5 No flue may pass through the vapour space above the tank contents.

APPENDIX 2

Data Available on Bitumen Heating

Extract (pp. 1-3) from "Progress Report on Bitumen Heating Research Project",
John Dawson, BCA

A2. DATA AVAILABLE ON BITUMEN HEATING

A2.1 Overseas Practice

Enquiries made through Shell Oil NZ Ltd indicated that there did not appear to be any official publication setting down the maximum allowable heating rates for bitumen.

A2.1.1 Electric Heating

Traditional practices varied from country to country. For example, in the UK it is usual to limit heat input in the case of electrical heaters to 0.7W/cm^2 (7kW/m^2) for bitumen in the range of 100 to 200 penetration grades. This figure is generally accepted in Germany but in France it is usual to adopt the lower figure of 0.5W/cm^2 (5 kW/m^2).

Table A2.1 Heating rates and fuel consumption for flame tube heating.

Weight of bitumen (tonnes)	Rate of Temp Rise (°C/h)	Rate of Heat Gain (kW)	Area of Heating Surface (m^2)	Rate of Fuel Consumption (l/h)
5	29	84.5	5	n.a.
10	29	169	10	22.7
15	19.5	170	10	22.8
20	14.5	169	10	22.7
20	29	338	20	45.4
40	21.5	502	40	67.5

Assumptions: The fuel is gas oil density 0.85kg/litre
Specific energy (calorific value) 45000 kJ/kg
Overall thermal efficiency is 70%

Note: Based on the above, the heat input into the bitumen would be about 1.7 W/cm^2, assuming the heat was evenly distributed over the entire surface of the flame tube.

In practice a high proportion of the heat transfer into the bitumen takes place in the radiant heat zone of the burner flame.

A2.1.2 Hot Oil Heating

In the oil industry the recommended practice is to utilise heat-transfer oil as the heating medium in tank coils, suction heaters and pipe tracers. The oil enters the heat exchange equipment at 250°C and leaves it at 200°C. Coking does occur over long periods of operation and methods used to minimise this are the adoption of finned tubes in coils and suction heaters to increase the heat transfer area.

A2.1.3 Flame Tube Heating

The traditional practice for flame tube heating is even more inexact. It is usual to make the heat transfer area large enough to avoid hot spots.

Stainless steel or ceramic liners long enough to exceed the maximum length of flame may also be fitted.

A2.2 Current New Zealand Practice

A2.2.1 Electric Heating

Most electric elements used for bitumen heating in New Zealand are locally made and usually have a heat rate of 1.22 W/cm^2 (about twice the ratings used in Europe).

These elements when tested in bitumen, by an element manufacturer, yielded the following results:

Bitumen Temperature	Element Tube Temperature
150°C	200°C
170°C	220°C

During the test it was noticed that the surface temperature of the element rose to 200°C soon after commencing and held this while the bitumen temperature rose from room temperature to 150°C, after which the bitumen temperature continued to increase.

A2.2.2 Hot Oil Heating

Apart from bulk bitumen installations at the main distribution centres, there are very few contractors using oil heating.

A2.2.3 Flame Tube Heating

Where rapid temperature boosting is required, flame tubes are normally used and this is the most common method of heating bitumen in road tankers.

The evolution of flame tube/burner configurations has been largely by trial and error because of a lack of research information.

APPENDIX 3

Testing Procedure

A3. TESTING PROCEDURE

Testing of the tanker/flame tube configuration was spread over three winters (1991, 1992 and 1993) as the test vehicle was returned to service during the intervening summers. Photographs of the tanker and probe arrangements illustrate some of the equipment used.

1. The test tanker with probes attached was loaded with 180/200 grade bitumen.

2. The burner and nozzle to be tested were fitted, and the fuel supply was attached.

3. The tank contents were cooled naturally, without recirculation.

4. The TAUPO data logger was attached to the cold junction compensator leads on top of the tanker.

5. The tank was recirculated for 15 minutes to mix the contents; the recirculation was then stopped and the burner started.

6. The primary air damper of the burner was adjusted either to deliver the minimum of excess air for stoichiometric combustion; or to be fully open for maximum air flow.

7. Heating continued until the burner control thermostat turned the burner off at 165°C. The data logger recorded temperatures every five minutes throughout this period.

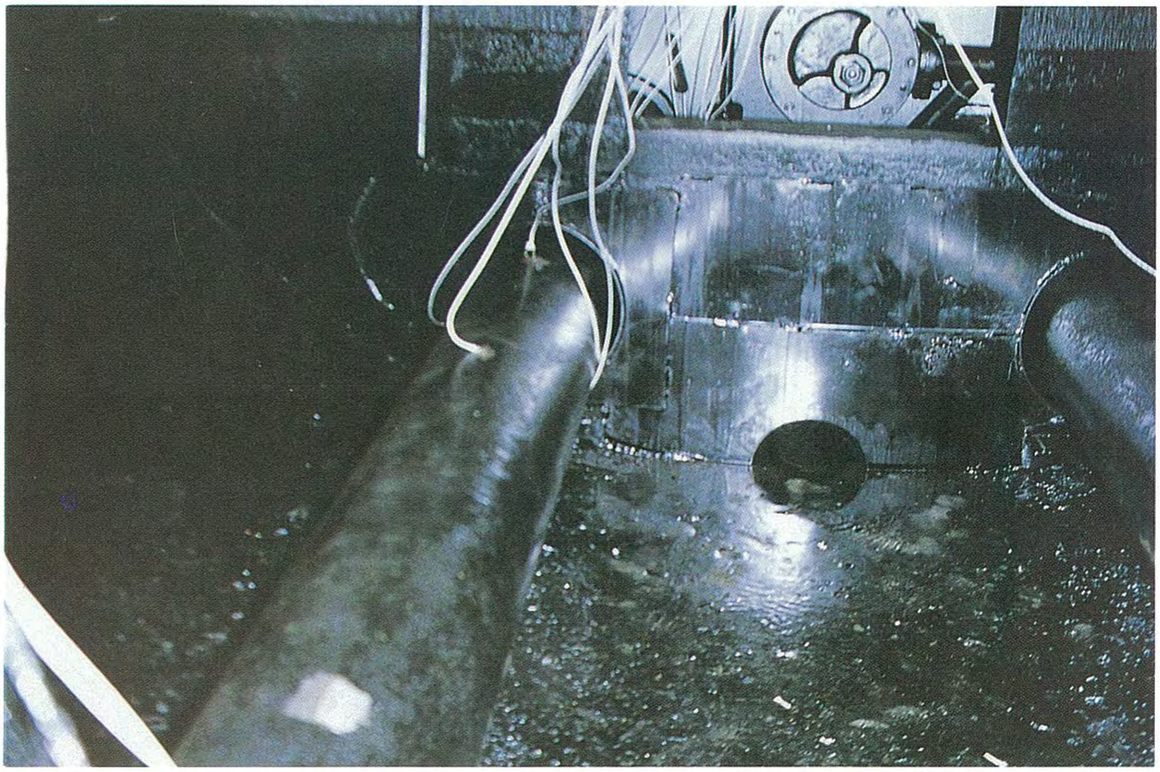
8. Tank contents were recirculated for another 15 minutes before turning off the data logger.

9. The test vehicle was left to cool before a new test was commenced.

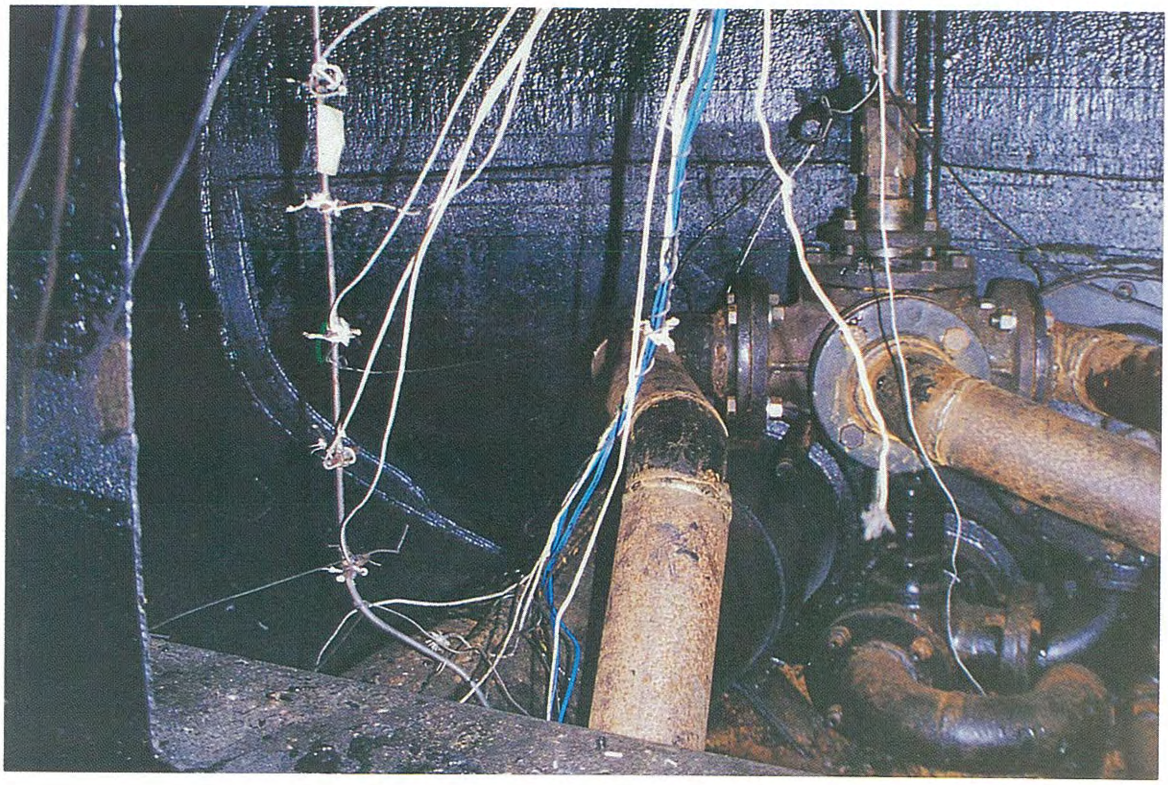
The Test Tanker

The Test Tanker from the rear.

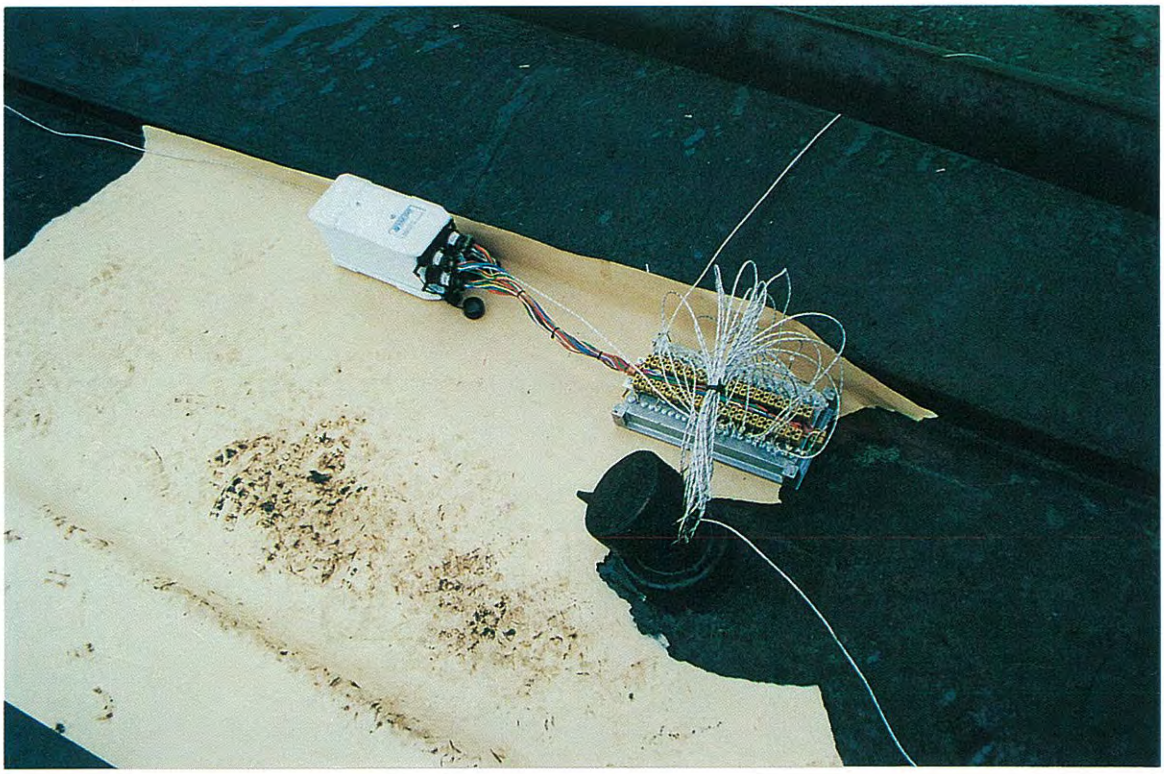
Burner and Thermostatic Control Box.



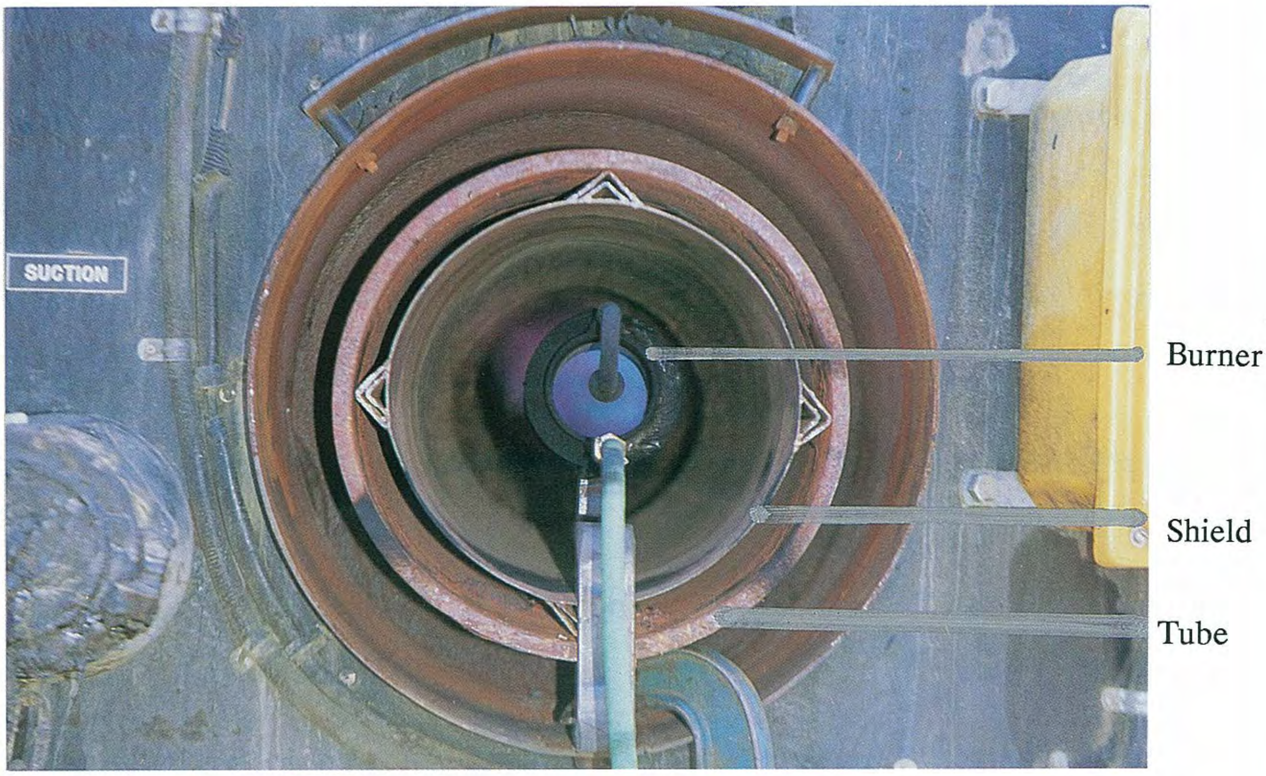
Thermocouple probes welded to flame tube inside tank.



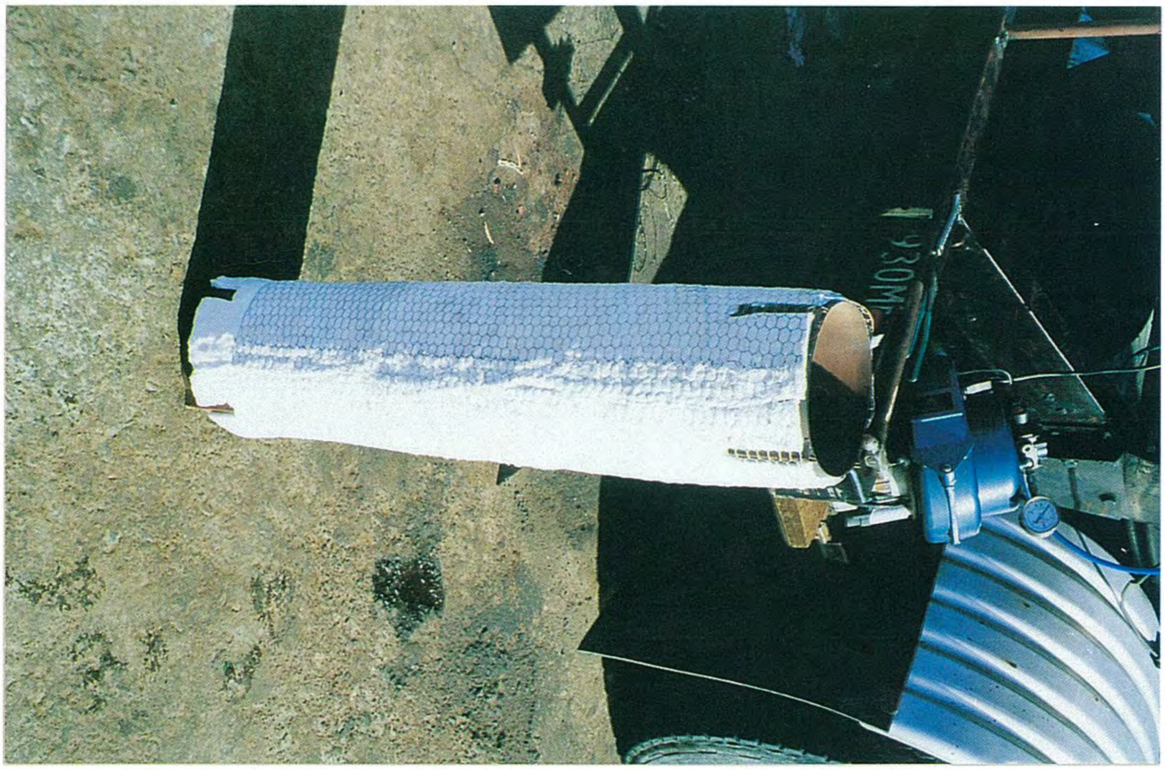
Thermocouple probes at different heights in the bitumen.



Thermocouples terminating at a Cold Junction Compensator.
The white box is the Taupo Data Logger.



Matthews burner inside flame tube, showing relative diameters of shield and tube.



KAO Wool surrounding 1200mm flame shield.

APPENDIX 4

Testing Equipment:

1. Test tanker
2. Recirculation
3. Burners
4. Nozzles
5. Air Flow
6. Testoterm Combustion Efficiency Analyser
7. Taupo-F Field Data Logger
8. Thermocouples

A4. TESTING EQUIPMENT

A4.1 Test Tanker

The tanker used for the testing was a 20,000 litre, six compartment, insulated road tanker, fleet number WKA333. It was less than two years old at the start of the testing programme on September 1991.

The tanker was fitted with an 18 metre long hairpin-shaped flame tube, the first 1.2m was 250mm diameter NB pipe, the rest being 200mm diameter NB pipe. This enlarged combustion zone section of the flame tube was fitted with an Inconel flame shield.

A4.2 Recirculation

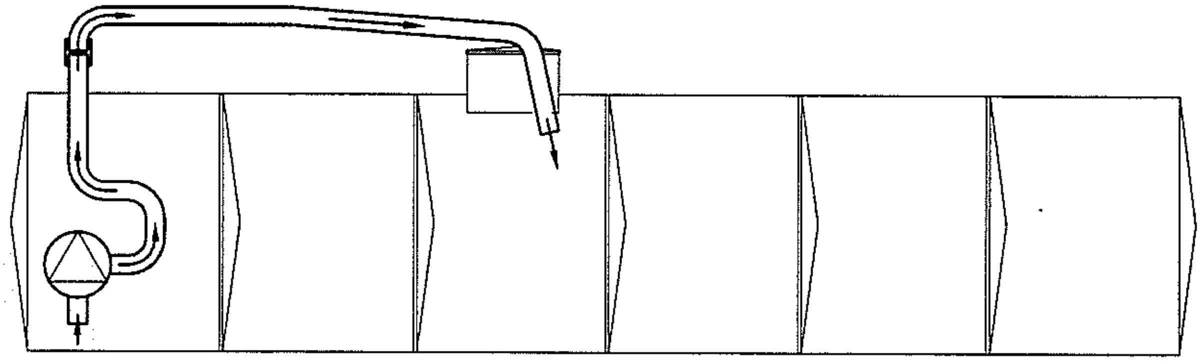
The tank incorporated an internally mounted 3-inch Brown Brothers pump.

In the 1991 series of tests, bitumen was pumped out through the overhead arm and back into the tank through the manhole. However, this method of recirculation did not mix the bitumen well enough and resulted in non-representative temperature readings. Temperatures of the entire mass are required to calculate the thermal efficiency of the heating test.

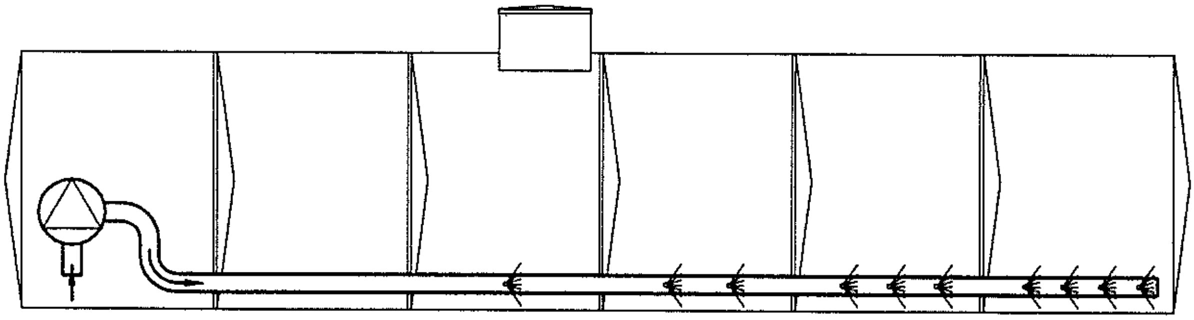
In the 1992 series of tests, a 3-inch recirculation pipe running the full length of the bottom of the tank was fitted to improve the recirculation of the bitumen. Holes were made in the pipe, with more holes in the front compartments of the tanker where bitumen movement is usually at a minimum (Figure A4.1).

This alteration would not change the heating characteristics of the tanker, but would improve mixing of the tank contents, and enable more representative readings of the overall bitumen temperatures to be recorded.

Figure A4.1. Methods of recirculation in bitumen tank.
(upper) Recirculation used in 1991.
(lower) Recirculation after modification, used in 1992 and 1993.



RECIRCULATION 1991



RECIRCULATION 1992 & 1993

A4.3 Burners

The burners tested were:

Riello Mectron 20M - diesel, capacity 95kW to 240kW
Boral Nu-Way NOL6 - diesel, capacity 97kW to 193kW
Boral Nu-Way NOL5 - diesel, capacity 59kW to 183kW
Boral Nu-Way NG7 - LPG nozzle and Natural Gas nozzle
Boral Nu-Way NG5 - LPG nozzle, capacity 88kW to 184kW
Technic - non-fan assisted, LPG
Matthews - non-fan assisted, LPG

The types of burners were:

1. Pressure jet oil burner (Riello Metron 20M, Boral Nu-Way NOL6, Boral Nu-Way NOL5). The fuel (diesel) is forced through a nozzle under pressure and atomised. The fuel is mixed with air that is forced by the fan into the flame tube.

2. Fan-assisted gas burner (Boral Nu-Way NG7, Boral Nu-Way NG5). The fuel (gas) is delivered to the nozzle at a regulated pressure and mixed with the forced air from the fan, and combustion takes place.

3. Vaporising burner (Technic, Matthews). This gas burner has a pre-combustion chamber to heat the incoming gas and ensure it is fully vaporised before reaching the combustion chamber through the nozzle. It has no fan and relies on both regulator pressure and pressure created by the gas vaporisation to force the flame into the tube.

A4.4 Nozzles

The nozzles used were:

Danfoss S
Monarch AR
Delevan B
LPG nozzle
Natural Gas nozzle

Nozzle configuration is given as either 30° or 45°. This is the angle of the spray exiting the nozzle. For example, the 30° configuration produces a long narrow spray pattern which reaches further down the flame tube before contacting the side. The spray pattern of fuel from the 45° nozzle generally impinges on the side of the tube where carbon build-up can occur.

All the nozzles produce a solid cone spray pattern, which provides a droplet distribution throughout the entire spray.

Nozzle sizes are commonly referred to in imperial units, usually US gallons per hour at 100 psi. For the purposes of this report, all measurements are quoted in metric units. The equivalent imperial units are listed below:

2.0 gph at 100 psi = 6.3 kg/h at 6.9 bar
2.5 gph at 100 psi = 8.0 kg/h at 6.9 bar

A4.5 Air Flow

The air flow into the burners was either:

Stoichiometric -	The damper is adjusted to allow only sufficient air to enter to give complete combustion. An outlet combustion test would show 2-6% oxygen and no carbon monoxide.
Maximum -	The damper is fully open to allow as much air to enter the combustion zone and flame tube that the fan is capable of supplying.

A4.6 TESTOTERM Combustion Efficiency Analyser

This is a measuring system for electronic combustion gas analysis, consisting of an indicator and controller, analyser and flue gas probe.

It is microprocessor controlled, and gives O_2 and CO_2 as a percentage of the volume, CO in parts per million, and temperature in °C. It also calculates the flue gas loss and efficiency.

A4.7 TAUPO-F Field Data Logger

Supplied by:
Solid State Equipment Ltd
5 Rishworth Street, Gracefield, PO Box 30089, Lower Hutt, New Zealand.

The Taupo-F 48-channel field data logger is a small data logger designed for unattended operation. It has no external controls or display. It takes readings from its inputs, and stores the information internally for subsequent retrieval through its serial port. An IBM PC was used as the computer interface for data retrieval.

The logger took readings from the selected inputs at a regular interval time of 5 minutes and stored these values in memory.

A4.8 Thermocouples

A4.8.1 Positions

K type thermocouple probes were welded directly onto the flame tube surface using a TAU thermocouple welder. The thermocouple leads were fed out through the dipstick tube to the Taupo data logger via a cold junction compensator.

In 1991, 34 probes were attached to the flame tube, with others measuring the drain filter, tank contents, flue gas, and ambient air temperatures.

In 1992, 24 probes were attached to the flame tube, another 5 attached to the baffles, 8 at different levels through the bitumen, and others measuring the pump suction flue gas and ambient air temperatures. See Diagrams for Thermocouple Locations used in 1991 and in 1992 (pp. 69, 71).

The burner control thermostat probe which causes the burner to cut-out once bitumen reaches spraying temperature, was located between the forward and return pass of the flame tube at a position approximately 100mm above the tube surface.

A4.8.2 Thermocouple Conversion

The following formulae were supplied by George Jones of Solid State Equipment Ltd, for the conversion of millivolt readings of type K thermocouples to degrees Centigrade.

$$E = a + bT + cT^2 + dT^3 + eT^4 \text{ where E is in microvolts and T in } ^\circ\text{C}$$

$$a = 0,\ b = 4.0981103 \times 10,\ c = -1.5992510 \times 10^{-4},$$
$$d = -1.2525700 \times 10^{-5},\ e = 3.2784725 \times 10^{-8}$$

This formula gives values between -25 and +20 microvolts in the temperature range 0° to +400°C.

$$T = f + gE + hE^2 + iE^3 + jE^4 \text{ where E is in microvolts and T in } ^\circ\text{C}$$

$$f = 0,\ g = 2.4383248 \times 10^{-2},\ h = 9.7830251 \times 10^{-9},$$
$$i = 3.6276965 \times 10^{-12},\ j = -2.5756438 \times 10^{-16}$$

This formula gives values between -0.5°C and +0.6°C in the temperature range 0° to +400°C.

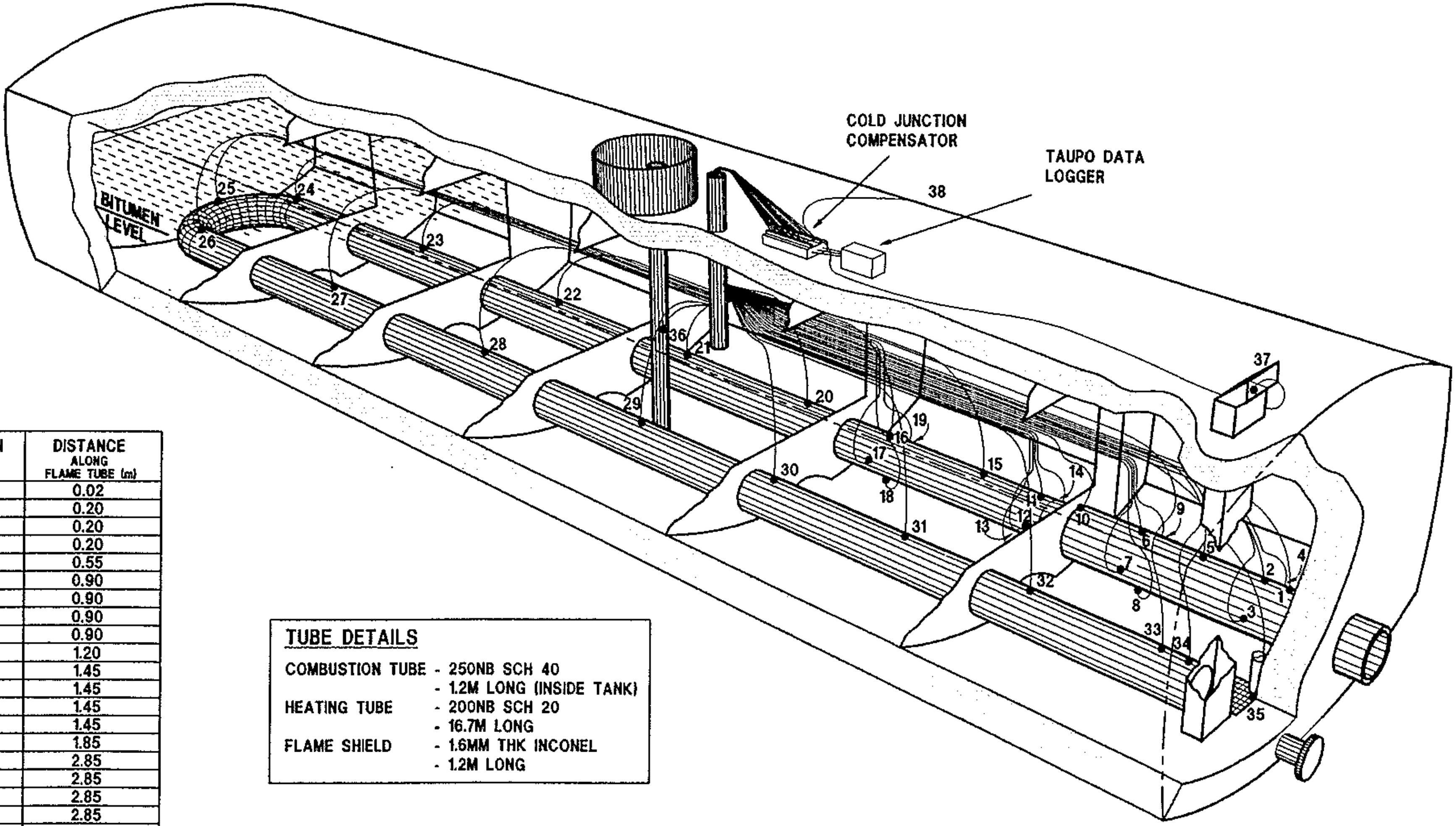
To use these formulae, take the ambient millivolt reading (input 47, range 4) and divide by 10 to get °C, call this T and calculate E (in millivolts) from the first formula.

Then take the thermocouple reading (input x, range 0 or 1) and multiply by 1000 to get microvolts, add to the first formula result, and call the sum E. Then calculate T from the second formula - this will be in °C.

An example is given here:

Ambient millivolt reading: 257.3
T = 25.73
E = 1054.13891 mV

Thermocouple reading: 11.199
E = 11199 + 1054.13891 = 12253.13891 mV
T = 301.10796 °C



TUBE DETAILS

COMBUSTION TUBE - 250NB SCH 40
- 1.2M LONG (INSIDE TANK)

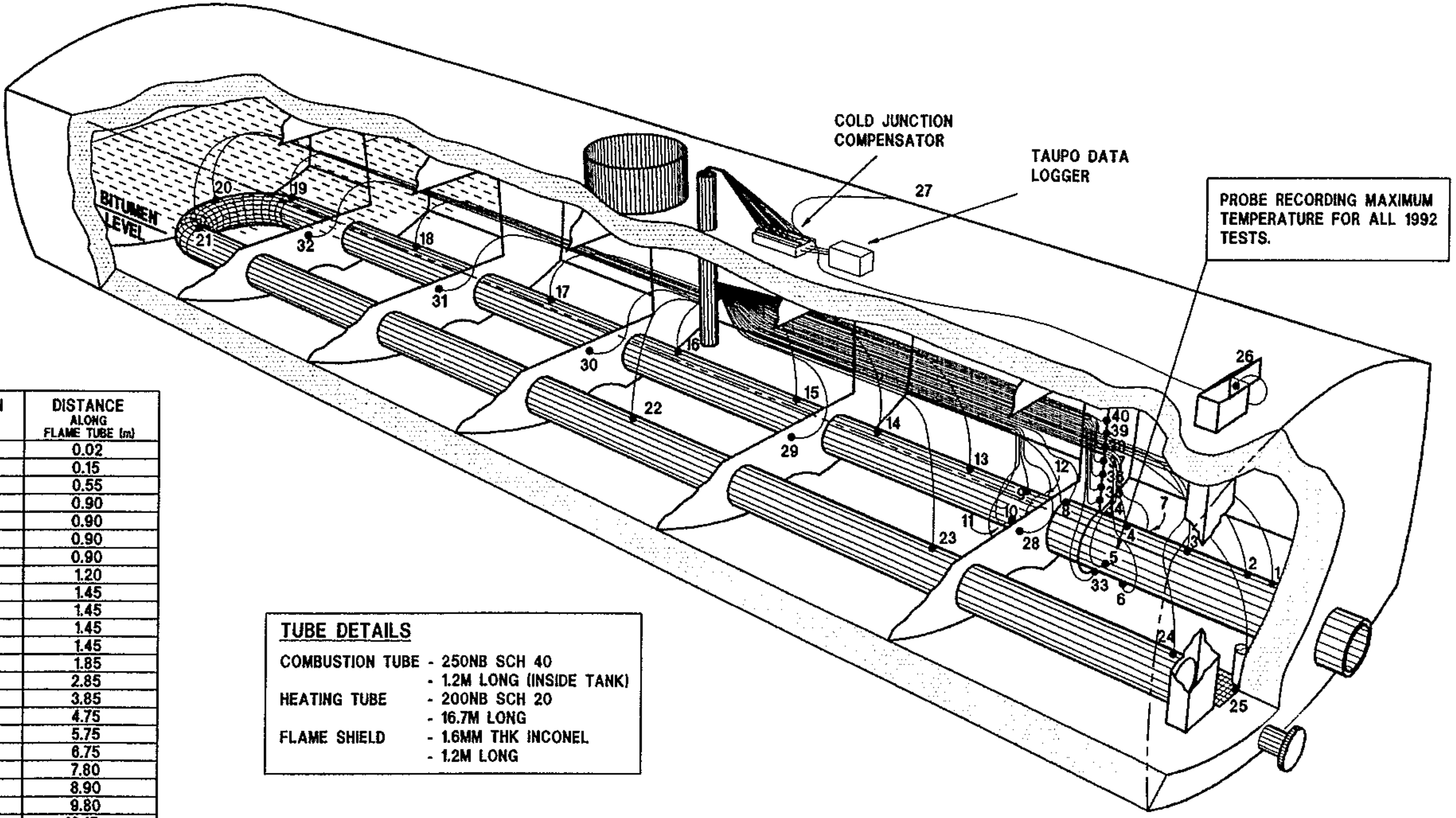
HEATING TUBE - 200NB SCH 20
- 16.7M LONG

FLAME SHIELD - 1.6MM THK INCONEL
- 1.2M LONG

PROBE No	POSITION	DISTANCE ALONG FLAME TUBE (m)
1	TOP	0.02
2	TOP	0.20
3	LEFT	0.20
4	RIGHT	0.20
5	TOP	0.55
6	TOP	0.90
7	LEFT	0.90
8	BOTTOM	0.90
9	RIGHT	0.90
10	TOP	1.20
11	TOP	1.45
12	LEFT	1.45
13	BOTTOM	1.45
14	RIGHT	1.45
15	TOP	1.85
16	TOP	2.85
17	LEFT	2.85
18	BOTTOM	2.85
19	RIGHT	2.85
20	TOP	3.85
21	TOP	4.75
22	TOP	5.75
23	TOP	6.75
24	TOP	7.80
25	TOP	8.90
26	TOP	9.80
27	TOP	10.80
28	TOP	11.95
29	TOP	13.15
30	TOP	14.15
31	TOP	15.15
32	TOP	16.10
33	TOP	17.10
34	TOP	17.70
35	DRAIN FILTER	N/A
36.	TANK CONTENTS	N/A
37	FLUE	N/A
38	AMBIENT	N/A

THERMOCOUPLE LOCATION AND IDENTIFICATION
(1991 TESTS)

TRACE companies



PROBE No	POSITION	DISTANCE ALONG FLAME TUBE (m)
1	TOP	0.02
2	TOP	0.15
3	TOP	0.55
4	TOP	0.90
5	LEFT	0.90
6	BOTTOM	0.90
7	RIGHT	0.90
8	TOP	1.20
9	TOP	1.45
10	LEFT	1.45
11	BOTTOM	1.45
12	RIGHT	1.45
13	TOP	1.85
14	TOP	2.85
15	TOP	3.85
16	TOP	4.75
17	TOP	5.75
18	TOP	6.75
19	TOP	7.80
20	TOP	8.90
21	TOP	9.80
22	TOP	13.15
23	TOP	16.10
24	TOP	17.70
25	PUMP SUCTION	0.10
26	FLUE	N/A
27	AMBIENT	N/A
28	BAFFLE #1	
29	BAFFLE #2	
30	BAFFLE #3	
31	BAFFLE #4	
32	BAFFLE #5	
33	BITUMEN #1	0.90
34	BITUMEN #2	0.90
35	BITUMEN #3	0.90
36	BITUMEN #4	0.90
37	BITUMEN #5	0.90
38	BITUMEN #6	0.90
39	BITUMEN #7	0.90
40	BITUMEN #8	0.90

TUBE DETAILS

COMBUSTION TUBE	- 250NB SCH 40 - 1.2M LONG (INSIDE TANK)
HEATING TUBE	- 200NB SCH 20 - 16.7M LONG
FLAME SHIELD	- 1.6MM THK INCONEL - 1.2M LONG

THERMOCOUPLE LOCATION AND IDENTIFICATION
(1992 TESTS)

TRACE companies

APPENDIX 5

Bitumen used for Tests

1. Bitumen Monitoring
2. Bitumen Properties
3. Labtech Services Ltd Reports -
    - Bituminous Binder Test Report, Number 36-1-5089
    - Bitumen Testing, Number 1000-10
    - Effect of heating on 180/200 Bitumen, Number 1036-1
    - Effect of heating on 180/200 Bitumen, Number 1256-1

A5. BITUMEN USED FOR TESTS

A5.1 Bitumen Monitoring

The tanker and flue were clean and free from other product contamination at the beginning of each set of heating tests.

A5.1.1 Bitumens Used for 1991 Tests

10,760 litres of 180/200 bitumen were obtained from the New Zealand Refinery Company at Marsden Point.

The bitumen was sampled on 17/12/91 and tested by Labtech (results recorded in Lab Report No. 36-1-5089), when it had a needle penetration value of 114. The bitumen was not sampled between each test.

A5.1.2 Bitumens Used in 1992 Tests

11,340 litres of 180/200 bitumen were obtained from New Zealand Refinery Company.

The bitumen was sampled between each heating test, between 30.6.92 and 23.9.92 (or 86 days). The needle penetration and kinematic viscosity at 70°C were tested by Labtech (results recorded in Lab Report Number 1000-10).

A5.1.3 Bitumens Used in 1993 Tests

The bitumen in a full tanker was sampled every day for 16 days, between 12.10.93 and 28.10.93. The needle penetration was tested by Labtech (results recorded in Lab Report No.1036-1).

The bitumen in a half-full (46%) tanker was sampled every day for 17 days, between 23.12.93 and 9.1.94. The needle penetration was tested by Labtech (results recorded in Lab Report No.1256-1).

For both tests the burner thermostat cut-out temperature was set at 170°C and the unit was left to run for 16 and 17 days respectively. The bitumen was sampled daily after the tank contents had been recirculated.

A5.2 Bitumen Properties

A5.2.1 Penetration and Viscosity

The penetration value steadily decreased during the 1992 tests, reaching 121 from the initial 181. This is significant hardening. However Grant Bosma (Labtech, pers.comm.) is of the opinion that the specific heat of bitumen would not have significantly altered with such bitumen hardening. This means the bitumen heating properties can be assumed to be constant throughout the period of testing. The kinematic viscosity value also steadily increased, reaching 33500 from the initial 19200.

A5.2.2 Durability

The durability of bitumen is a key factor in its use on roads. The durability decreases with thermal oxidation of the bitumen, causing it to harden. Long-term studies have shown that if a bituminous surfacing is to achieve its design life the bitumen should not harden excessively during storage, during the manufacturing process, or in service on the road.

Bitumen is affected by the presence of oxygen, ultra-violet radiation and temperature changes. These cause it to harden, measured by a decrease in penetration, and an increase in softening point.

A5.2.3 Storage

Storage of bitumen even at relatively low temperatures while exposed to air causes a significant hardening of the bitumen, as shown by previous testing. The degree of oxidation is highly dependent on temperature, time, and the extent of the surface area exposed to oxygen.

Bitumen should be heated as uniformly as possible with minimal local overheating, and should be kept at elevated temperatures for as short a time as possible, to minimise bitumen deterioration caused by oxidation.

A5.2.4 Safety

Bitumen typically has a flash point of between 300-320°C. In New Zealand it is commonly mixed with kerosine or diesel, but this lowers the flash point. For example, at 20% (by volume) kerosine and 80% 180/200 bitumen, the flash point has dropped to 60.5°C. This is now a Class 3B Flammable Liquid.

Bitumen has an approximate auto-ignition temperature of 500°C; and a specific heat capacity of 2.28kJ/kgK.

A5.3 Labtech Services Ltd Reports of Tests

The results of the monitoring tests carried out on the bitumens before and during the heating tests are presented in this appendix in the original form of the reports.

LabTech

LABTECH SERVICES LIMITED

PHONE (0064) (06) 7586993 FAX (0064) (06) 7588135
PRIVATE BAG DEVON ROAD NEW PLYMOUTH NEW ZEALAND

BITUMINOUS BINDER TEST REPORT

Report Number: 36-1-5089

Page 1 of 1 Pages

Sample Number: 5089	Date of Manufacture: —
Sample Description: 180/200	Date Sample Received: 17/12/91
Batch Number: ACL tanker	Sampled By: M. Tyne
Client: ACL	Date of Test: 17/12/91
Client Order Number: C 54749	Tested By: M. Wilson

TEST	METHOD	RESULT	UNIT	SPEC	MIN	MAX
Needle Penetration (25°C, 100g, 5sec)	ASTM D5	114	dmm	TNZ M/1	180	200
Needle Penetration (0°C, 100g, 5 sec)	ASTM D5		dmm			
Cone Penetration (25°C, 150g, 5 sec)	ASTM D3407		dmm			
Cone Penetration (50°C, 150g, 5 sec)	ASTM D3407		dmm			
Resilience (25°C)	ASTM D3407		%			
Softening Point Water/Glycerine	ASTM D36		°C			
Kinematic Viscosity at ______ °C	ASTM D2170		cSt			
Torsional Recovery at ______ °C	Works		%			

Checked By: CBGoh

Issued By: MWilson

Date of Issue: 17/12/91

**INNOVATIONS
IN
BITUMEN
TECHNOLOGY**

TELARC
REGISTERED
LABORATORY

LabTech

LABTECH SERVICES LIMITED

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PRIVATE BAG DEVON ROAD NEW PLYMOUTH NEW ZEALAND

Report Number: 1000-10 **Page 1 of 4 Pages**

Bitumen Testing

Client: Bitumen Contractors Association
Sample Description: Bitumen ex Heating Trials:
5552, 5561, 5563, 5569, 5578, 5587, 5589, 5590,
5611, 5612, 5631, 5632, 5635, 5636, 5638, 5639,
5652, 5653, 5665, 5667, 5677
Sampled By: A. Rayner
Tested By: M.D. Wilson
Sub-Contracted to Works Consultancy Services
Limited, as indicated
Date Tested: to 27 September 1993
Test Methods: ASTM D5 - 86, ASTM D36 - 86, ASTM D92 - 90
ASTM D113 - 86, ASTM D2042 - 81
ASTM D2170 - 85, TNZ M/1:1989, §1.1
AS 2341.13:1986
Report By: G.M. Bosma
Results: (see over)

Date of Issue: 5 October 1993

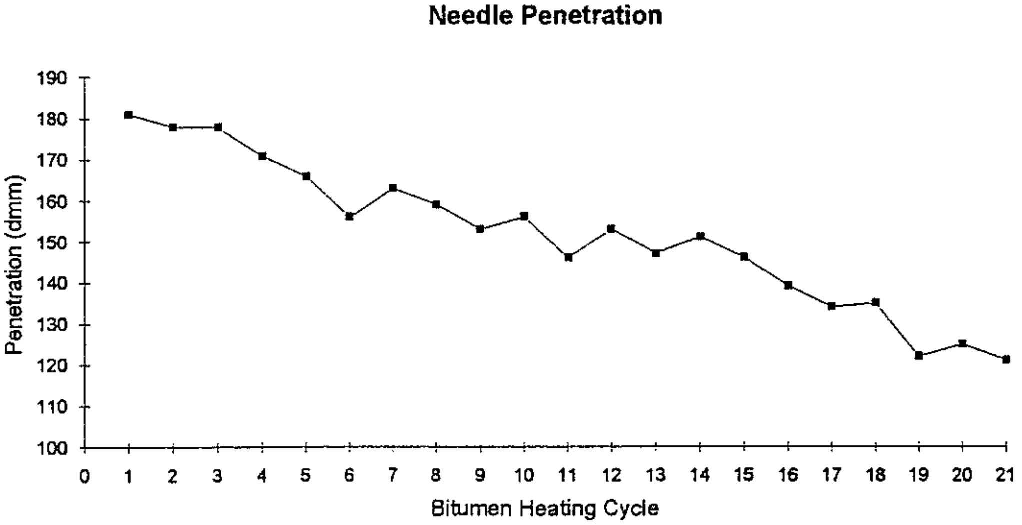
Issued By: Bosma

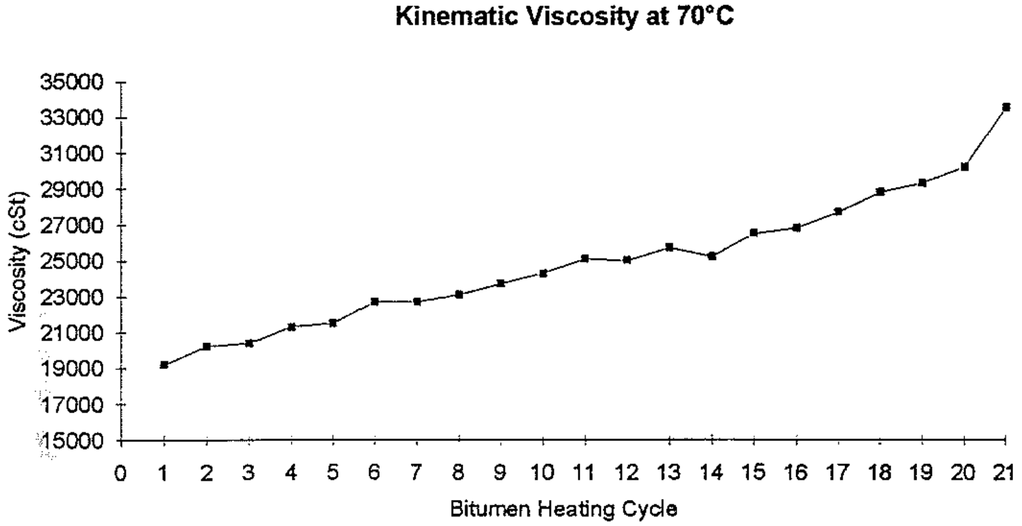
Checked By: MDWilson

Bitumen hardening is known to occur during hot storage. This exercise was intended to assess the degree of hardening of 180/200 bitumen in a typical road tanker with each heating and cooling cycle, and to determine whether hardening is a result of high flame tube temperatures or exposure to atmospheric oxygen (or both).

Twenty one bitumen samples were obtained, one from each heating and cooling cycle. These samples were initially tested in the laboratory for Penetration and Viscosity, tabulated and graphed as follows:

Sample No.	**Sample**	**Needle Penetration (dmm)**	**Kinematic Viscosity @ 70°C (cSt)**	**Softening Point (°C)**	**Ductility @ 25°C (cm)**
	180/200 Specification	**180-200**	**> 14,000**	**37 - 43**	
5552	**1:** 30/6/92	181	19200	40.3	>110
5561	**2:** 6/7/92 9:55am	178	20200		
5563	**3:** 6/7/92 4:30pm	178	20400		
5569	**4:** 10/7/92 10:45am	171	21300		
5578	**5:** 13/7/92 2:50pm	166	21500		
5611	**6:** 16/7/92	156	22700		
5587	**7:** 23/7/92	163	22700		
5589	**8:** 24/7/92 3:50pm	159	23100		
5590	**9:** 28/7/92 2:00pm	153	23700		
5612	**10:** 31/7/92 10:30am	156	24300		
5631	**11:** 17/8/92 10:00am	146	25100		
5632	**12:** 17/8/92 2:00pm	153	25000		
5635	**13:** 21/8/92 10:30am	147	25700		
5636	**14:** 21/8/92 1:50pm	151	25200		
5638	**15:** 24/8/92 2:50pm	146	26500		
5639	**16:** 25/8/92 4:50pm	139	26800		
5652	**17:** 2/9/92 4:00pm	134	27700		
5653	**18:** 4/9/92 8:00am	135	28800		
5665	**19:** 7/9/92 4:20pm	122	29300		
5667	**20:** 10/9/92 12:30pm	125	30200		
5677	**21:** 23/9/92 11:30am	121	33500	43.7	>110





From these results it appears that the bitumen is not significantly hardened for up to three heating cycles, although other tanker and burner combinations may give different results.

The initial and final samples (samples 1 and 21) were subjected to further testing as follows:

Material		"Sample 1"	"Sample 21"
Age (No. of Heat Cycles)		1	21
Laboratory Sample Number		5552	5677
Penetration	(dmm)	181	121
Softening Point	(°C)	40.3	43.7
Penetration Index		-0.35	-0.61
Kinematic Viscosity at 70 °C	(cSt)	19200	33500
Flash Point*	(°C)	306	304
Ductility*	(m)	>1	>1
Ductility after RFTO*	(m)	>1	>1
Durability*	(days)	13.3	10.1
Solubility*	(%)	-	100

*Subcontracted to Works Central Laboratories

Conclusions

Hardening of the bitumen by repeated heating cycles has not significantly affected the flash point or the ductility. The similarity of the two flash point values suggests that exposure to high surface temperatures on the burner tubes is not generating volatile fractions by thermal cracking. Therefore, it has been tentatively concluded that the hardening is due to reaction with atmospheric oxygen.

A solubility of 100% indicates that coking is not taking place over 21 heating cycles.

The tanker was only half full during these heating trials, hence the maximum possible surface area of the bitumen would be exposed. Additionally, the greater ullage volume of the partly filled tanker would contain more oxygen than would a full tanker. It may be concluded rate of hardening would be less for a full tanker of bitumen.

The reduction of durability is surprisingly less than expected, considering that 80/100 results are typically not much greater than four days. This fact, coupled with the reduced Penetration Index, suggests that the mechanism of hardening is different to conventional hardening of bitumen by air blowing during refining.

LabTech

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PRIVATE BAG DEVON ROAD NEW PLYMOUTH NEW ZEALAND

Report Number: 1036-1 **Page 1 of 2 Pages**

Effect of heating on 180/200 Bitumen

Client:	Asphaltic Construction Limited
Sample Description:	Bitumen Samples from Tanker Heating Trials
Sample Numbers:	6488, 6489, 6490, 6491, 6492, 6499, 6500, 6502, 6503, 6507, 6508, 6509, 6510, 6511, 6512, 6516, 6519
Tested By:	MD Wilson
Date Tested:	14,18, 21, 26, 27 October, 1 November 1993
Report By:	MD Wilson
Test Methods:	ASTM D5 - 86 (Penetration)

Date of Issue:	8 November 1993
Approved Signatory:	
Checked By:	

TELARC

All tests reported herein have been performed in accordance with the laboratory's terms of registration

TELARC REGISTERED LABORATORY

Introduction

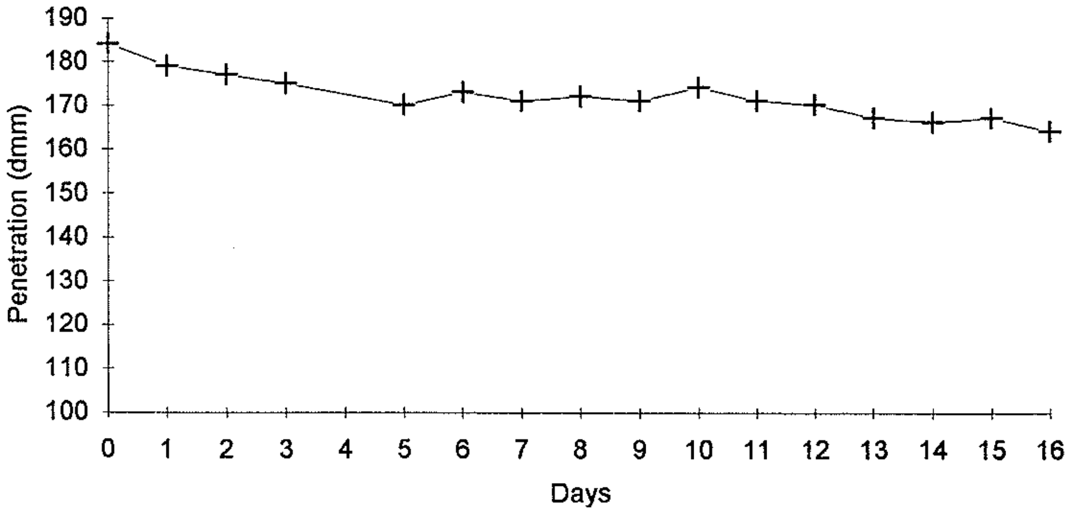
A bitumen tanker was filled with 180/200 bitumen and maintained at a temperature of 170°C. Bitumen samples were scooped from the top at daily intervals, after being circulated for 15 minutes. The samples were tested for penetration in order to determine the degree of hardening.

Results

Sample No.	Sample	Needle Penetration (dmm)
	180/200 Specification	**180-200**
6488	**Day 0:** 12/10/93 5:00pm	184
6489	**Day 1:** 13/10/93 4:30pm	179
6490	**Day 2:** 14/10/93 4:30pm	177
6491	**Day 3:** 15/10/93 4:30pm	175
6492	**Day 5:** 17/10/93 4:30pm	170
6499	**Day 6:** 18/10/93 4:30pm	173
6500	**Day 7:** 19/10/93 4:15pm	171
6502	**Day 8:** 20/10/93 4:15pm	172
6503*	**Day 8:** 20/10/93 4:15pm	173
6507	**Day 9:** 21/10/93 4:15pm	171
6508	**Day 10:** 22/10/93 4:15pm	174
6509	**Day 11:** 23/10/93 4:00pm	171
6510	**Day 12:** 24/10/93 4:30pm	170
6511	**Day 13:** 25/10/93 4:15pm	167
6512	**Day 14:** 26/10/93 4:30pm	166
6516	**Day 15:** 27/10/93 5:15pm	167
6519	**Day 16:** 28/10/93 4:30pm	164

* Sampled using a tube 1 metre long by 25mm diameter.

Needle Penetration



LabTech

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PRIVATE BAG DEVON ROAD NEW PLYMOUTH NEW ZEALAND

Report Number: 1256-1 **Page 1 of 4 Pages**

Effect of heating on 180/200 Bitumen

Client:	Asphaltic Construction Limited
Sample Description:	Bitumen Samples from Tanker Heating Trials
Sample Numbers:	6724, 6725, 6726, 6727, 6728, 6729, 6730, 6731, 6732, 6733, 6734, 6735, 6736, 6737, 6738
Tested By:	MD Wilson
Date Tested:	13 January 1994
Report By:	MD Wilson
Test Method:	ASTM D5 - 86 (Penetration)

Date of Issue: 14 January 1994

Approved Signatory: MWilson

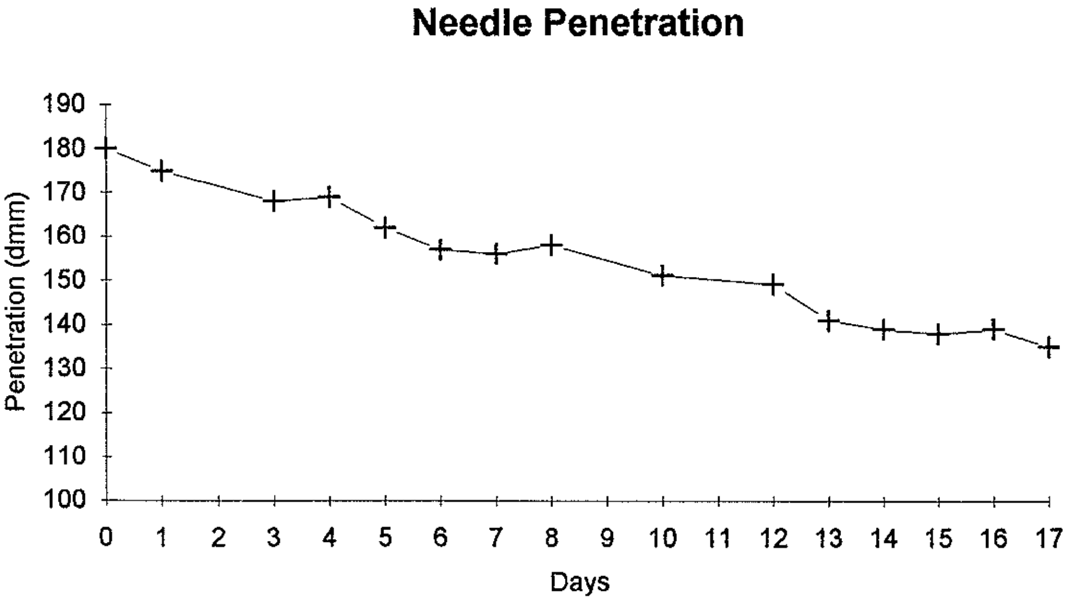
Checked By:

Introduction

A bitumen tanker was half filled with 180/200 bitumen and maintained at a temperature of 170°C. Bitumen samples were scooped from the top at daily intervals, after being circulated for 15 - 20 minutes. The samples were tested for penetration in order to determine the degree of hardening.

Results

Sample No.	Sample	Needle Penetration (dmm)
	180/200 Specification	**180-200**
6724	**Day 0:** 23/12/93 11:00am	180
6725	**Day 1:** 24/12/93 10:30am	175
6726	**Day 3:** 26/12/93 11:45am	168
6727	**Day 4:** 27/12/93 2:15pm	169
6728	**Day 5:** 28/12/93 2:35pm	162
6729	**Day 6:** 29/12/93 11:50am	157
6730	**Day 7:** 30/12/93 3:30pm	156
6731	**Day 8:** 31/12/93 12:00pm	158
6732	**Day 10:** 2/1/94 3:00pm	151
6733	**Day 12:** 4/1/94 12:15pm	149
6734	**Day 13:** 5/1/94 1:45pm	141
6735	**Day 14:** 6/1/94 11:15am	139
6736	**Day 15:** 7/1/94 10:50pm	138
6737	**Day 16:** 8/1/94 1:30pm	139
6738	**Day 17:** 9/1/94 12:30pm	135



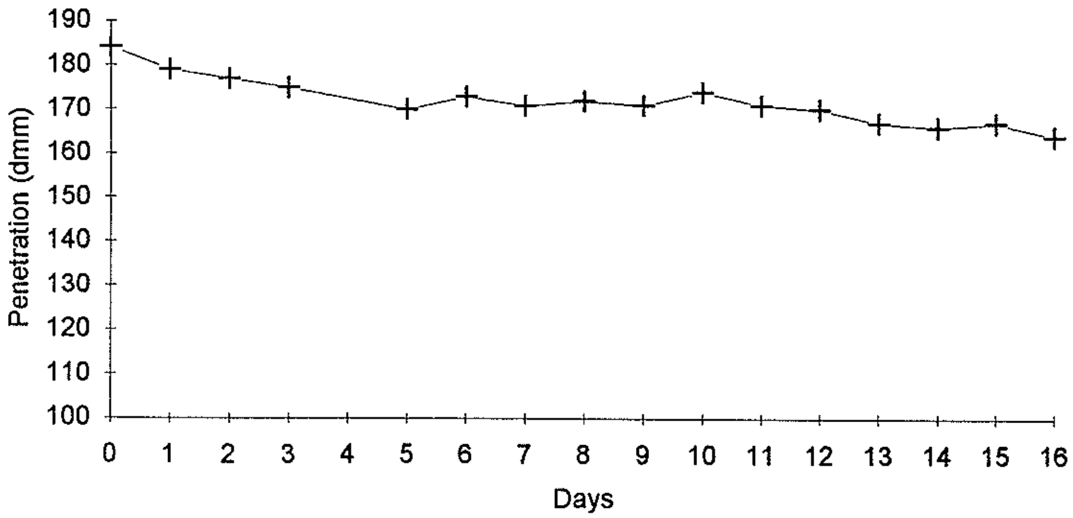
Previous tests were conducted in October 1993 using a full bitumen tanker (refer Labtech Services Report 1036-1). Following are the results of this work.

Results

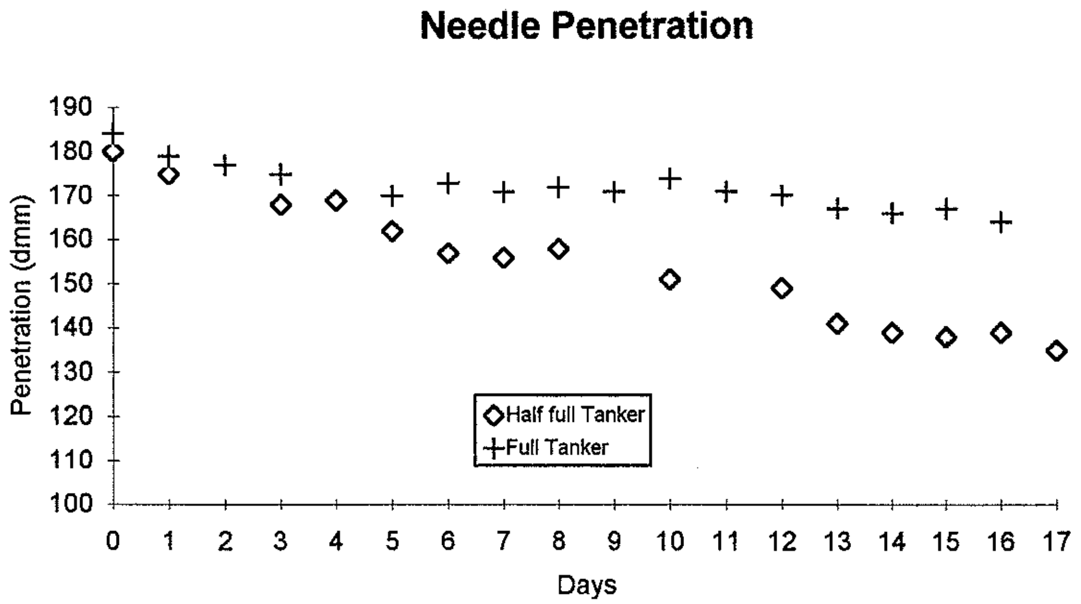
Sample No.	Sample	Needle Penetration (dmm)
	180/200 Specification	**180-200**
6488	**Day 0:** 12/10/93 5:00pm	184
6489	**Day 1:** 13/10/93 4:30pm	179
6490	**Day 2:** 14/10/93 4:30pm	177
6491	**Day 3:** 15/10/93 4:30pm	175
6492	**Day 5:** 17/10/93 4:30pm	170
6499	**Day 6:** 18/10/93 4:30pm	173
6500	**Day 7:** 19/10/93 4:15pm	171
6502	**Day 8:** 20/10/93 4:15pm	172
6503*	**Day 8:** 20/10/93 4:15pm	173
6507	**Day 9:** 21/10/93 4:15pm	171
6508	**Day 10:** 22/10/93 4:15pm	174
6509	**Day 11:** 23/10/93 4:00pm	171
6510	**Day 12:** 24/10/93 4:30pm	170
6511	**Day 13:** 25/10/93 4:15pm	167
6512	**Day 14:** 26/10/93 4:30pm	166
6516	**Day 15:** 27/10/93 5:15pm	167
6519	**Day 16:** 28/10/93 4:30pm	164

* Sampled using a tube 1 metre long by 25mm diameter.

Needle Penetration



Following is the graph containing both sets of results.



APPENDIX 6

Definitions of Terms and Formulae

A6. DEFINITION OF TERMS AND FORMULAE

A6.1 Time

Burner start time - was noted during the test, and is indicated by a rise in the temperature recorded in the flue (probe 37 in 1991, probe 26 in 1992).

Burner stop time - was noted during the test, and is indicated by a fall in the temperature recorded in the flue (probe 37 in 1991, probe 26 in 1992).

Recirculation time - was noted during the test, and is indicated at the end of testing by a rise in the temperature recorded at the drain filter (probe 35 in 1991) or pump suction (probe 25 in 1992).

A6.2 Temperature

A6.2.1 1991 Tests

The **initial temperature** was calculated by taking the average temperature as measured by probes 35 and 36 at the time the burner started, after the tank had been recirculating for 15 minutes. Probes 35 and 36, which take measurements from the drain filter and the tank contents respectively, should give the most representative measurement of the temperature of the entire contents of the tank.

The **finish temperature** was calculated by averaging probe 35 and 36 after the burner had stopped and the tank had been recirculated.

A6.2.2 1992 Tests

The **initial temperature** was calculated by taking the average temperatures measured by probes 28 to 32 at the time the burner started, after the tank had been recirculating for 15 minutes. Probes 28 to 32 took bitumen temperature measurements at the baffles in each compartment of the tank.

The **finish temperature** was calculated by averaging probes 28 to 32 after the burner had stopped and the tank had been recirculated.

Tank temperature loss to the surroundings from this tank in both years was measured at 1°C per hour for the time that the burner was going.

All times are accurate to ± 5 minutes, temperatures accurate to ± 0.5°C.

A6.3 Temperature Rise

$$\text{Temperature rise (°C/h)} = \frac{\text{finish temp - initial temp}}{\text{time}} + \text{tank loss}$$

Where Time = time the burner was operating in hours
Tank loss = 1°C per hour

A6.4 Firing Rate

Burner output (kW) = heat input / time
Firing rate (kW/m^2) = heat input / (time x surface area)

Heat input (kJ) = $\text{mass}_{\text{fuel}} \times c_v$
c_v = calorific value of fuel
c_v of LPG = 49.7 MJ/kg
c_v of diesel = 45.8 MJ/kg
c_v of natural gas = 40.5 MJ/m^3

Time = burner on time (seconds)

Surface area = 1.2 metres of 10" NB (0.273m OD) pipe + 16.7 metres of 8" NB (0.219m OD) pipe
= (1.2 x pi x 0.273) + (16.7 x pi x 0.219)
= 12.5 m^2

So, firing rate (kW/m^2) = $\text{mass}_{\text{fuel}} \times c_v / (12.5 \times \text{time})$

Heat rating (kW/m^2) = firing rate x thermal efficiency

Thermal efficiency = 70% (BCA Code of Practice)

* The firing rate and heating rate are average values for the entire flame tube.

A6.5 Thermal Efficiency

A6.5.1 1991 Tests

This was not calculated in 1991 as too few probes were in the bitumen and the circulation was not considered adequate to give representative temperature readings.

A6.5.2 1992 Tests

Thermal efficiency = heat out / heat in

$$= \frac{\text{mass}_{\text{bitumen}} \text{ x specific heat}_{\text{bitumen}} \text{ x change in temperature}_{\text{bitumen}}}{\text{mass}_{\text{fuel}} \text{ x calorific value}_{\text{fuel}}}$$

Specific heat capacity c_p of bitumen = 2.28 kJ/kgK
This figure is an average value for the bitumen over the temperature range experienced during heating.

Change in $\text{temp}_{\text{bitumen}}$ = finish temp - initial temp + (1°C x time in hours)
This assumes an average product temperature rise over the entire tank contents.

Any variations in the results between the interim and final reports is due to standardisation and refining of the formulae used in the calculations, as detailed above.

The provisional BCA Code of Practice assumes the thermal efficiency is 70%.

APPENDIX 7

Data from Test 14

an example of the format used for recording the results

BITUMEN HEATING TEST NUMBER 14

Sheet 1 of 2

Burner: Boral Nu–way NOL6
Nozzle: Danfoss S 30° 8kg/hr

Air Supply: Maximum

Fuel Pressure: 10.3 bar

Fuel: 55.016kg Diesel

Bitumen Quantity: 11340kg

Date: 9/7/92

TIME [MIN]	TEMPERATURE READING °C PROBE IDENTIFICATION																																								COMMENTS
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	
0		94	98	100	99	96	98	99	99	97	96	98	97	98	97	97	98	97	97	97	97	97	98	94	99	15	11	97		98	99	102	96	99	100	102	96	94	93	93	RECIRCULATE TANK CONTENTS
5	143	152	169	212	203	181	200	187	194	175	173	183	174	165	161	157	155	152	150	151	144	144	142	139	99	215	12	98	P	98	99	102	95	98	100	102	102	97	96	95	FINISH RECIRC & BURNER START
10	190	209	240	272	269	241	264	251	250	229	226	235	231	215	211	204	198	192	189	191	180	177	174	170	99	234	12	99		98	99	102	92	99	99	102	118	112	110	108	
15	216	238	261	285	288	261	283	272	269	249	245	253	252	235	232	226	216	211	207	209	197	193	189	185	99	248	12	100	R	98	100	102	89	99	101	109	140	126	124	122	
20	230	247	267	289	294	267	289	278	274	256	252	260	257	242	240	233	224	219	216	217	206	200	196	192	97	254	12	100		99	100	103	88	100	100	99	146	134	131	128	
25	238	250	267	291	297	270	292	281	277	259	255	262	260	244	243	235	228	223	219	221	211	204	200	196	96	258	12	101	O	99	101	104	88	101	107	104	146	139	136	133	
30	242	254	267	291	298	272	294	280	278	260	256	264	261	245	245	235	229	226	221	222	211	206	203	198	94	263	12	102		103	102	106	88	102	102	109	152	143	140	137	
35	244	256	265	291	298	272	294	280	279	261	257	264	261	248	245	238	229	226	221	223	212	207	204	199	92	263	12	102	B	105	103	109	87	100	100	110	154	146	142	139	
40	247	257	264	292	299	273	295	279	279	261	258	265	262	247	245	237	229	228	222	223	213	207	204	200	91	266	11	103		106	106	111	86	101	101	111	152	147	145	142	
45	248	256	265	293	299	273	295	279	280	261	258	265	262	246	245	237	229	227	222	223	212	207	204	201	90	267	12	105	E	107	111	114	86	99	105	114	154	150	147	144	
50	249	256	265	293	300	273	296	279	280	261	258	265	260	246	245	237	229	226	223	223	213	207	205	201	89	267	12	106		108	114	117	86	100	107	116	156	152	149	147	
55	250	257	266	293	300	274	296	279	282	262	258	266	260	245	242	236	229	226	222	223	212	206	205	201	89	266	12	107		109	117	119	85	103	108	118	160	154	151	148	
60	252	256	265	292	300	274	296	278	281	261	258	265	258	243	241	236	229	225	222	223	212	206	205	201	88	267	12	108	F	109	119	121	85	106	110	120	160	155	152	150	
65	250	258	265	292	300	274	296	279	280	262	258	265	258	243	241	236	229	225	222	223	212	206	205	201	87	267	12	110		111	121	122	84	109	111	121	161	156	154	151	
70	248	256	266	292	300	274	297	279	279	261	258	265	257	242	240	237	229	224	221	222	212	206	205	201	87	268	13	111	A	111	123	124	84	111	113	123	161	157	155	153	
75	248	259	266	292	301	274	297	280	280	262	258	266	257	241	239	237	229	224	221	221	211	206	204	201	87	268	12	113		111	124	124	83	117	114	125	163	158	156	153	
80	248	256	264	292	301	274	297	279	279	262	258	265	255	241	239	236	228	224	221	220	211	206	204	201	86	268	13	114	U	113	126	125	83	112	116	126	166	158	156	154	
85	249	255	264	292	301	273	296	278	279	261	257	265	254	240	238	236	228	223	220	220	210	206	204	200	86	268	12	116		114	127	126	83	110	118	128	164	159	156	155	
90	248	255	263	291	301	273	296	278	280	261	257	265	253	238	238	236	228	223	220	219	211	206	204	200	86	268	13	117	L	116	129	127	82	111	118	129	166	160	157	155	
95	248	255	264	291	301	273	296	278	280	261	257	266	252	239	237	236	227	223	220	219	210	206	204	200	85	267	13	119		118	130	128	82	113	118	129	165	160	157	156	
100	248	255	263	291	301	273	297	278	281	261	257	266	252	239	237	236	227	222	220	219	210	206	203	200	85	268	13	120	T	120	132	129	82	114	121	132	164	160	157	156	
105	247	255	263	290	301	273	297	278	281	262	257	266	252	238	236	236	227	222	220	219	210	206	203	200	85	269	13	122		121	133	129	82	115	122	133	165	160	157	155	
110	248	254	264	291	301	273	297	278	279	262	257	266	251	238	236	236	226	222	220	218	210	206	203	200	85	268	13	123		122	134	130	81	117	124	134	165	160	157	156	
115	247	255	264	291	302	273	297	279	281	262	257	267	252	238	236	236	226	222	220	218	210	206	203	201	84	267	13	124		124	135	130	81	119	124	136	166	160	157	155	
120	247	253	264	289	302	273	297	279	277	262	257	267	252	238	236	236	226	222	219	219	210	206	203	200	84	268	13	126		125	135	131	81	120	127	136	165	159	157	155	
125	246	253	265	288	302	273	297	279	276	262	257	267	252	238	235	235	226	222	219	219	210	206	203	201	84	268	13	127		126	136	132	81	120	128	137	164	159	156	155	
130	247	253	265	289	303	274	297	279	281	263	258	268	252	238	235	235	226	222	220	219	210	207	204	201	84	267	13	128		128	137	132	81	122	129	138	164	158	157	155	
135	247	253	265	290	303	274	297	280	277	263	258	268	251	238	236	234	227	222	220	219	211	207	204	201	84	268	13	130		129	138	133	81	123	131	139	165	159	156	155	
140	247	252	265	288	303	273	297	279	278	263	258	268	251	238	235	234	227	222	221	220	211	207	204	201	83	269	13	131		130	138	134	81	125	132	139	165	158	156	155	
145	247	251	264	288	303	273	297	280	277	263	258	268	251	238	235	234	226	222	221	220	211	207	204	201	83	270	13	132		131	139	134	81	126	133	140	166	157	155	154	
150	246	251	264	287	302	273	297	280	278	263	258	268	250	239	235	234	226	222	221	220	212	208	205	202	83	270	13	134		133	140	135	81	128	134	141	166	157	155	154	
155	245	251	264	287	302	274	297	279	278	264	258	269	250	239	236	234	226	223	222	220	212	208	205	202	83	270	13	135		134	140	136	81	130	135	141	166	157	155	154	
160	247	251	264	288	303	274	298	280	278	264	258	269	250	240	236	234	226	223	222	221	212	208	206	203	83	270	13	136		135	141	137	81	132	137	142	166	157	155	153	
165	246	251	264	287	303	274	298	280	275	264	259	269	250	240	236	234	227	223	222	221	213	209	206	203	83	272	13	137		136	141	138	81	133	138	143	167	157	155	153	
170	245	251	263	288	303	274	298	280	277	264	259	269	250	240	236	234	227	224	223	221	213	209	206	204	83	272	13	138		137	142	139	81	135	139	144	167	156	154	153	
175	246	251	264	288	303	274	299	280	274	265	259	270	249	240	236	234	227	224	223	222	214	210	207	204	82	272	13	139		138	143	140	81	136	140	144	169	156	155	153	
180	245	252	264	288	303	274	299	279	274	265	259	270	249	240	236	234	227	224	224	222	214	210	207	204	83	273	13	140		139	143	141	81	138	141	145	169	156	154	153	
185	245	252	264	289	303	274	299	279	273	265	259	270	249	241	237	235	227	225	224	223	215	211	208	205	83	272	13	141		140	144	141	81	139	142	146	167	155	154	152	
190	245	253	263	290	304	275	299	279	274	265	259	271	249	240	237	236	228	225	224	223	215	212	208	205	82	273	12	142		141	145	142	81	140	143	146	165	155	153	152	
195	246	253	263	293	304	275	300	280	274	266	260	271	250	242	238	237	228	226	225	224	216	213	209	206	82	275	13	143		142	145	143	81	141	145	147	163	154	153	152	
200	247	253	265	289	305	276	300	280	274	266	260	272	250	242	238	237	229	227	225	224	216	213	210	207	82	275	13	144		143	146	144	81	142	145	148	164	155	153	152	
205	247	253	265	292	306	276	301	281	274	267	261	273	252	242	238	238	229	227	226	225	217	214	211	208	82	275	13	145		144	146	145	81	144	146	148	164	155	154	153	
210	247	254	264	292	306	276	301	281	274	267	261	273	252	242	239	239	230	228	227	225	217	215	211	208	82	276	12	146		145	147	147	81	145	146	150	164	155	154	153	
215	247	253	264	293	306	277	301	281	274	267	261	273	251	243	239	239	230	228	227	226	218	215	212	209	82	276	13	147		146	148	147	82	146	148	150	165	156	154	153	
220	248	254	264	292	306	277	301	281	274	268	261	273	251	244	239	239	231	229	228	226	218	216	212	209	81	276	13	148		147	149	148	82	147	149	152	164	155	154	154	

BITUMEN HEATING TEST NUMBER 14

Sheet 2 of 2

Burner: Boral Nu–way NOL6
Nozzle: Danfoss S 30° 8kg/hr

Air Supply: Maximum

Fuel Pressure: 10.3 bar

Fuel: 55.016kg Diesel

Bitumen Quantity: 11340kg

Date: 9/7/92

TIME	TEMPERATURE READING °C																																								COMMENTS
[MIN]	PROBE IDENTIFICATION																																								
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	
225	247	253	264	294	306	276	301	281	272	267	261	273	251	244	239	239	231	229	228	227	219	216	213	210	81	277	12	149		148	149	149	82	148	149	152	165	156	155	154	
230	247	253	265	291	306	277	302	281	272	267	262	274	251	244	240	240	232	229	228	227	219	217	213	210	81	276	13	150		149	150	150	82	149	151	154	164	156	155	154	
235	249	254	266	291	306	277	302	281	273	268	262	274	252	245	241	240	232	230	229	228	220	217	214	211	81	278	12	151		150	151	150	82	150	152	153	163	156	155	155	
240	248	255	266	291	306	277	302	282	273	268	262	275	253	244	241	241	233	231	229	228	221	218	215	211	81	278	13	151		151	152	151	82	151	153	154	166	157	156	155	
245	249	256	267	291	307	278	303	282	273	269	263	275	254	246	241	242	234	231	230	229	221	219	215	212	81	280	12	153		152	153	152	82	152	154	156	167	157	156	155	
250	249	256	267	292	307	278	304	282	274	269	263	276	254	246	242	243	234	231	230	229	222	219	216	213	81	279	12	153		152	154	153	83	153	155	156	166	158	157	156	
255	250	256	267	291	308	279	304	282	273	270	264	277	255	246	243	243	235	232	231	230	222	220	216	213	81	280	12	154		153	154	154	83	154	156	157	167	158	157	156	
260	251	257	267	293	309	279	305	282	273	270	264	277	255	247	243	243	235	232	232	230	223	220	217	214	81	280	12	155		154	155	154	83	155	157	159	168	158	157	157	
265	251	257	267	293	306	279	305	282	274	270	264	277	255	247	244	244	236	233	232	230	223	221	218	214	81	281	12	156		155	156	155	83	156	157	159	168	159	158	157	
270	251	257	267	291	306	279	304	281	274	270	264	277	255	247	244	244	236	233	232	231	223	221	218	214	81	281	12	157		155	157	156	83	157	158	159	169	159	158	158	
275	251	258	267	292	306	279	305	281	274	271	265	278	255	247	244	244	236	234	233	231	224	222	218	215	81	282	12	158		156	158	157	83	158	159	162	170	160	159	158	
280	252	258	267	293	306	279	305	282	274	271	265	278	255	248	245	244	237	234	233	232	225	222	219	216	81	281	12	159		157	159	158	83	159	160	162	170	160	159	159	
285	251	259	267	294	308	280	305	282	275	271	265	278	256	249	245	245	237	234	234	232	225	223	220	216	81	283	12	160		158	159	158	83	160	161	161	170	161	160	159	
290	252	258	267	294	308	280	306	282	275	271	265	278	256	248	246	245	237	235	234	232	225	223	220	217	81	282	12	161		159	160	159	83	160	162	162	172	161	160	160	
295	252	259	267	294	309	280	306	282	275	272	266	279	256	249	246	245	238	235	235	233	226	224	220	217	81	285	12	161		160	161	160	84	161	162	163	172	162	161	161	
300	253	259	268	295	309	280	306	282	276	272	266	280	257	249	247	246	239	236	235	233	227	224	221	218	81	284	12	162		161	162	161	84	162	163	164	173	163	162	161	
305	253	260	269	296	310	281	307	282	276	273	267	280	257	250	247	247	239	237	236	234	227	225	222	219	81	286	12	163		162	163	162	84	163	164	165	173	163	162	162	
310	254	260	270	296	310	282	308	283	277	273	267	281	258	251	248	247	240	237	237	235	228	226	223	219	81	286	12	164		162	163	163	84	164	165	166	174	164	163	162	
315	254	260	270	298	311	282	308	283	277	274	268	281	258	251	248	248	240	238	237	235	229	226	223	220	81	286	12	165		164	164	164	84	165	166	167	174	164	163	163	
320	255	261	270	296	311	282	308	283	277	274	268	282	259	251	249	248	241	239	238	236	229	227	224	221	81	288	11	166		165	165	165	84	166	167	170	174	165	164	163	
325	255	262	271	299	312	283	309	284	279	275	268	282	260	252	249	249	242	239	238	236	230	227	225	221	81	288	12	167		165	166	165	84	167	168	168	175	166	165	164	
330	256	262	272	298	312	283	309	284	278	275	269	283	260	252	250	249	242	240	239	237	231	228	225	222	81	288	11	168		166	167	166	85	168	169	169	175	166	166	165	
335	256	263	272	300	312	283	310	284	278	275	269	283	260	253	250	249	243	240	239	237	231	228	225	222	81	289	11	169		167	168	167	85	169	170	170	175	167	166	165	
340	256	263	272	300	312	283	310	284	279	276	269	283	260	254	251	250	243	241	239	238	231	229	226	222	81	289	11	169		168	169	168	85	170	171	171	177	167	167	166	
345	258	263	272	300	313	284	310	285	279	276	269	283	260	254	251	250	244	241	240	238	232	230	227	223	81	289	11	170		169	170	169	85	171	172	173	168	168	167	167	
350	233	236	240	242	256	240	254	241	232	235	228	237	225	223	221	222	217	216	216	215	211	210	208	205	162	200	11	170		170	170	169	92	172	172	173	178	169	168	167	STOP BURNER
355	204	204	206	202	207	200	206	202	194	193	192	193	194	192	193	189	191	191	192	189	189	186	188	187	171	148	12	168		165	162	163	156	173	173	174	176	167	166	165	RECIRCULATE TANK CONTENTS
360	188	188	188	182	185	182	183	181	178	177	178	177	180	180	179	177	179	179	179	176	177	175	177	177	165	168	11	163		163	163	163	161	171	172	173	175	166	165	164	FINISH RECIRCULATION