ANGLO PLATINUM

Centrifugal Pump Explosions

"Rise of the machines"

Brian P. O'Connor

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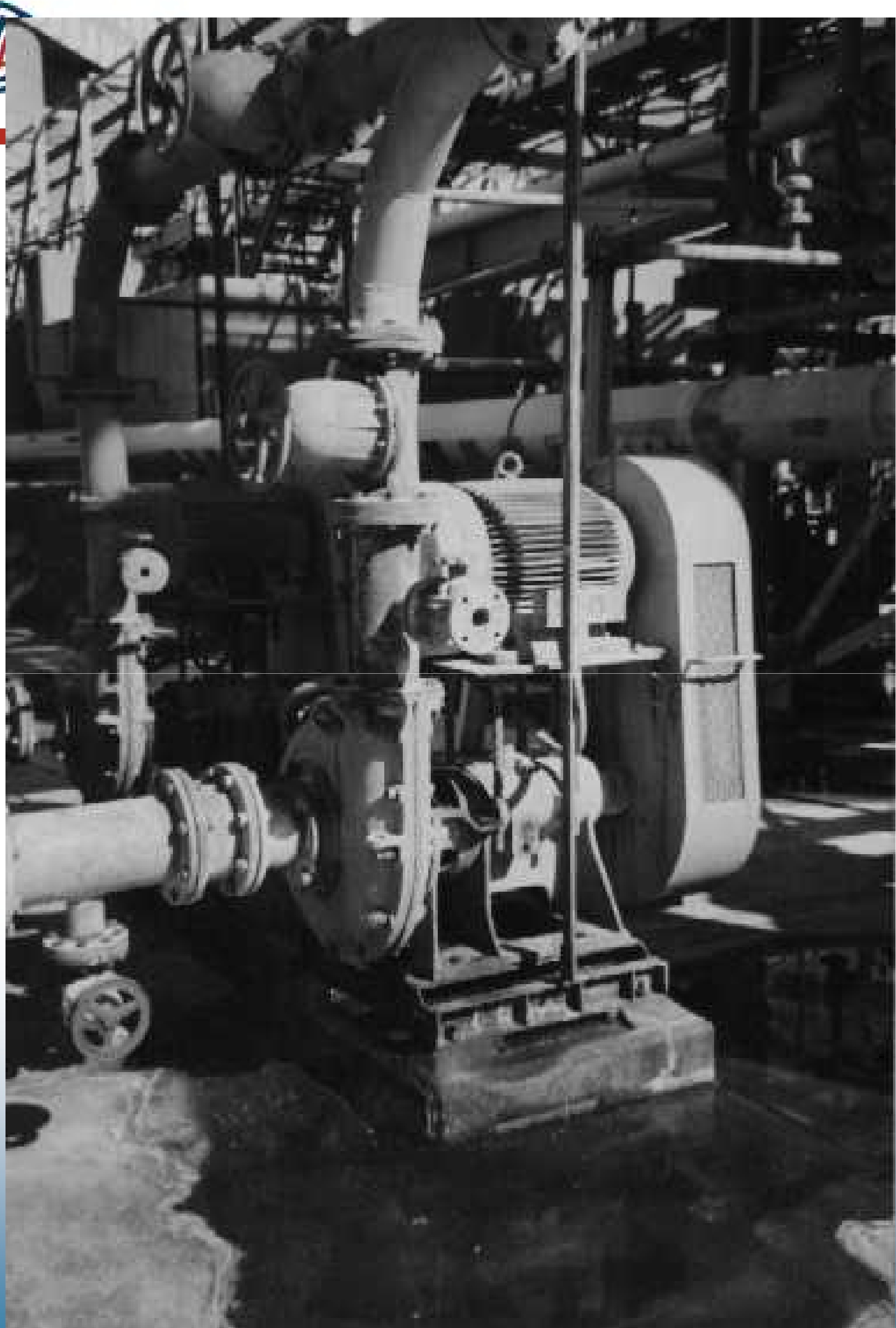
Introduction

- At AngloGold Metallurgical operation in South Africa, we were experiencing on average one pump explosion per annum
- In all cases, the explosions occurred in single-stage centrifugal process type pumps where the suction and delivery valves were either closed or the lines were blocked
- Research revealed that this is a world-wide phenomenon
- It was decided to investigate to determine the causes and try eliminate or at best reduce, the risk of further occurrence.

Introduction

- Process pumps range from 50 mm to 600 mm suction diameters
- Motors range from 2 kW to 375 kW
- Speeds typically range from 500 to 1200 rpm
- The casings are usually SG castings
  - Solid casing bolted to a frame
  - Symmetrically split
  - Three piece construction



Typical centrifugal pump

ANGLO PLATINUM Description of recorded incidents

1. Chilled water brine pump at a US nuclear defence facility – Aug 98 300 kW motor; 189 l/s - ran for 2h before failure. Valves closed for maintenance – pump inadvertently started.

2. Underground at a US mine, a sand pump exploded when delivery and suction were blocked. A miner standing 10m away was seriously injured.

3. Island Creek Coal Company, Virginia, USA - 28 January 2002

   Fatal accident that is well documented. Fine coal transfer pump became blocked after standing for two days. It was started without gland service water and quickly overheated. When the operator stopped the pump, the gland service water entered the red hot all-metal casing creating steam exploding the pump killing the operator.

All-metal coal fines transfer pump that exploded killing its Operator.

Description of incidents …

4. Underground at US mine. Explosion felt 280m away. 80kg of pump material was not found.

5. Fatal in Australia when a Warman pump exploded. No records.

6. Bong Mine Liberia. 14/12 pump exploded destroying pump house roof.

7. No.8 Gold plant, AngloGold CD frame water pump - 2000


8 1 52

Description of incidents

8. North 2 Gold Plant - November 2001.
   Cyanide transfer pump.

9. West Float & Acid Plant - February 2001.
   Calcine water pump.

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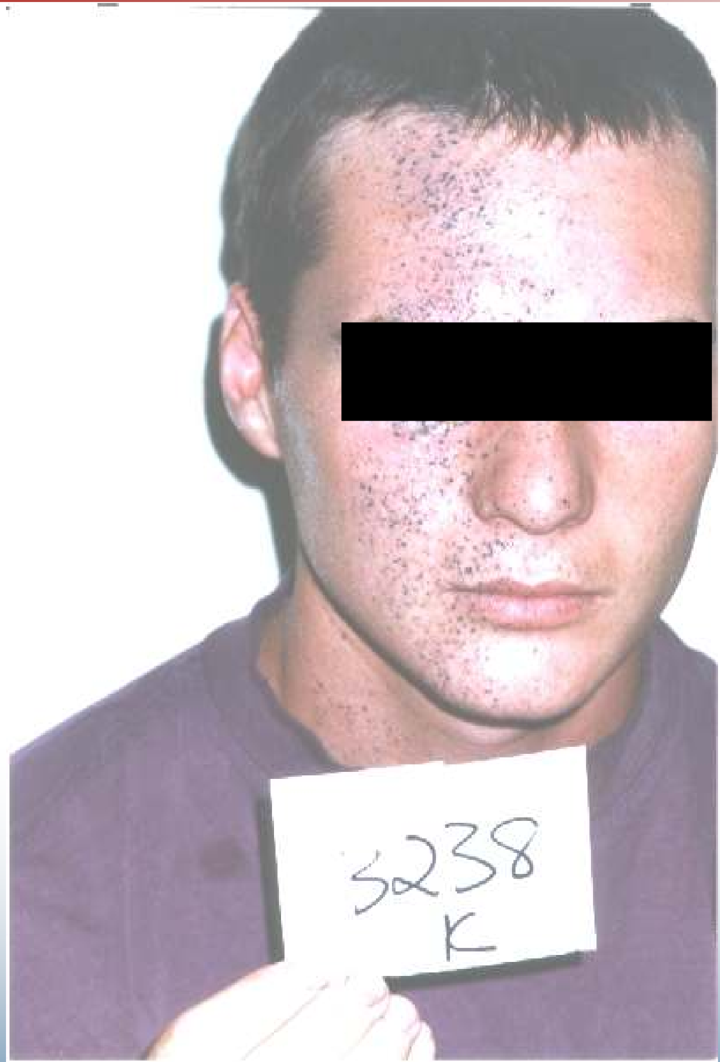
10. North 1 Gold Plant – January 2003
    Carbon transfer pump

Carbon pump injuries



Apprentice with facial injuries from carbon transfer pump burst.

Second Apprentice, mother of two, not injured

Description of incidents

8. North 2 Gold Plant - November 2001.
   Cyanide transfer pump.

9. West Float & Acid Plant - February 2001.
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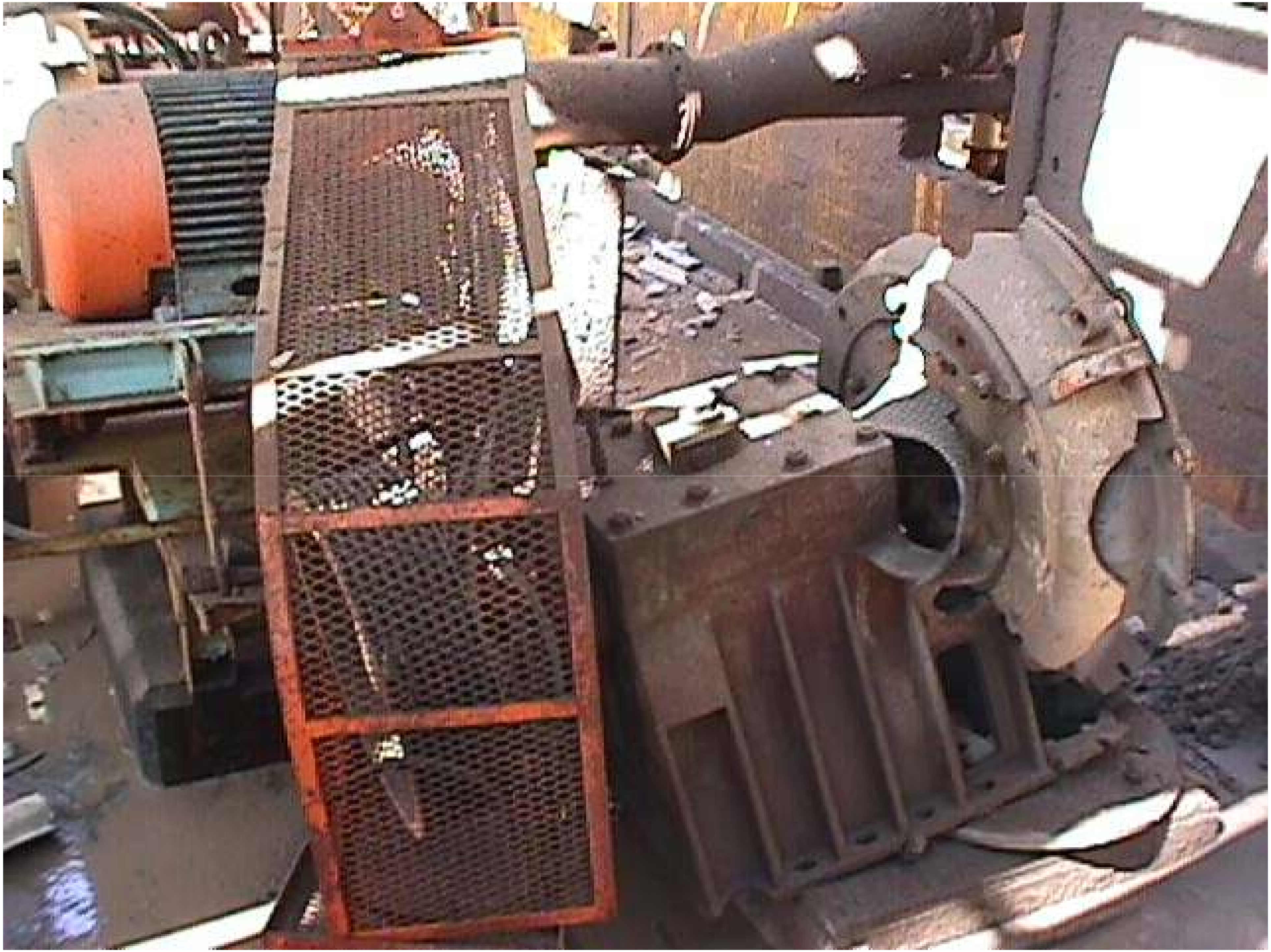
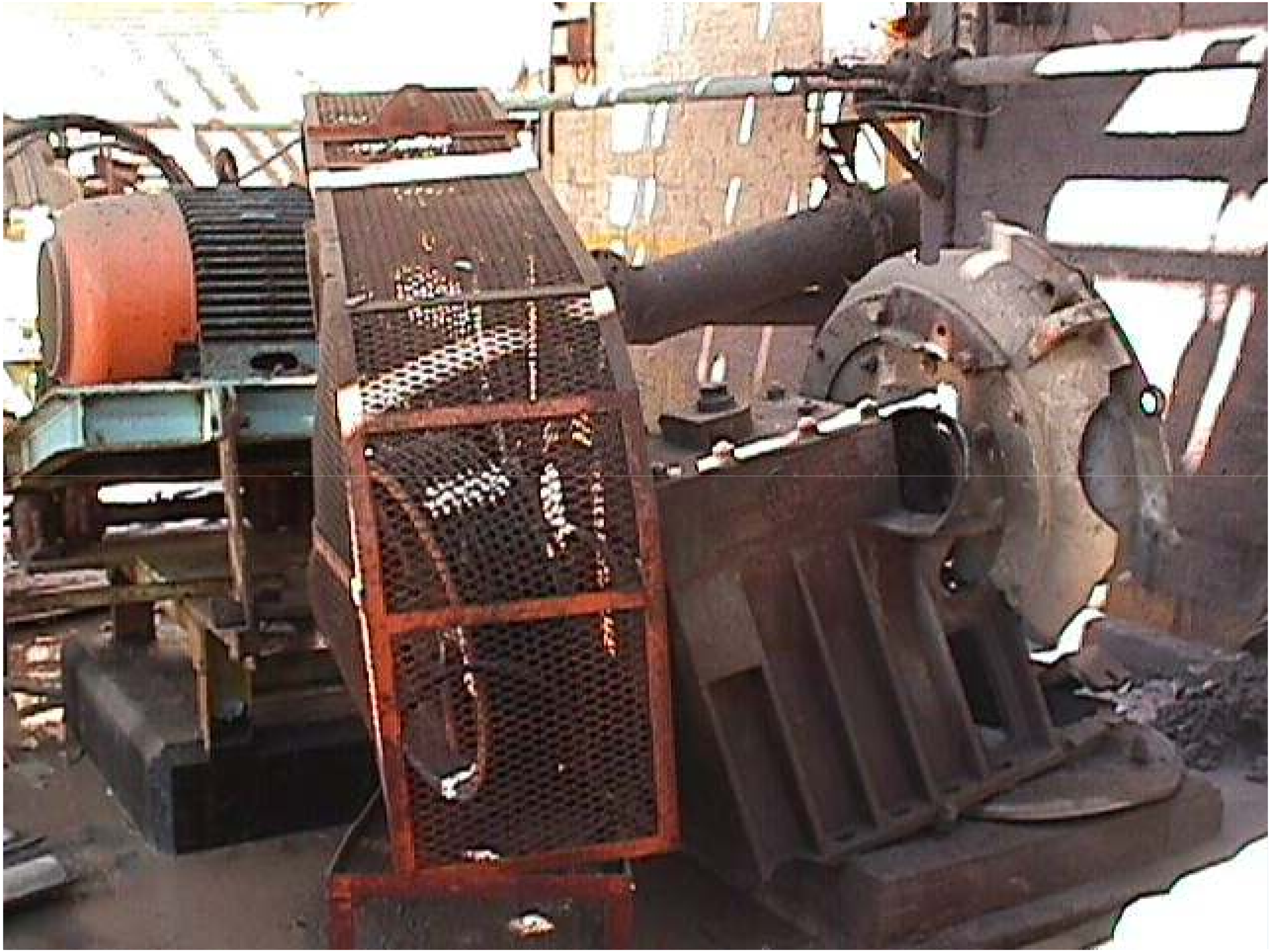
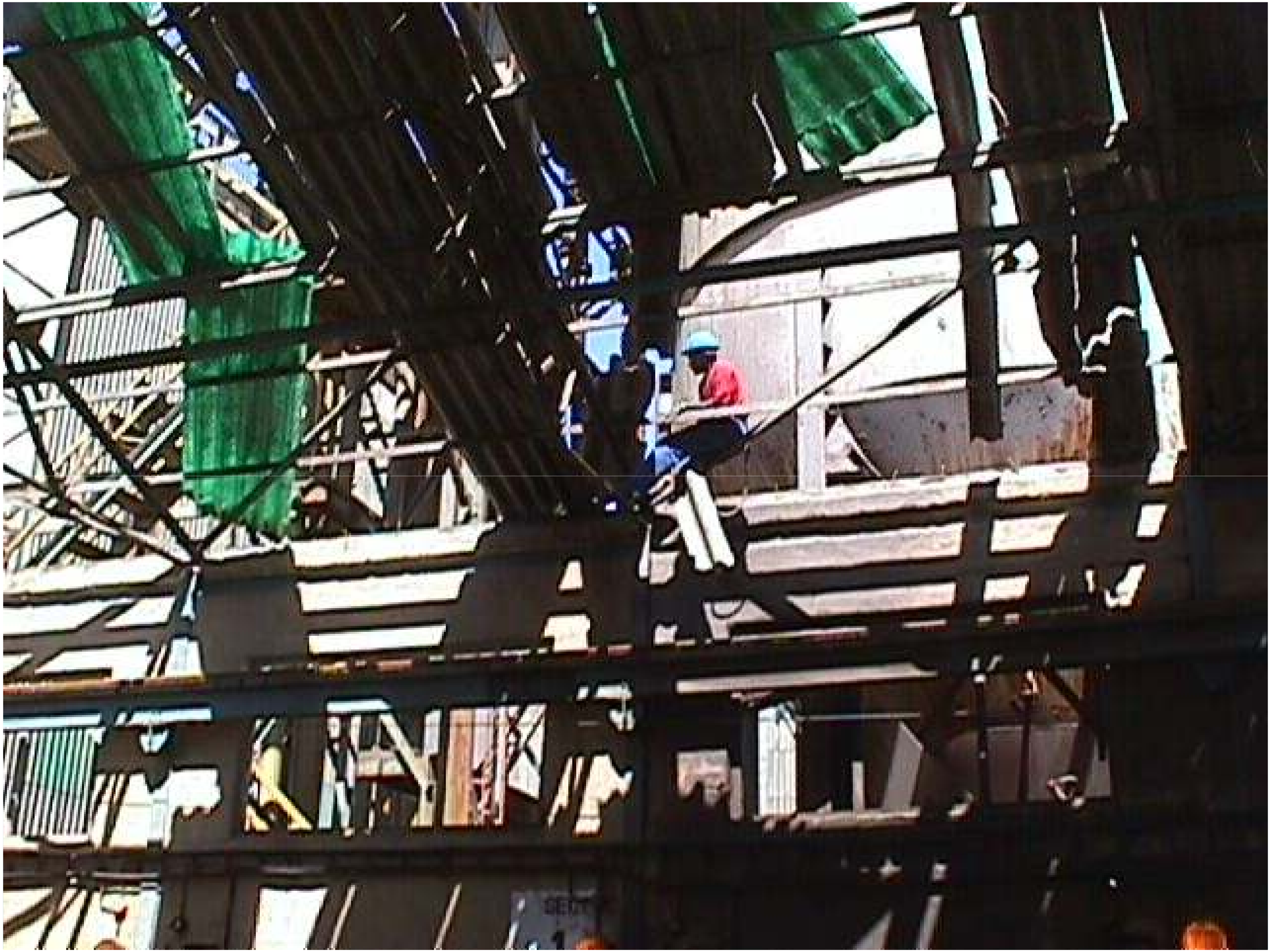
10. North 1 Gold Plant – January 2003.
    Carbon transfer pump.

11. Residue transfer pump at Namdeb, Namibia in March 1999



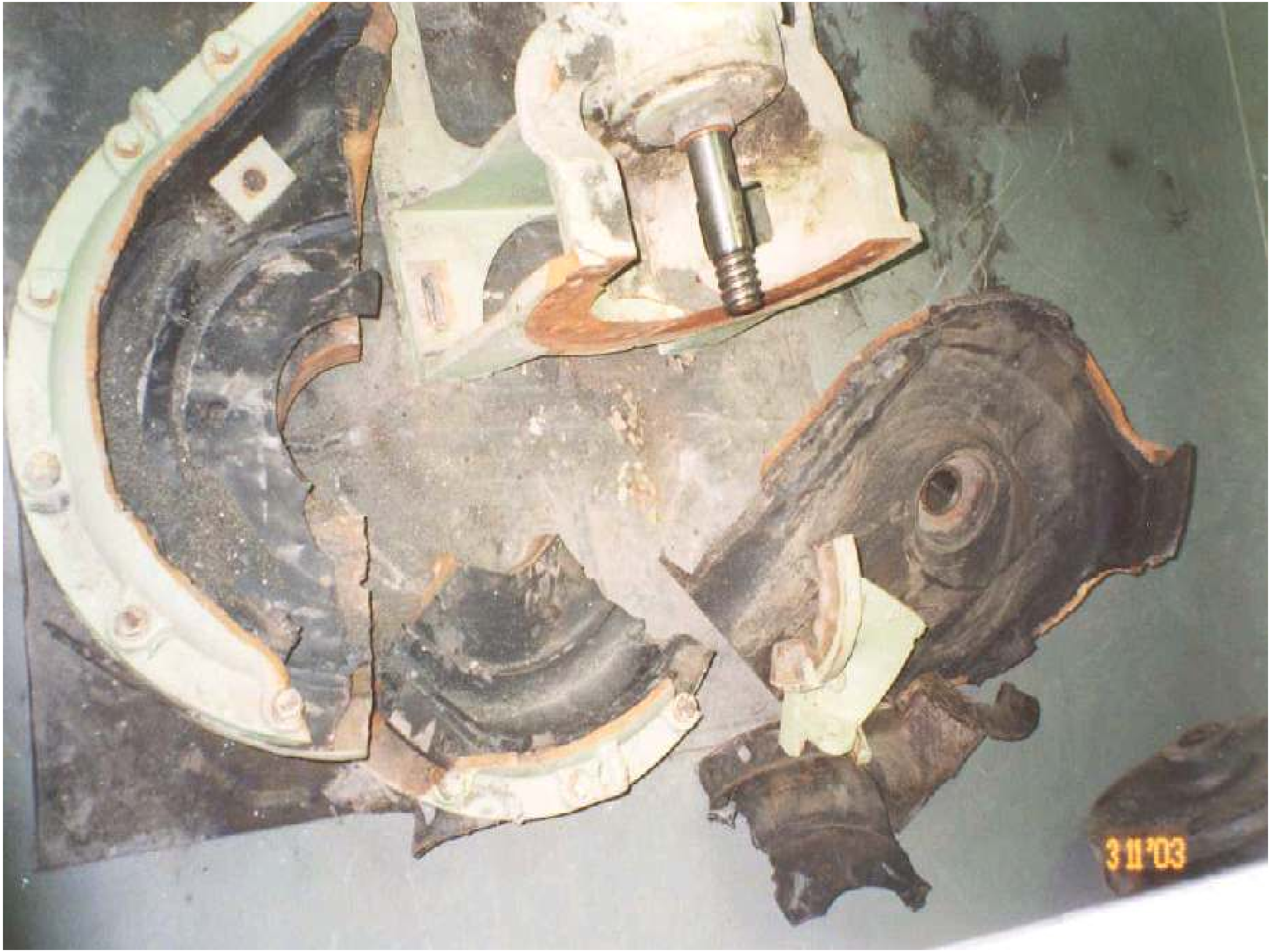




Description of incidents

8. North 2 Gold Plant - November 2001. Cyanide transfer pump.
9. West Float & Acid Plant - February 2001. Calcine water pump.
10. North 1 Gold Plant – January 2003. Carbon transfer pump.
11. Slimes transfer pump at Namdeb diamond mine in Namibia on 3 March 1999.
12. Platinum UG2 transfer pump at Modikwa 25 October 2003

Modikwa UG2 transfer pump explosion on 25 October 2003 resulting in operator loosing three toes.

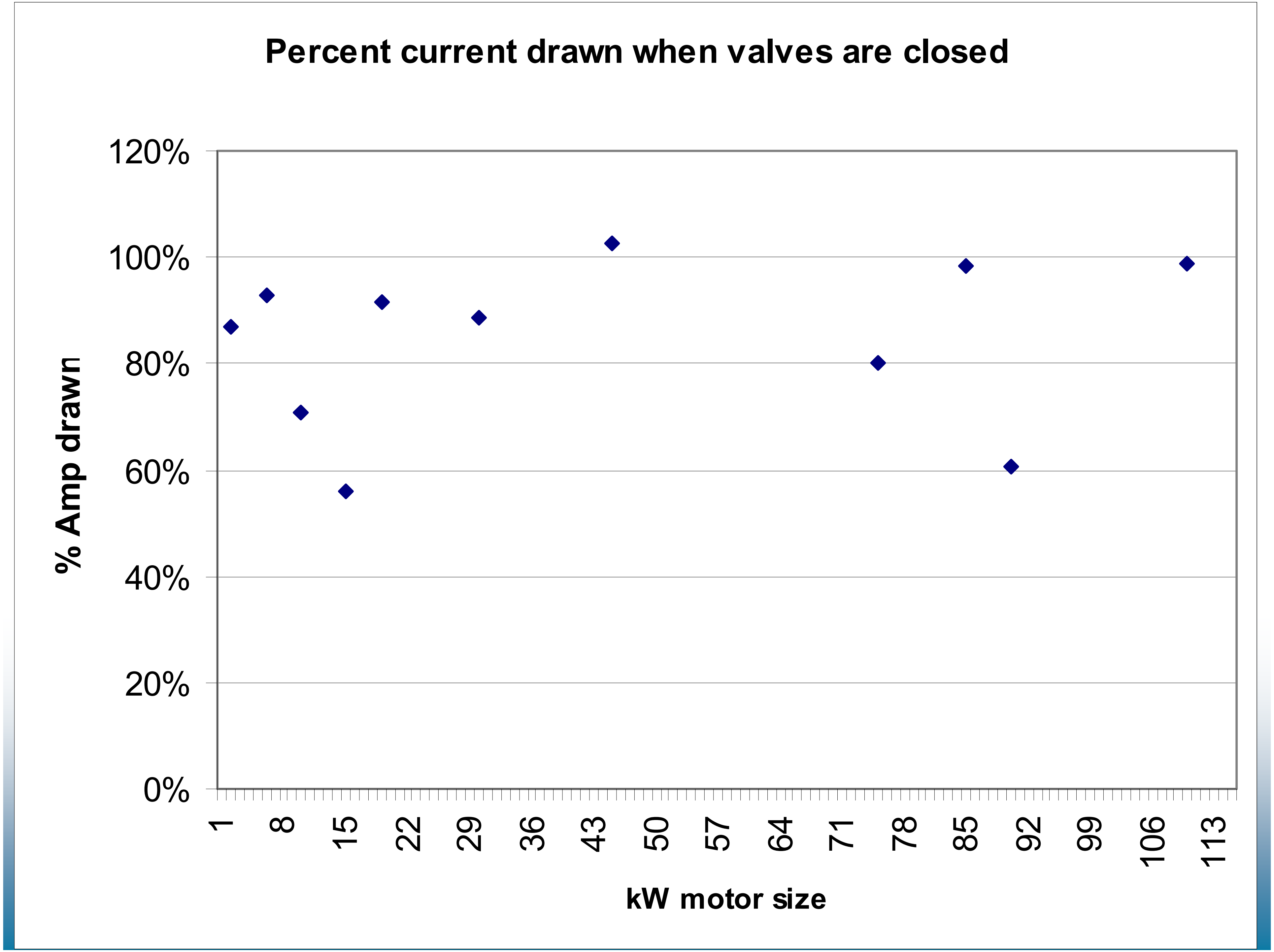

3 11 '03

13. Bulyannulu Gold Mine in Tanzania – July 2004

Search for a solution

- Current detection
  - Assumed that the current dropped when the valves are closed
  - Found that there is no relationship between current change and size of pump, motor, duty or speed

Tests were done on eleven motors between 2 and 110 kW


Percent current drawn when valves are closed
120%
100%
80%
60%
40%
20%
0%
% Amp drawn
1
8
15
22
29
36
43
50
57
64
71
78
85
92
99
106
113
kW motor size

Search for a solution

- Current detection
- Pressure sensing

- Again what relationship between pressure at immediate delivery before and after valve closures or blockages occurring?

- Because it behaves like a boiler, pressure will only rise significantly enough to detect when the fluid starts to boil, which is too close to failure by explosion.

- Pockets with probes will be problematic with chemicals and slurries.

- Expensive option > R3 000/pump

Search for a solution

- Current detection
- Pressure sensing
- Temperature monitoring

  -Probes would have to be positioned in pockets that can block

  -Will have to be hard wired to the breaker

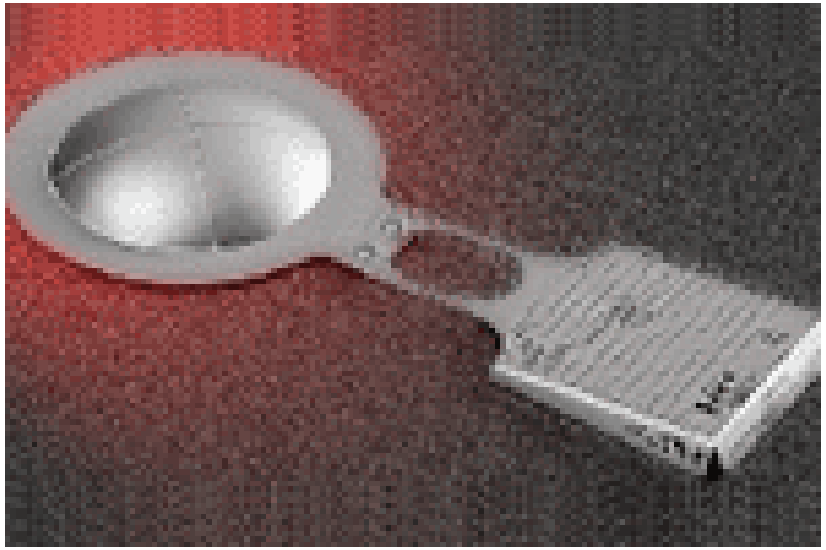
  -Expensive at > R2 000 per pump

  -Better option than pressure sensing due to immediate increase in temperature when valves are closed.

Search for a solution

- Current detection
- Pressure sensing
- Temperature monitoring
- Strain gauges
- Rupture discs
  - -Used in petrochemical industries
  - -Delicate and very expensive

Rupture discs



Aluminium rupture disc
R600

Disc holder
R1 400

Search for a solution

- Current detection
- Pressure sensing
- Temperature monitoring
- Strain gauges
- Rupture discs
  - Used in petrochemical industries
  - Delicate and very expensive
- Fusible plugs

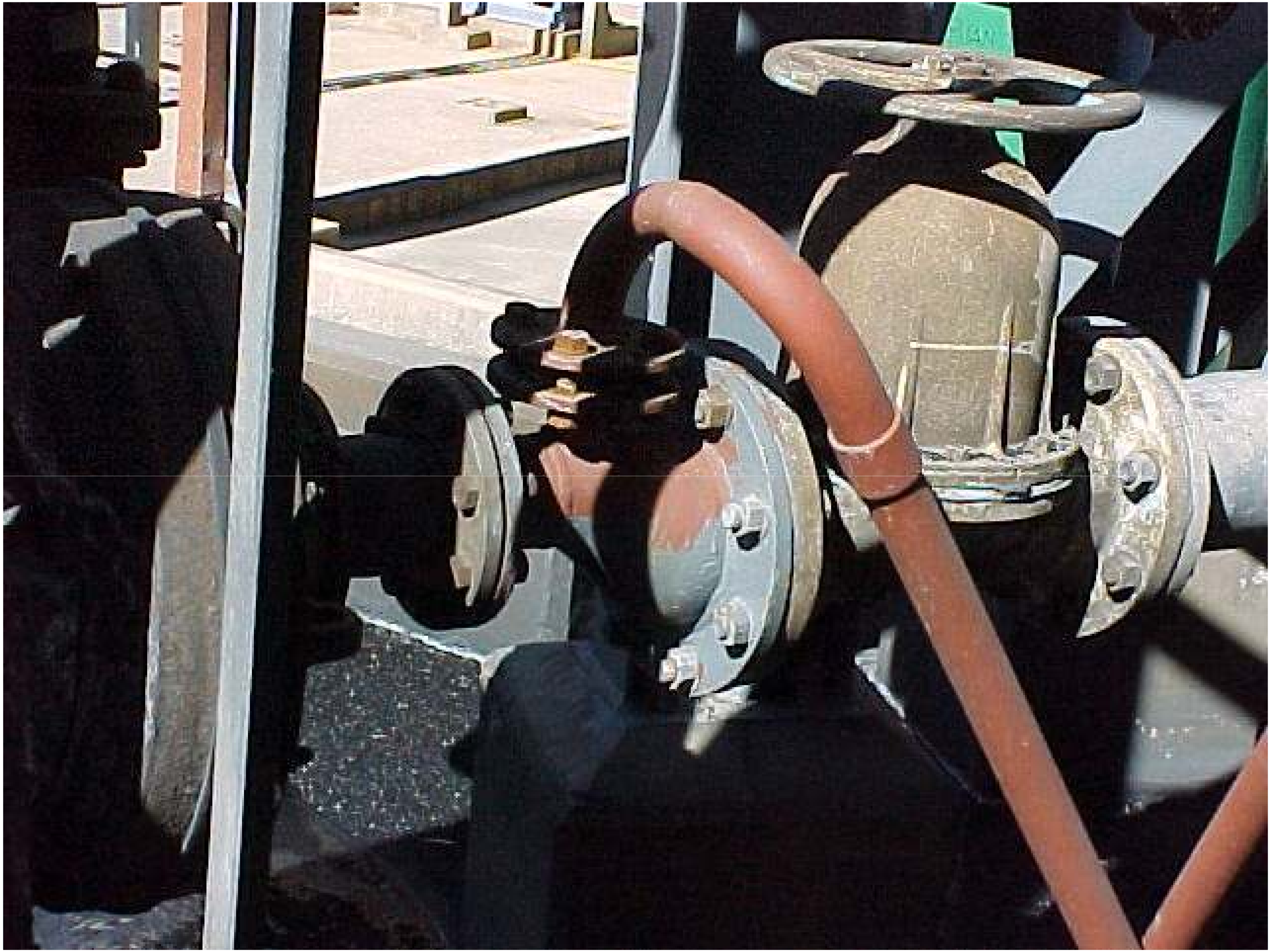
  Temperature sensing

  Pressure sensing

Search for a solution…..

Graphite bursting discs   R230


30 9:22



Disc installation

- Initial problems were experienced due to handling and installation.
- Standard disc was 6 bar rating.
- Discs that were scratched failed below their rating.
- Rubber gaskets were placed between flanges to avoid damage.
- Pumps that were fed from a higher pressure source than 3 bar were fitted with 8 bar discs.

Test pump

In order to try ascertain what actually happens within the casing of a centrifugal pump, a test pump was rigged up with suction and delivery sections of 500 mm each. Each section was fitted with a pressure and temperature gauge.

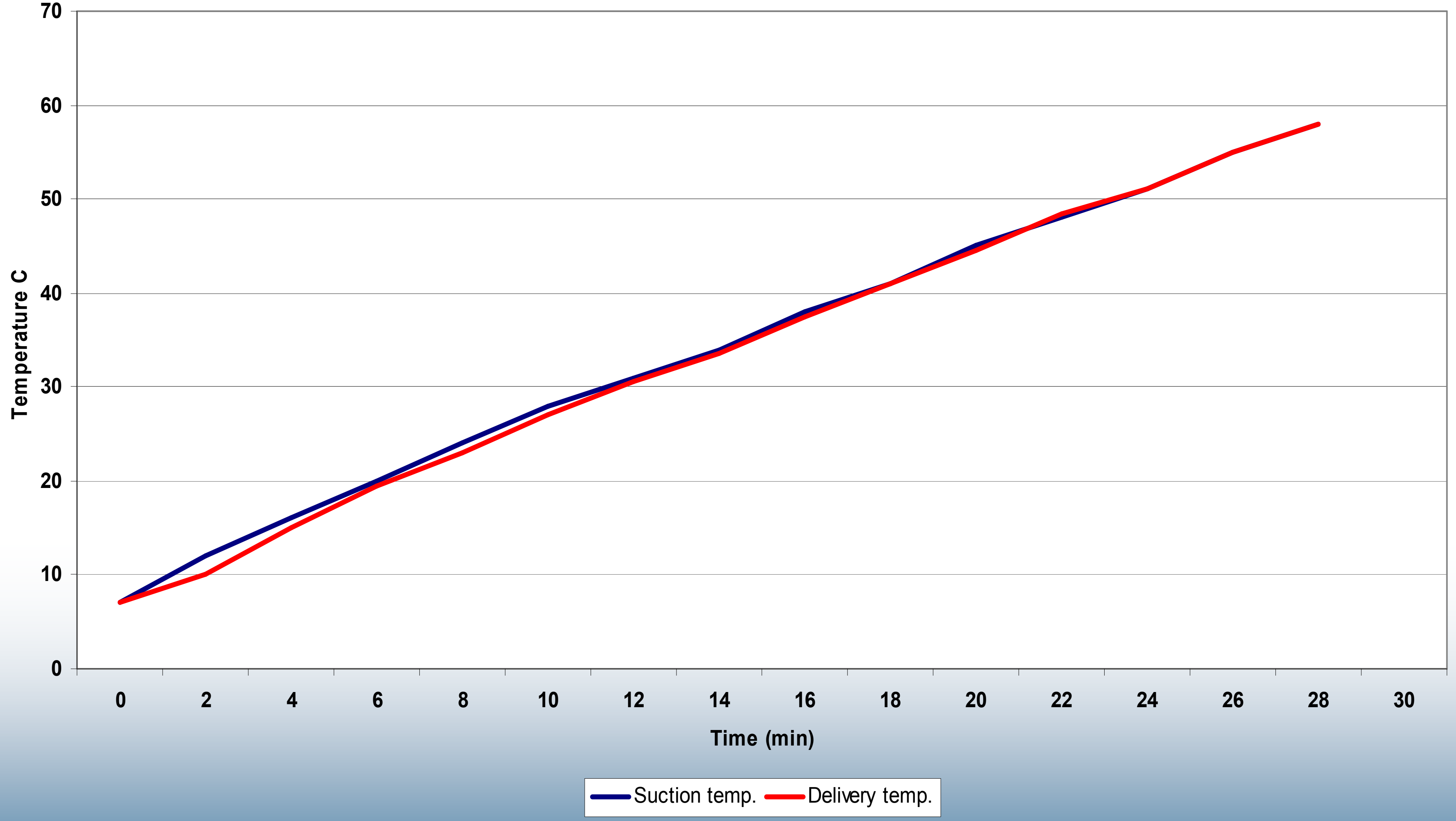
Several tests were conducted with various combinations of sections. The volumes of water used was measured on each occasion.

Test rig

Pump frame size:	AB
Pump type;	Rubber lined with rubber lined impeller
Casing volume:	10 litres
Pipe section volume:	2.5 litres per 500mm section
Motor rating;	11 kW
Motor speed:	1 470 rpm
Motor rated amps:	15 Amps
Motor voltage:	525 V three phase
No load current:	5 Amps
Pump speed:	1 140 rpm
Suction diameter:	80 mm
Delivery diameter:	75 mm
Casing pressure rating:	850 kPa
Casing factor of safety:	2.5 from manufacturer
Number and grade of casing bolts:	9 x Grade 4.6
Bolt diameter:	12 mm

Test pump with 500 mm suction and 1 000 mm delivery

Test 1 - 500mm suction and 500 mm delivery



Test 1 results

Heat energy addition:

m (kg) x Cp (kJ/kg/ ^{o}C) x Δ T = Total heat in kJ

Electrical power:

Power (kW) = 1.732 x Voltage (V) x current x Power factor

Total power transferred to fluid = 0.317 + 1.269 + 0.317 = 1.9 kW

Electrical power = 1.732 x 525 x 7.3 x 0.8 = 5.31 kW

Percentage of motor power transferred to fluid = 35.8%

Enthalpy calculations

The delivery pressure during the test was 180 kPa. The casing is rated at 850 kPa with a FOS of 2.5 = 2 125 kPa.

Using boiler enthalpy charts, the boiling temperature of water at 180 kPa is 117 C. The enthalpy at this point is 490 kJ/kg.

With constant heat addition of 1.9 kJ/s, the fluid converts to steam at constant pressure and temperature. At fully dry steam, the enthalpy is 2 702 kJ/kg. From here the steam is superheated up to the casing failure pressure of 2 125 kPa. The equivalent temperature at this point is 215 C. With only 0.28 kg of steam In the system, it takes only 85 seconds after reaching dry steam to casing explosion stage.

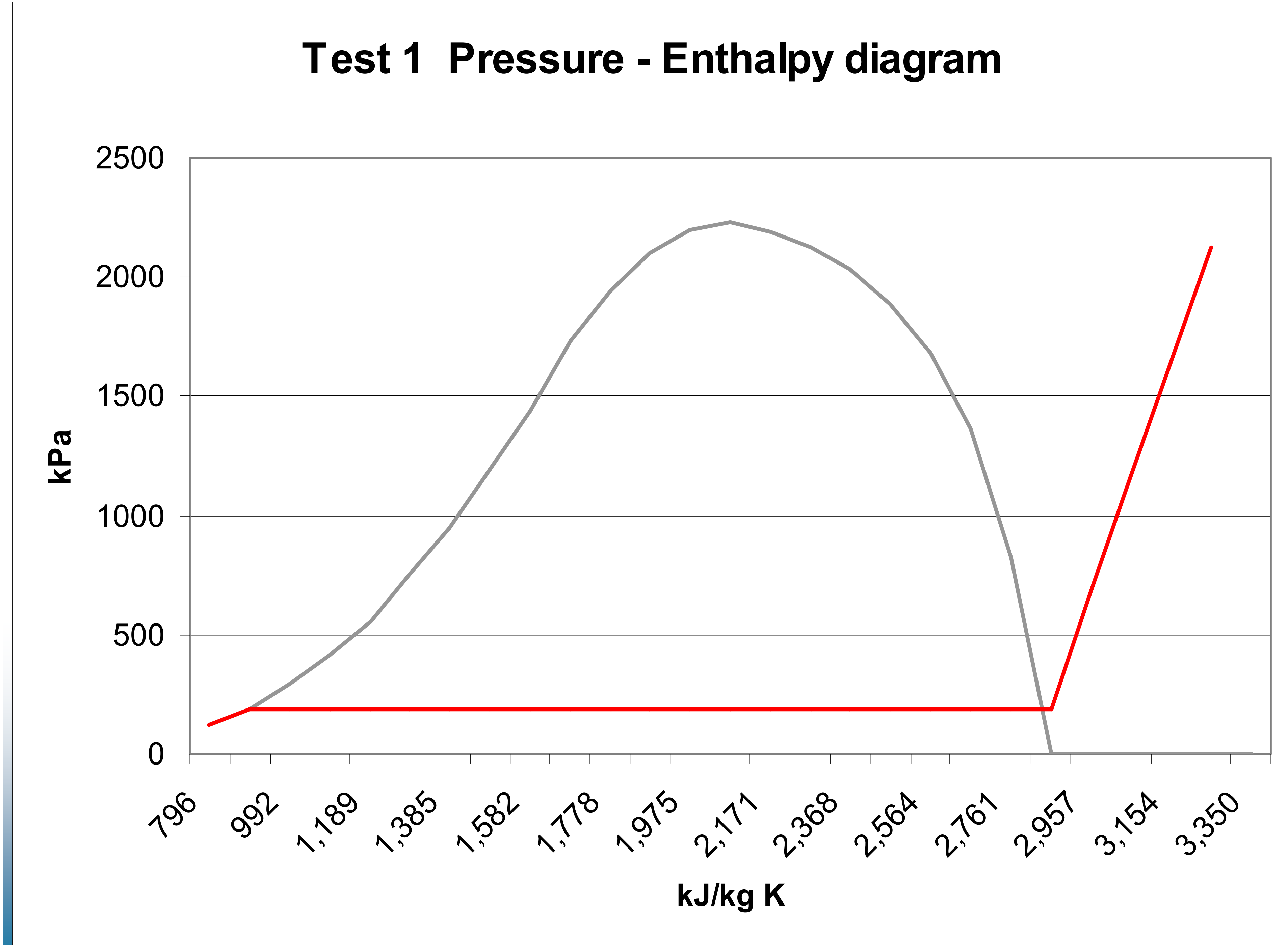
Heat addition stages

Time taken for water to heat from 7^o to 117^o C =
(117 –7) /1.82 = 60 minutes

Time taken to convert to steam = (2702 – 490) x 7.5kg /1.9
= 145 minutes

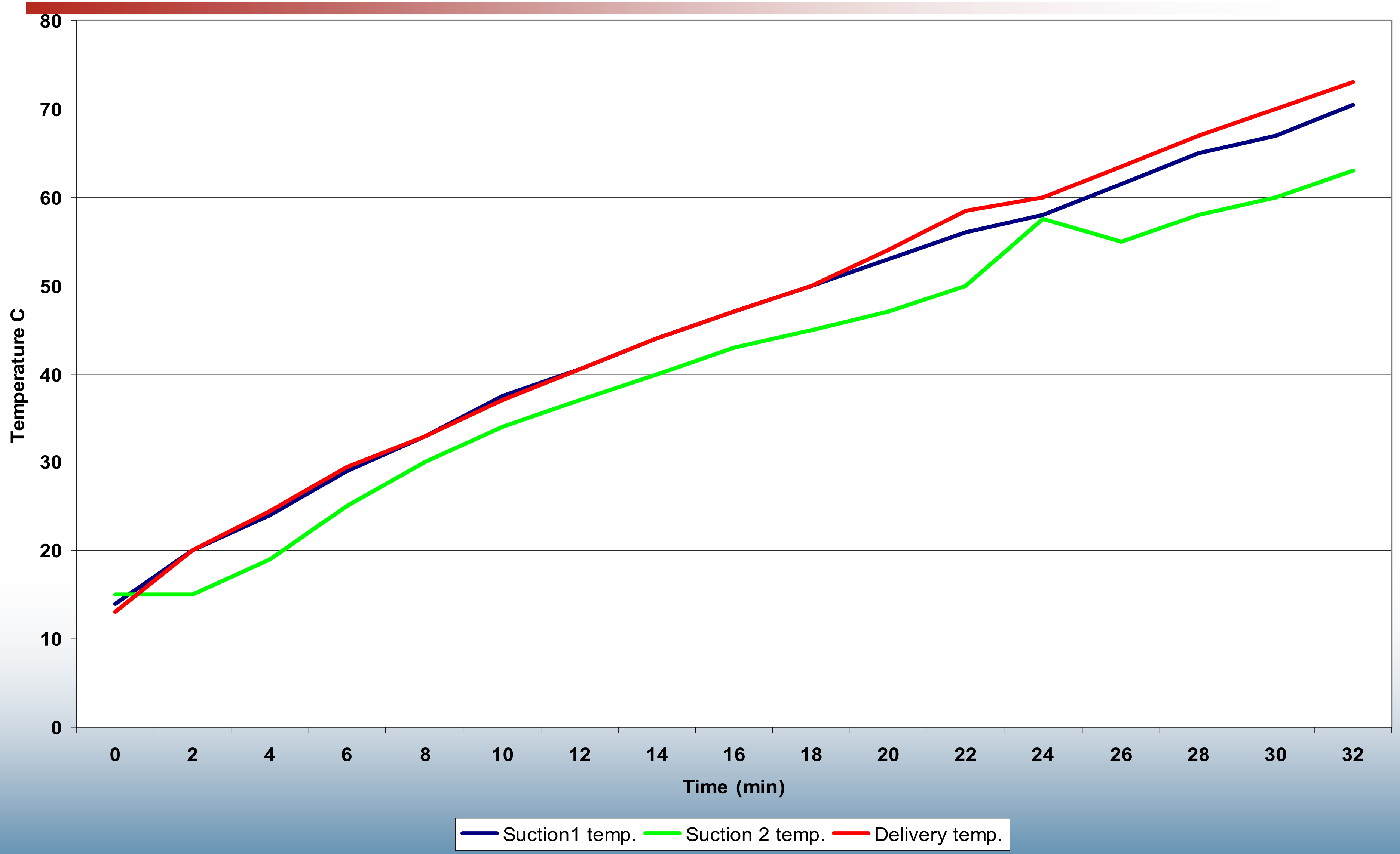
Time taken to superheat to failure = 162/1.9 = 1.5 minutes

Total time to failure = 206.5minutes or 3 ¾ hours.



Test 1 Pressure - Enthalpy diagram
2500
2000
1500
1000
500
0
kPa
796
992
1,189
1,385
1,582
1,778
1,975
2,171
2,368
2,564
2,761
2,957
3,154
3,350
kJ/kg K

Test 2 - 1 000mm suction and 500 mm delivery



Test 2 results

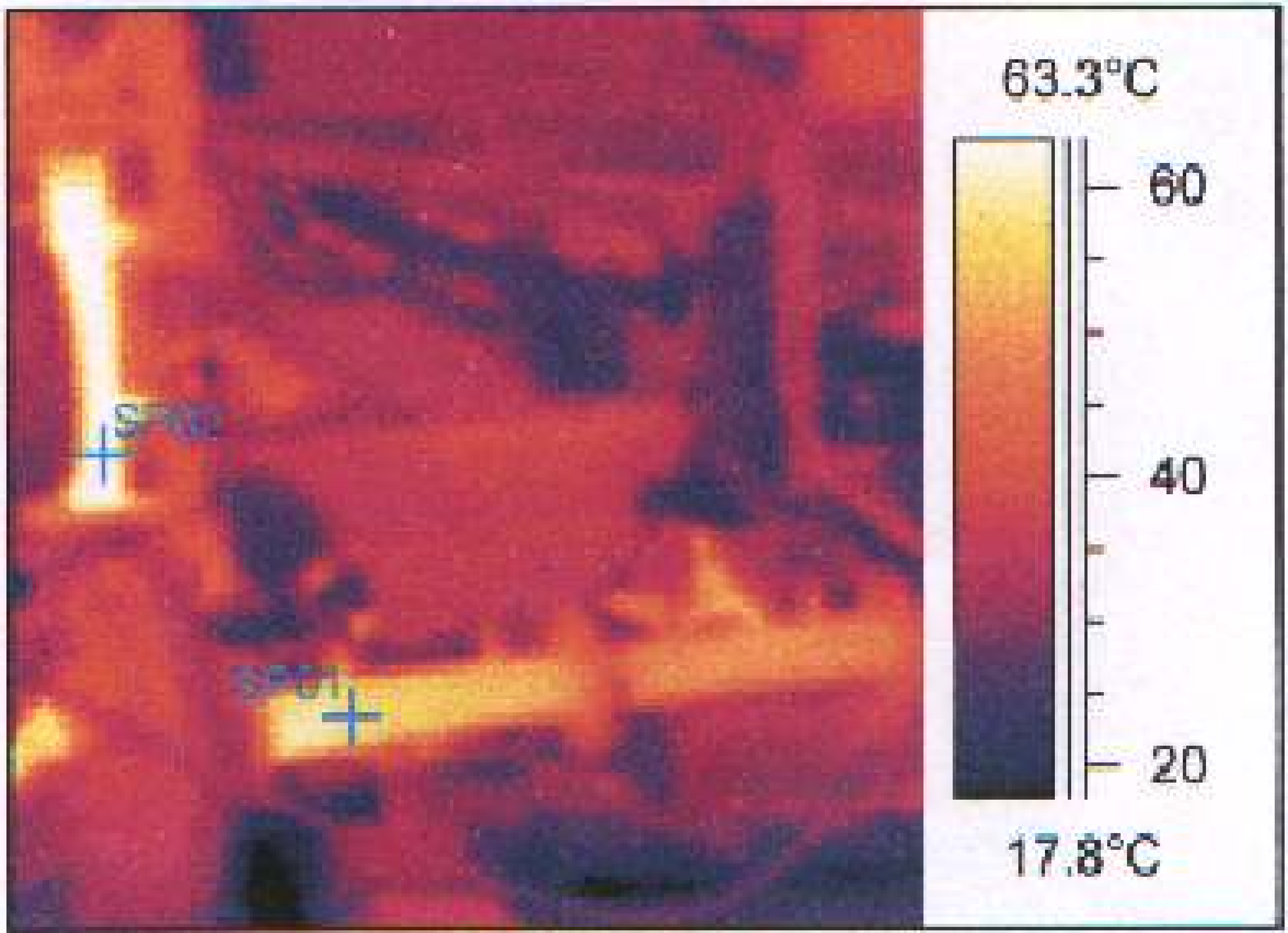
Total power transferred to fluid

Power = 0.308 + 0.261 + 0.327 + 1.263 kW
= 2.159 kW

Electrical power

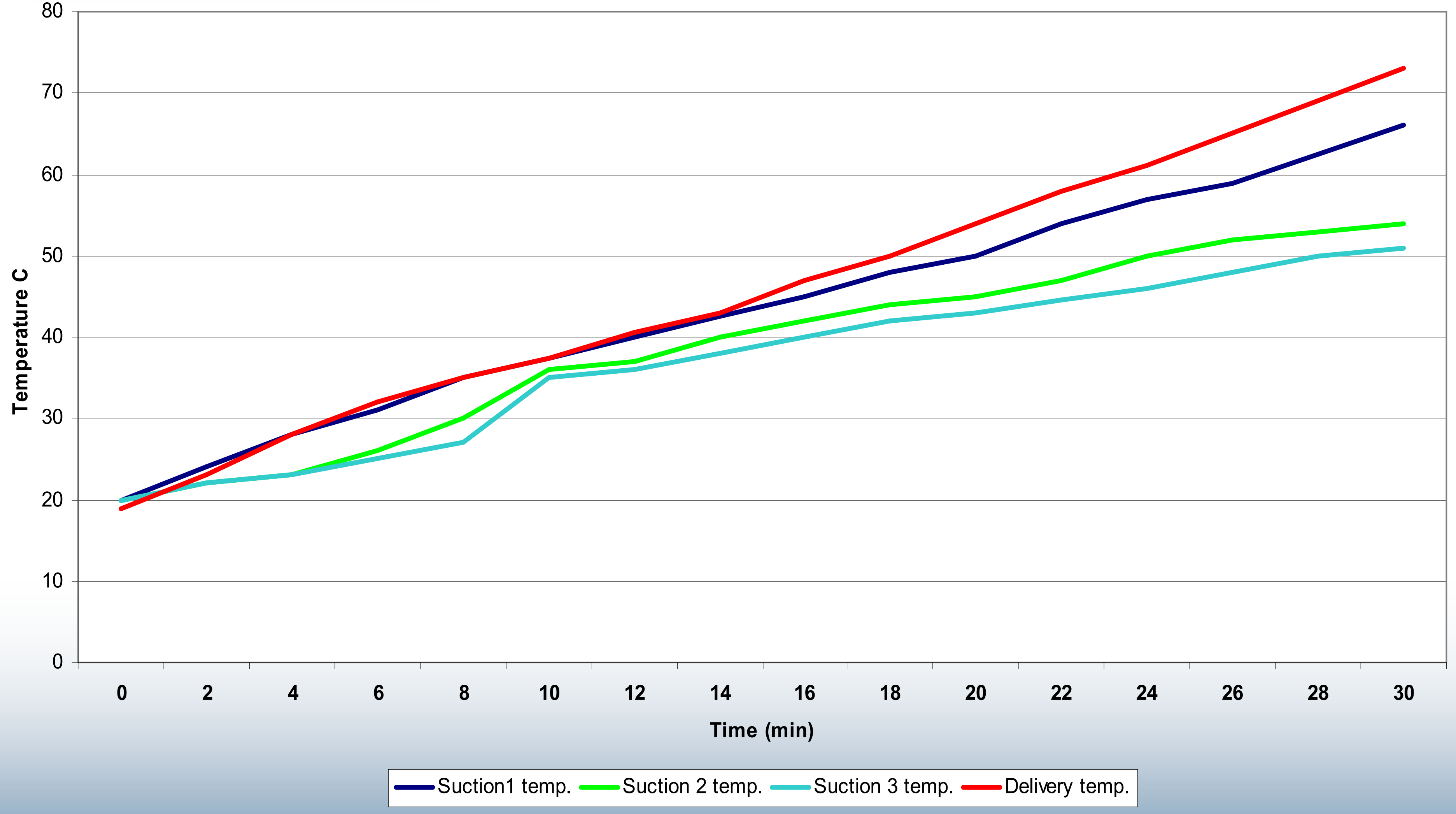
Power = 1.732 x 525 x 7.2 x 0.8
= 5.24 kW

Percent electrical power transferred to fluid = 41.2%



Test 2　Thermographic photograph

Test 3 - 1 500mm suction and 500 mm delivery



Test 3 results

Total power transferred to fluid =

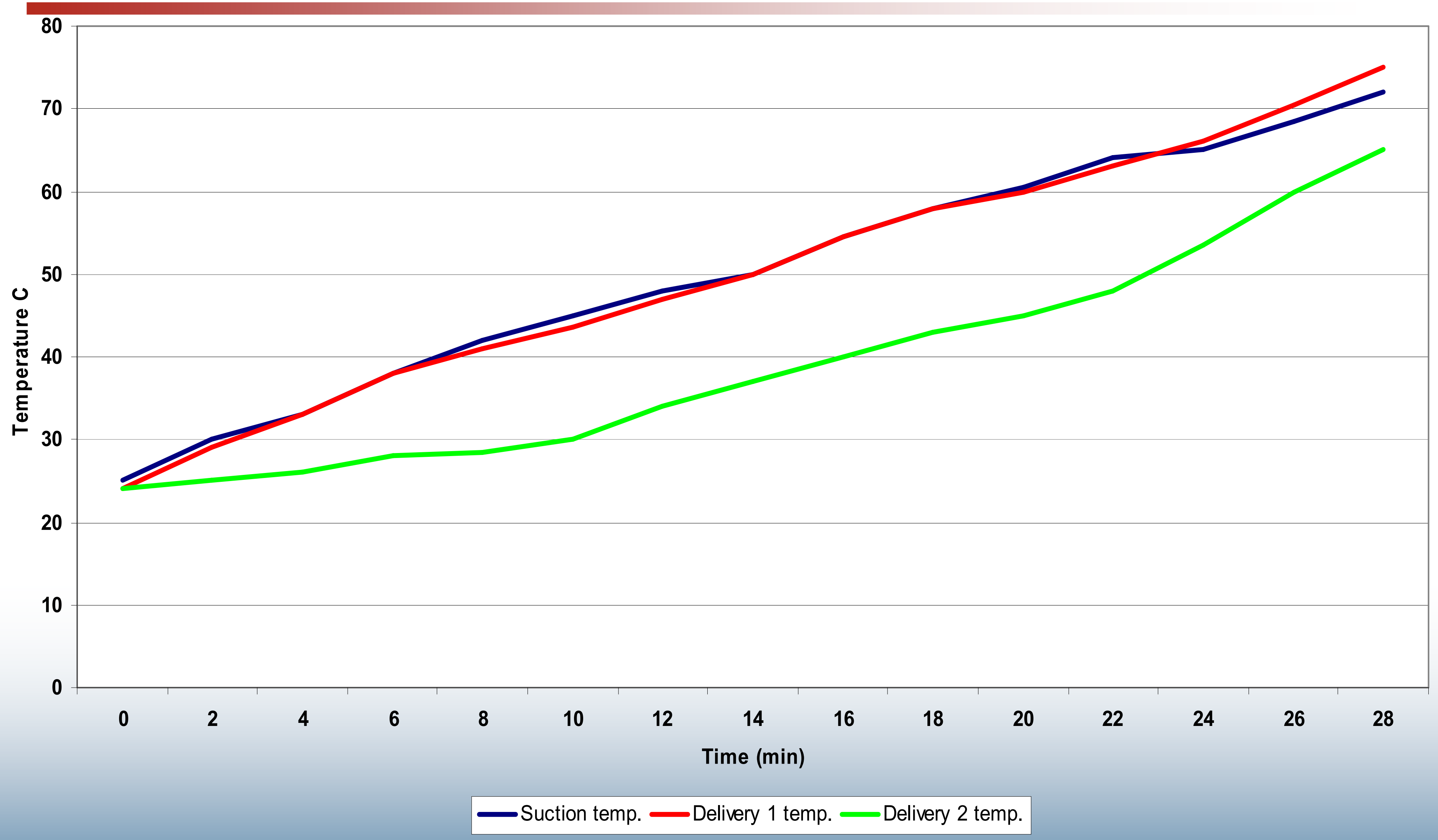
Power = 0.267 + 0.197 + 0.18 + 0.314 + 1.161 kW
= 2.119 kW

Electrical power

Power = 1.732 x 525 x 7.1 x 0.8
= 5.16 kW

Percentage heat transferred to fluid = 41.03%

Test 4 - 500mm suction and 1000 mm delivery



Test 4 results

Power transferred to fluid

Power = 0.292 + 0.317 + 0.255 + 1.219 kW

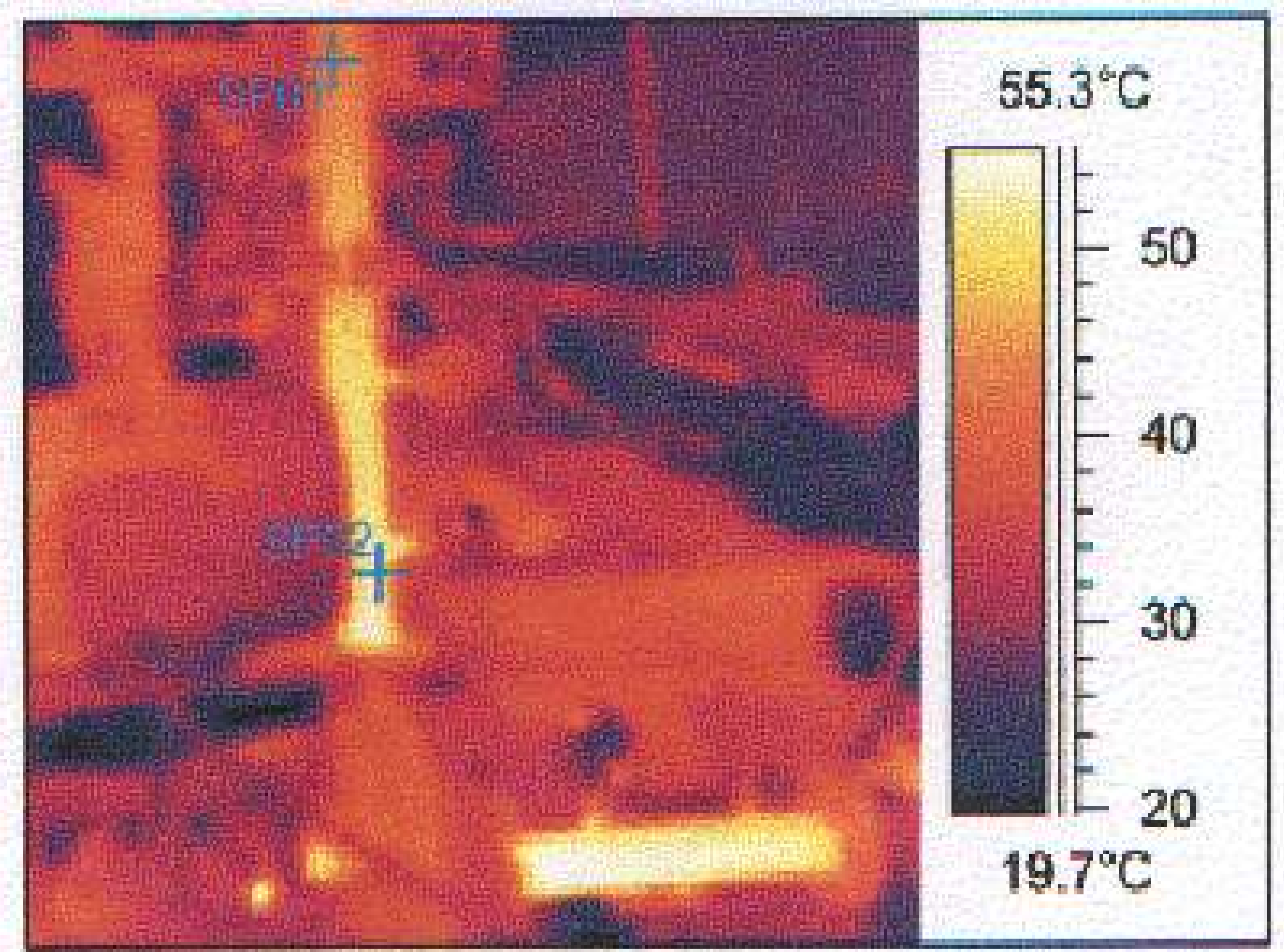
= 2.084 kW

Electrical power

Power = 1.732 x 525 x 7.5 x 0.8

= 5.46 kW

Percentage transferred to fluid = 38.2%



Test 4 Thermographic photograph

Lessons learnt from test pump

- About 40% of motor power is transferred to the fluid under closed valves condition
- Temperature rise in all cases is linear
- As expected, the temperature gradient is inversely proportional to the distance from the heat source

Pump design parameters

Currently pump designers do not consider whether their pump casing should be stronger or weaker than the casing bolts.

Casing strength = Projected area x rated pressure x FOS

Bolt strength = No. bolts x Sectional area x UTS

Consider three test cases ……………..

Test case 1 AB carbon transfer pump

The casing is held together with nine grade 4.6 M12 bolts. The casing is rated at 850 kPa with a FOS of 2.5. The projected area of the casing is 145 500 mm2.

Strength of casing = 145 500 x 850 x 2.5
= 309 kN

Strength of bolts = 9 x 113 mm2 x 240 MPa
= 244 kN

Bolts failed before the casing. This is a pressure burst not an explosion.

Test case 2 Orion HM200

Pump was accidentally tested to destruction in the factory breaking the casing. It has an operating pressure of 3 000 kPa and was being tested to twice working pressure. The casing was pumped with water to 7 500 kPa when the casing fractured.The casing is fixed onto the body with eight M20 grade 8.8 bolts. The casing sectional area is 280 000 mm2.

Casing strength = 7 500 kPa x 280 000 mm2
= 2 100 kN

Bolt strength = 8 x 314 mm2 x 640 MPa
= 1 608 kN

Bolts should have failed at 5 750 kPa.

Test redone – stretched slightly above 6 000 kPa

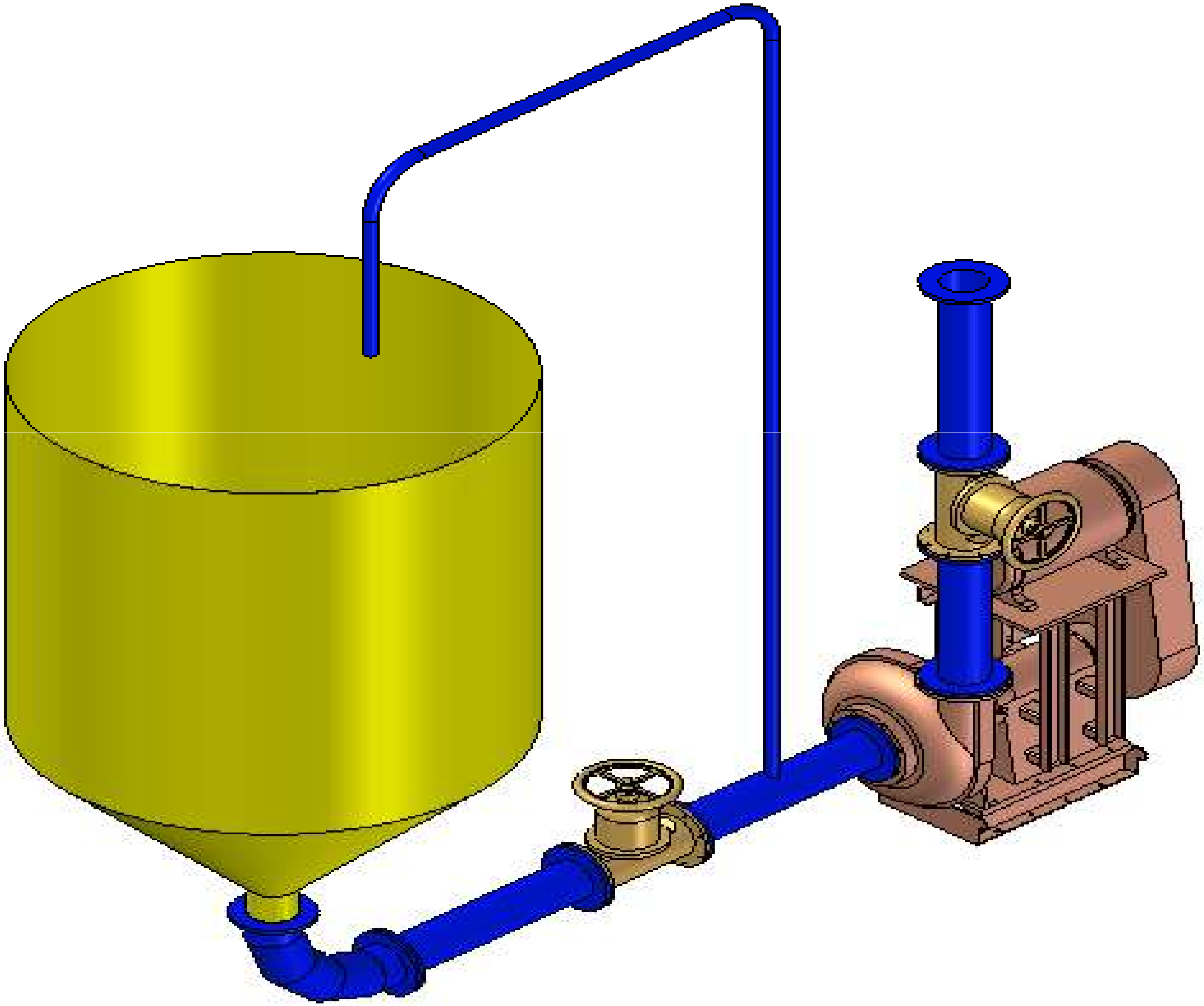
Test case 3 Hot calcine water pump

Feed temperature was 70 C.
Specific heat of fluid is 3.71.
Time to start boiling = 20 mins.

Time to failure = 2 ¾ hours

Casing force at failure = 370 kN.
Shear strength of front two M16 bolts = 30 kN

The simpler solution …. a stand pipe!



Centrifugal pump with stand pipe fitted

Summary and conclusions

- About 40% of motor power is transferred to the fluid under closed valve conditions.
- Manufacturers need to consider their obligations under Section 21 of the MH&S Act regarding design.
- Solution is simpler than we thought

Manufacturers stance

The major pump manufacturers have indicated that they are not prepared to change their bolt design to fail in tension before the casing fractures.

One of the companies have indicated, however, that they are working on a design to release the pressure through the stuffing box. They will make an announcement in 2005.

Who has done what?

AngloGold Ashanti

Risk assessments conducted on all pumps.
Standpipes installed on all simple systems.
Initial carbon discs installed found to wear in some cases.
Surge problems burst discs prematurely.
Home made pressure relief valves fitted (Photo).
All new installations have protection fitted.


27/06/2005

Who has done what?

Anglo Platinum

Various stages of implementation. All new pumps have protection fitted.

Alcoa

All high risk pumps being fitted with thermal cut-out switches.
All new pumps are double cased in construction and castings changed to cater for thermal probe.

Who has done what?

Barrick Gold Mining Co.

At their Bulyanhulu mine in Tanzania –

Additional instrumentation on valve positioning.
Intensive re-training of operational and maintenance staff.
Thermal fusible plugs rated at 65^{o} C fitted in discharge.

Recommendations

- In future designs, make suction and delivery lines as long as practically possible.
- If a pump has a flow meter, couple the signal with the motor running indication and trip the pump in ten minutes if the motor is running but there is no flow.
- Fit stand pipes as near to the suction as possible.
- Where a stand pipe is not practical, install rupture disc.
- Where a pump is fed from another pressure source, fit a higher rated disc or a pressure relief valve.
- More research is needed on design criteria.
- Further tests to be done to determine relationship between motor size, duty, pressure and drop in current when the valves are closed.

Recommendations

PROTECT YOUR

PUMPS !

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Thank you

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Acknowledgements

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