

# **THE USE OF STRAIN GAUGE STRESS MONITORING SYSTEMS ON AMMONIA REFRIGERATION PIPEWORK AFFECTED BY UNDERGROUND MINING SURFACE SUBSIDENCE.**

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## **ABSTRACT**

In 2008, an underground long wall coal mine was drilled approximately 200meters deep under part of an existing turkey processing facility which uses ammonia refrigeration piping systems for process cooling and cold storage. To minimize the risk of pipe work failure due to stress induced by ground subsidence, the pipe work at this site was replaced before the mining commenced. The replacement piping design was modelled using the Whesso Pipe Stress Analysis software PSA 5 and for selected sections of piping additional pipe support displacements (to simulate ground subsidence) were added to the model. This was necessary to demonstrate compliance with The Australian Standard AS4041 –Pressure Piping.

Strain gauges were installed on 64 sections of pipe work identified as likely to experience high stress. A web based monitoring and alarm system was installed to provide early warning if predetermined trigger levels were exceeded.

The paper discusses why flexibility analysis should be carried out on ammonia refrigeration piping systems, compares the predicted stresses with actual measured stress at a number of piping locations, shows how remedial action reduced actual stresses and provides lessons learnt from strain gauge installation and monitoring at an industrial food processing facility.

## **1. INTRODUCTION**

In Australia, the Refrigeration Standards state that any ammonia refrigeration piping installation shall comply with the relevant pressure and piping standards. To achieve this, it is necessary to have pipe stress calculations carried out to certify the pipe grade and materials used are suitable for the service duty. The standard also calls up that the piping system installation is to be to a designated installation class, this class designation nominates the welding, testing procedures and the supervision process.

The programme used by ISECO to carry out the stress calculations is PSA-5. This complies with ASME B31.3 Process Piping and in turn ASME B31.5 Refrigeration Piping both codes calling up identical rules for flexibility analysis.

## **2. REQUIREMENTS FOR AMMONIA PIPING DESIGN**

The Australian Standard AS 1677.2:1998 Refrigerating Systems clause 3.6.1 states that piping and fittings shall comply with AS/NZS 1200 Pressure Equipment. This also notes that AS/NZS 1200 references AS 4041 Pressure Piping and also states other standards for piping. ASME B31.5 would be acceptable under the alternative provisions of AS/NZS 1200.

It is our view this chain of references and standards make it mandatory that all ammonia systems piping design comply with AS 4041 – 2006 Pressure Piping.

### 3. BACKGROUND

The Colliery is located approximately 80 kilometers south west of Sydney in the township of Tahmoor NSW. The mining company has previously mined 24 longwalls to the north and west of the mine’s current location. Longwall 24A is a continuation of an existing mine and is located directly below the turkey plant property and is approximately 90 meters from the Processing Plant at its closest point.



Figure 1 Overlay with the mine plan.

### 4. RESULTS OF PIPING STRESS CALULATIONS

For each pipe section modeled, it was necessary to run two calculations, the first to determine a base stress level, which is the resultant pipe stress from self weight, operating pressure and thermal expansion and contraction. The second model had the predicted ground movements of up to 50 to 60mm ( at the pipe support points ) due to mining related subsidence added to the base case to give an overall result .

A summary of a sample of calculations for the low temperature piping systems is shown in Table 1

Table 1 Summary of stress calculations

Ref No	Location	Base Stress due to thermal and pressure	Stress due to thermal pressure and subsidence
1	Low temp wet return branch to carton freezer ( Nozzle 7 )	27 MPa	109 MPa
2	Low temp wet return line dropper to Stock room east/west (Nozzle 4 )	27.4MPa	77MPa
3	Low temp wet return connection to accumulator	37.8 MPa	54.8 MPa
4	Low temp wet return connection to low temp glycol chiller ( Nozzle 3 )	Less than 20 MPa	36.7 MPa

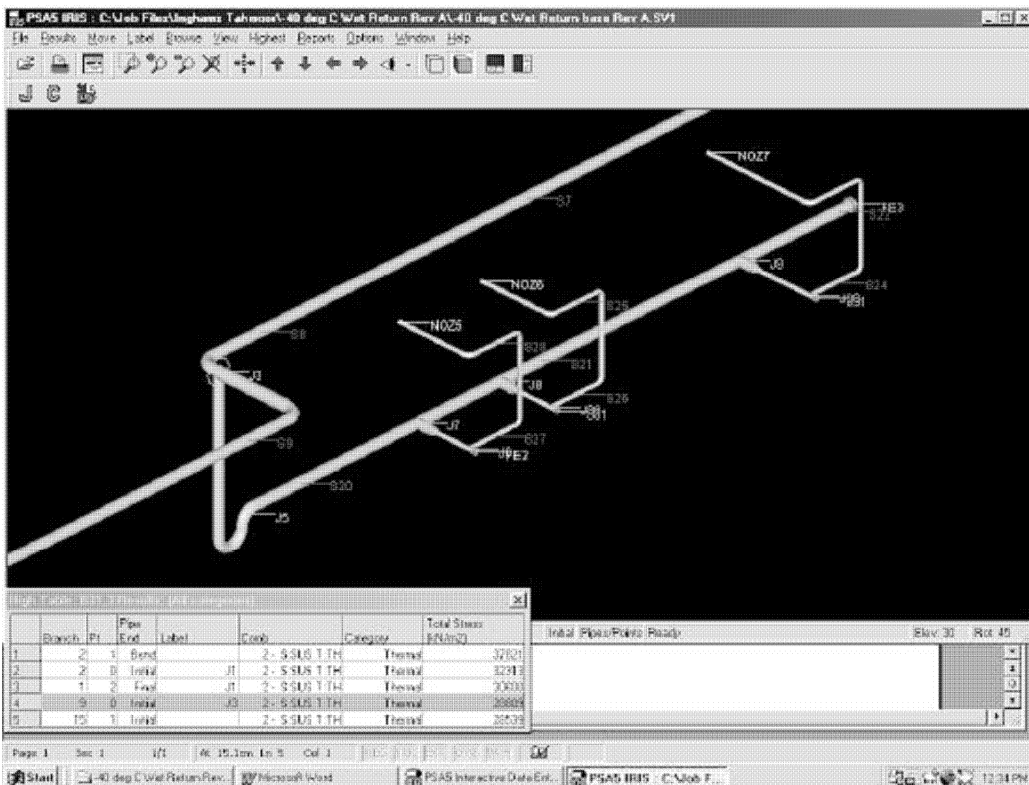


Figure 2 Visual representation of a section of the PSA stress model output

With the above information the maximum calculated stress can be compared against the allowable maximum stress for the piping material and welding and testing procedures allowed by the relevant standards.

## 5. INSTALLING STRAIN GAUGES

From the stress model outputs, the key locations of peak stress due to combined thermal and subsidence effects were identified. At each of these locations a configuration of electrical resistance strain gauges were installed by a specialist company . Longitudinal stress was measured at four equally spaced locations around the circumference of the pipe , hoop stress and 45degree torsional stress was measured with a multi element rosette gauge .

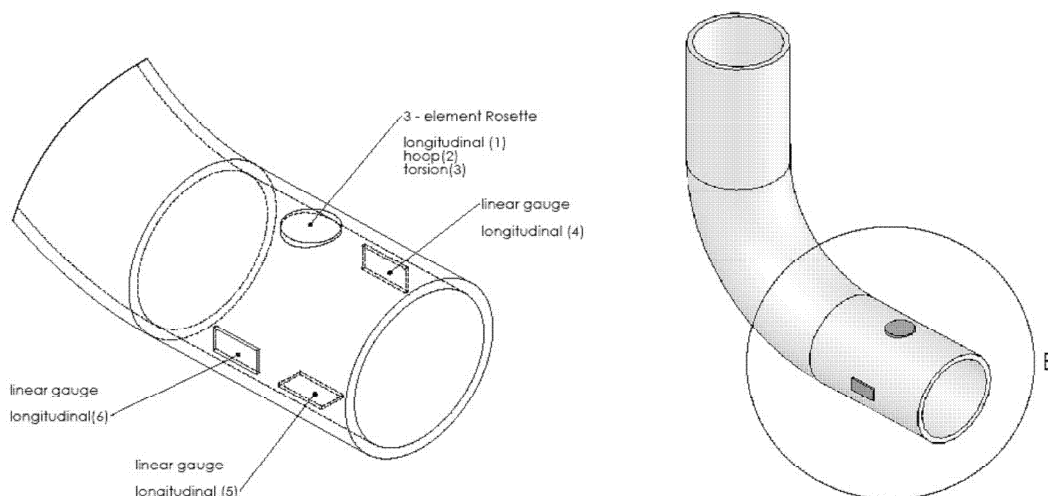


Figure 3 Location of Strain Gauges

## 6. COMPARING RESULTS TO OPERATION STATUS

### PRESSURE STRESS

To check the results of the pressure stress ( or hoop stress as its more commonly known ) is relatively easy if the actual internal pressure of the pipe and diameter and wall thickness are known.

Pressure stress is calculated from eq.(1)

$$S_p = Pd^2 / (D^2 - d^2) \quad (1)$$

The results of a spot check at one location are shown in the Table 2

Table 2 Comparison of measured and calculated Stress

Location	Time & Date	Pipe Pressure kPa Absolute	Pipe Outside diameter (mm)	Pipe inside diameter (mm)	Calculated Pressure Stress MPa	Measured Pressure Stress MPa	Predicted Pressure Stress MPa
Condenser gas inlet	10.38am 12/ 5/08	1191	88.9	77.9	3.95	4.1	6.7

Note : The predicted pressure stress is based on piping and refrigerant gas temperature at worst case design of 46 °C ( 1827 kPa A ).

From the above it can be seen that the actual measured pressure stress of 4.1 MPa agrees well with the calculated value of 3.95MPa.

### PIPE STRESS DUE TO DEFROST

The monitoring provided a unique opportunity to check actual stresses in a refrigeration piping network during a range of operating conditions. One such area that is presented below is the piping associated with a carton freezing tunnel on the site. Strain gauges were mounted on each of the coil connections. The figures below show the changes occurring during a manual defrost operation which had the following steps: Manually close the low temp pump liquid feed valve to the coil, 15minutes later manually open the hot gas valve to the coil, leave on defrost for approx. 1 hour.

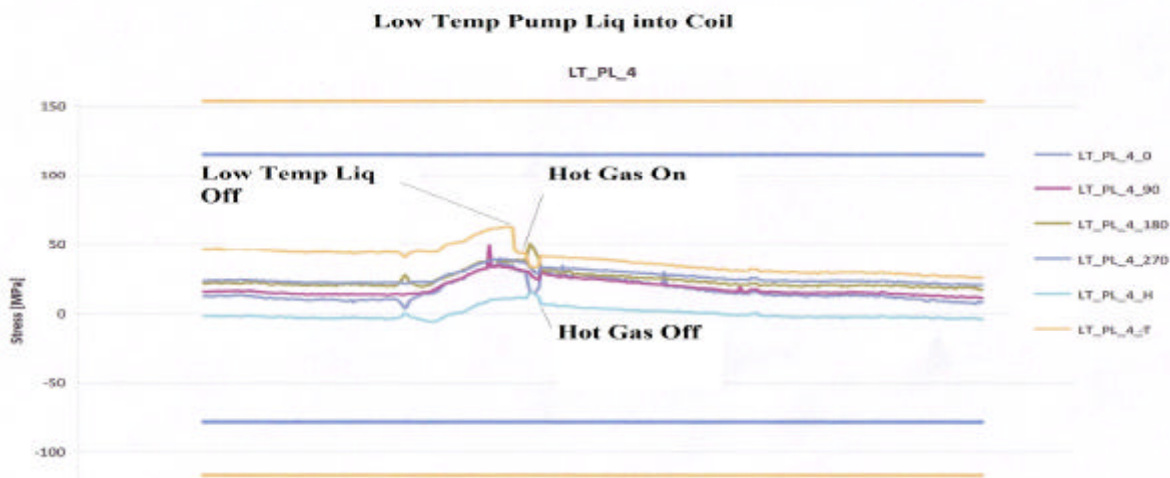


Figure 4 Low Temp Pumped Liquid into Coil

From Figure 4 the following pattern can be detected:

(Note: When analysing look at the direction and magnitude of change in stress)

- The torsional stress changes by approximately 20 MPa when the liquid supply is shut off but no significant changes in other stresses until the hot gas valve is opened.
- Once hot gas valve is opened, all stresses change with largest change of 15MPa on 270 degree longitudinal stress.
- The stresses on the 90 degree axis (ie opposite to 270 degrees) change by only 7 MPa in the same direction which implies that bending and a compression are occurring simultaneously. (If this was pure bending the 90 degrees would be mirror image of the 270 degrees.)
- The 0 degrees and 180 degrees stresses are opposite in sign with the 180 degrees being 13.8MPa compared to 9.6 MPa on the 0 degrees.

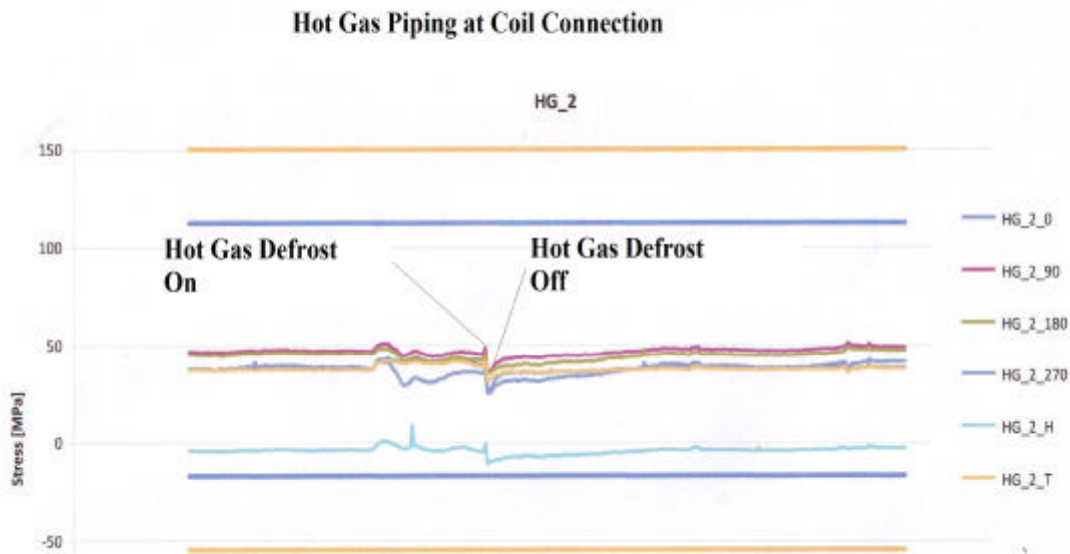


Figure 5 Hot Gas into Coil

From Figure 5 the following can be observed:

- The largest variation in stress is the 270 degree axis, which changed by 12.1MPa
- All stress values have moved in the same direction indicating that stresses are mainly compressive or tensile with some torsion.

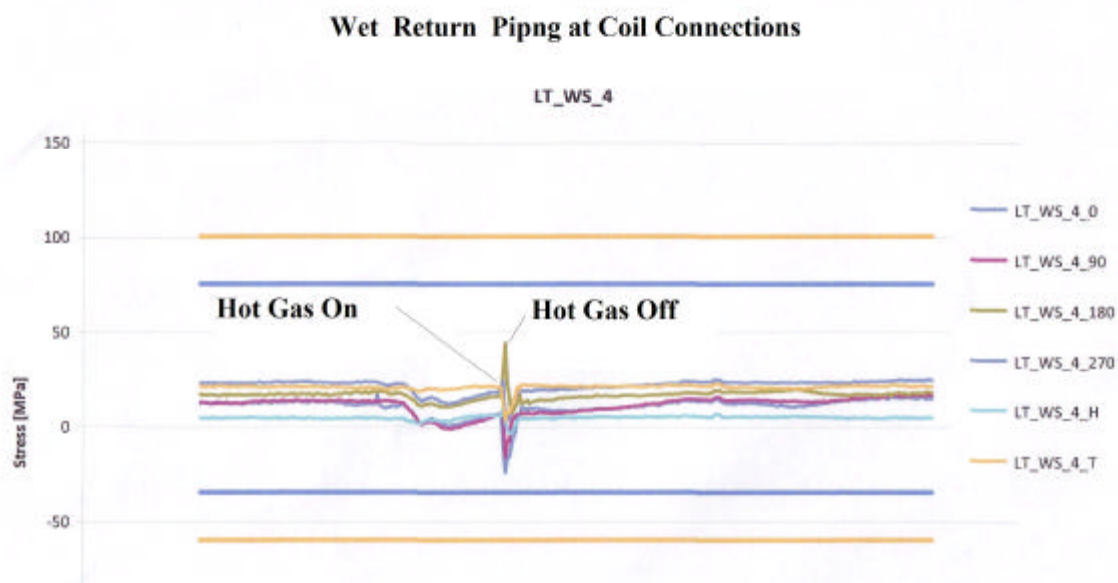


Figure 6 Low Temp Wet Return Out of Coil

From Figure 6 the following can be observed:

- a) The largest change in stress was on the 180 degree axis, nearly 40 MPa. On the opposite axis 0 degrees, stress values changed in the opposite direction by 30 MPa indicating bending and some compression or tensile stress.
- b) The 90 degree and 270 degrees changed in the same direction indicating compression or tensile stress ( probably compressive as pipe warms up during defrost ).
- c) The hoop stress increased initially then dropped before stabilising at its original level .

In summary , the above shows that stresses in refrigeration pipes do change as the process changes and as would be expected, the largest changes in stress occurred in the larger diameter wet return piping which has the least flexibility.

### 7. REMEDIAL ACTION AS A RESULT OF STRESS MONITORING

On the 2<sup>nd</sup> of May 2008 we identified that the stress on the strain gauge set Cond- 3 located at the 80mm NB discharge gas inlet pipe to the condenser was increasing steadily .

As part of the monitoring procedure , trigger levels for remedial action had been set by taking the maximum allowable stress for the type of piping material and operating temperature ,less a safety factor. An early warning level known as the Blue level was set and a higher level known as Amber was also set. Figure 7 shows the 90 degree axis longitudinal strain gauge trending towards a blue trigger .

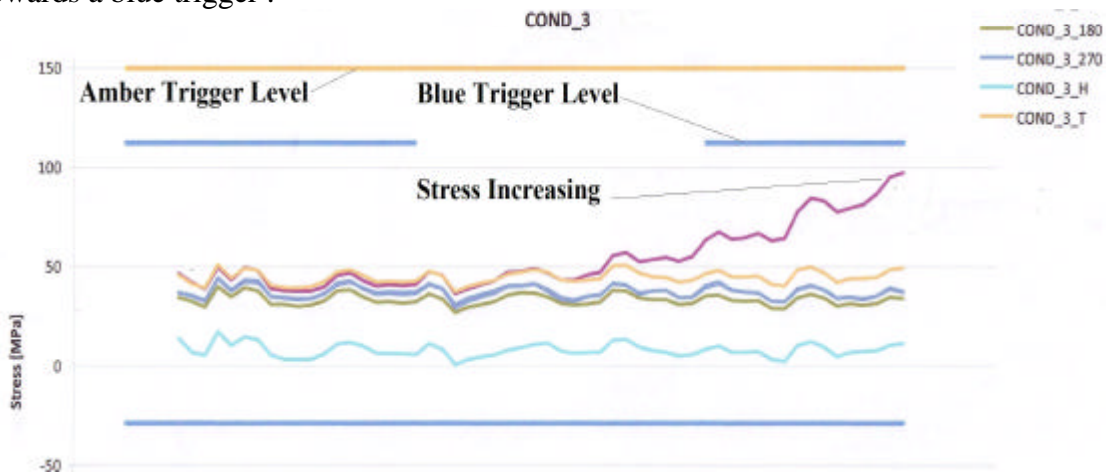


Figure 7 Increasing Stress on 90 degree axis

The analysis showed that the change in stress was likely to be caused by an increasing bending in the pipe due to minor tilting of the condenser foundations most likely as a result of mining induced ground settlement . Refer to Figure 8 which shows how the combination of an existing tensile stress plus the new bending could create the pattern shown on the gauges.

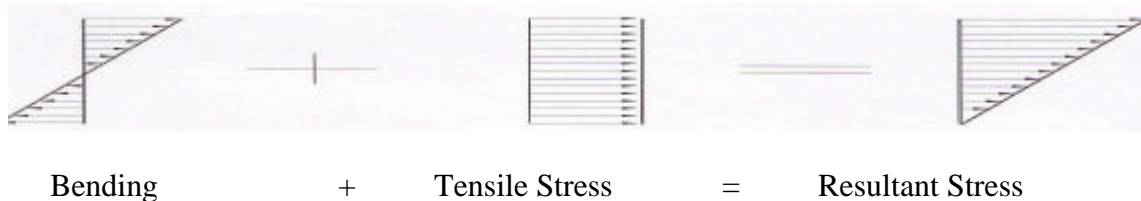


Figure 8 Combining Stresses

An instruction with marked up photographs was issued to site to increase the length of the support rod on the hanger upstream of the gauge point to reduce the bending stress experienced. This was completed on the 2<sup>nd</sup> of June and the resultant reduction in stress is as shown in Figure 9 .

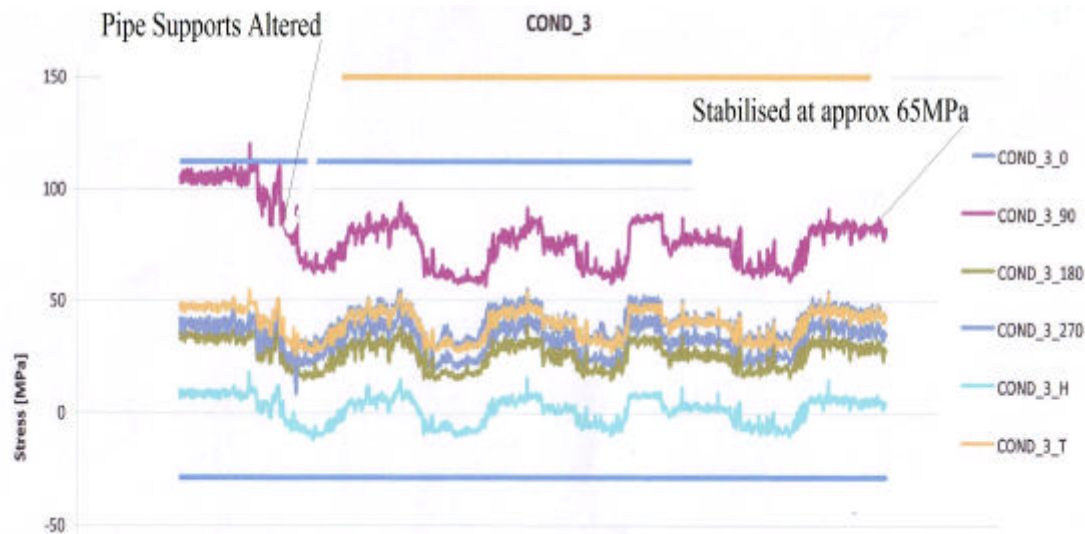


Figure 9 Reduced Stress on 90 degree axis

This shows that as predicted the mining induced stresses would change at a reasonably slow rate and that the use of appropriate trigger levels and remedial actions can safely counter those effects.

## 8. LESSONS LEARNT STRAIN GAUGING & REFRIGERATION PIPING

To provide a guide for future projects where strain gauges may be required on refrigeration piping the following should be considered:

- Three dimensional piping drawings showing pipe support locations, all pipe lengths, bends, insulation & cladding etc should be used as input to the stress models. These can then be marked up to indicate required position of strain gauges.
- Take care that baseline readings are taken with pipes empty and at ambient temperature (This was difficult in a production environment).
- It was found that the wiring and data taker units had susceptibility to temperature which would show as a gradual reduction in stress as temperature increased and then increasing again at night. In future more work should be done to eliminate this effect.
- Gauges located in plant rooms and other areas with large amounts of electrical equipment often showed rapid spikes due to electrical interference, causing false trigger alarms.
- Care should be taken to seal junction boxes from water ingress.

## 10. CONCLUSIONS

All ammonia refrigeration piping systems should be subjected to a flexibility analysis. Where the designer has doubt regarding the ability of the system to comply, a comprehensive analysis should be made.

The Whesso PSA-5 Pipe Stress Software based on ASME B31.3 & B31.5 has been found suitable for use in modelling refrigeration pipe stresses under thermal and subsidence loadings and provides an easily used output.

The use of electric resistance strain gauging to measure refrigeration pipe stress changes in a site subjected to unusual ground subsidence has been proven workable.

### NOMENCLATURE

Sp	pressure stress	(Pa)	Subscripts
P	internal pressure	(Pa)	A Absolute Pressure
D	outside diameter	(m)	
D	inside diameter	(m)	

### REFERENCES

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