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Technical Investigation

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Investigation into the Avoidance of static electrical discharge during gas main purging operations

Revision	Description	Date
A	Initial Report	8 October 2014
B	Added branch flow considerations	20 October 2015
C	Added reference in Appendix D to excel spreadsheet	25 Feb 2016

CONTENTS PAGE

1 BACKGROUND

This version is nearly identical to the previous version the main exception is the addition of purging of branch pipes. This report has been provided to the standards committee revising AS/NZS4645:2008 to be used for the considering changes to the relevant parts of the standard. The intellectual property will remain with Energy*Safety*.

Energy*Safety* became aware of an incidence where a gas fire had been initiated during a purging operation. The gas was ignited by static electricity built up in the plastic pipe fitting due to excessive velocity through a small leak. The purpose of this Energy*Safety* report and the accompanying desktop study was to highlight the operating and working conditions that cause dangerous levels of static electricity to accumulate and identify a number of risk mitigation methods to be included in AS/NZS 4645.3:2008 – Gas distribution networks Part 3: Plastics pipe systems.

Currently, AS/NZS 4645.3 (referred herein as “the Standard”) Appendix E provides guidance on ‘in-field purging operations’ and addresses a number of issues that are not dealt with by codes such as IGE/SR/22” (refer to Appendix A in this report). The purpose of AS/NZS 4645.3 Appendix E is twofold:

1) to limit purging velocities in plastic mains to the boundary conditions of 1 and 20 m/s, and;
2) to provide guidance to network operators how purging can be undertaken in a controlled manner.

When using the Standard as a guide, this desktop study found that purging flow velocities in smaller plastic purge fittings such as hoses and tapping bands, can exceed 50 m/s... Moreover, Energy*Safety* had become aware by a network operator’s incident investigations that current in-field practises could contribute significantly to the production of environments conducive for static fires, via excessive and largely uncontrolled velocities.

Energy*Safety* commissioned a literature review (Appendix B) to study the pressure, velocities and the conditions that cause the dangerous accumulation of static electricity. The review considered accepted industry practise and peer reviewed research.

The literature review found that static electricity becomes problematic in gas piping when the mains pressure exceeds 100 kPa, increasing exponentially with the presence of sand and grit. Also, the literature review found that most studies were reluctant to nominate an exact static electricity velocity threshold or guidance on this matter, preferring to otherwise state that any increase in velocity will give rise to the risk and the accumulation of static electricity. However, the Institute of Gas Engineers in the UK state “if the velocity is limited to a maximum of 20 m/s, then dust particles or debris are unlikely to cause a problem” (IGE 1992).

There are been no official reported fires from the medium pressure 40 kPa PVC mains in Western Australia. However, discharges over extended times at 40 kPa mains pressure can also give rise to a built-up of static electricity based on anecdotal evidence provided by a network operator. There are no reported incidences on 10 kPa mains. Therefore 10 kPa and the aforementioned 20 m/s became a quasi-benchmark for this study. Furthermore, it is accepted that PE was more prone to static electricity than PVC because of its higher surface resistance. As the PVC pipe in Western Australia is progressively being replaced with PE during scheduled programs, and during maintenance and repair , , it is conceivable that PE pipe operating at 40 kPa and above will inevitably be damaged and be purged at some stage. Both these occurrences give rise to the possibility of ignition of gas fires through the accumulation of static electricity. It should be noted that PE gas pipe is also used extensively throughout Australia in the 100 – 500 kPa pressure range.

The Energy*Safety* literature review found that the overriding factor for the accumulation of static electricity in plastic gas mains is the discharge velocity which is highly dependent on the mains pressure. Throughout Energy*Safety's* calculations, the control pressure was taken as 7 kPa. 7 kPa was chosen as the selected operating pressure for the purge as this will give network operators sufficient pressure to purge low pressure mains and services.

Although Appendix E in AS/NZS4645.3 Plastic Pipe Systems is a good starting point evidently few network operators have taken steps such as these detailed herein and in the accompanying calculations to implement their own exacting direct purge methodologies. This report aimed to bridge this gap by providing guidance for orifice sizing methodologies to use in series with the take-off hosing or near the flow-stopping device to limit velocities in plastic mains and fittings well below the threshold where static electricity becomes problematic. It is in the public's and network operators' best interests to reduce purging velocities in plastic mains and fittings below the static accumulation thresholds stated above, and reduce the risk of static electrical fire..

2 CONCEPTUAL DESIGN OF WORK METHODOLOGIES

With these objectives in mind, Energy*Safety* has calculated orifice sizes and developed in-field work methodologies which form suggested refinements for Appendix E (AS/NZS4645.3).

AS 4645.3 recommended that purging operations should be kept within a velocity boundary of 1 – 20 m/s. However, it should be noted that high velocities well in excessive of this boundary can not be avoided where the pressure drops significantly, i.e. through a squeeze-off, or some other control such as a ball valve or indeed an open-ended pipe. Ideally, Energy*Safety's* sized orifices should be placed in the earthed take-off between the main and the purge pole to ensure velocities in the plastic fittings, and subsequently the pressure mains, remain well below the static electricity threshold. (A diagram of the suggested arrangement can be found in Appendix C1).

Alternatively, an orifice and throttling valve could be placed in the inlet side of the purging arrangement over the flow stopping devices. This could be achieved by, monitoring the differential pressure across the orifice. The instrument needed to measure differential pressure is however more complicated than simply reading a gauge pressure, that is considered adequate when the orifice is placed on the discharge side. For this paper and accompanying calculations, a nominal differential pressure of 7 kPa should be maintained. Though in theory, any reasonable pressure can be selected as long as engineering design principles are employed to ensure plug flow (Reynolds number >4000) and velocities are kept within 1 – 20 m/s to avoid static accumulation (See Appendix C).

It should also be noted, that effective purging operations are conducted in the range of 50% - 100% of the operating capacity of the gas main and thus, hoses and take-offs must be sized accordingly to provide this flow-through. Further, the orifice must be the authority flow restriction for this paper's premise to work in practice. Using these suggested controlled conditions, releases of gas are still quite significant.

This methodology involves a squeeze-off or bypass valve (or some other control) operated via instructions from a person at a pressure gauge located upstream of an orifice who then communicates the purge rate expressed in kPa to a person managing the flow stopping arrangement. The aim of the exercise is to balance and maintain 7 kPa at the orifice for the entire duration of the purge. This method automatically compensates for the variations in pressure flow resistance between the start and end points located at different distances.

The work methodology is summarised below:

2.1 Orifice at purge pole:

- The squeeze-off and taping band/s are put in place as per usual under the network operators own work procedures
- The purge pole is set up in the usual fashion in accordance with procedures. The purge pole must be bonded to earth. The orifice is placed just before the entrance to the purge pipe. The orifice arrangement must be gas tight, made out of metal and be electrically bonded to the purge pole.
- One end of a braided or electrically bonded hose is connected to the orifice arrangement, the other end to the tapping band or other take-off method. The hose must contain an isolation ball valve and be initially closed.
- With the ball valve open at the purge connection, the squeeze off (or rider) is gently eased-off to generate flow observing the upstream pressure at the orifice.

- The operators work together to maintain a purging pressure of 7 kPa. G for the duration of the purge.
- Once two readings of 100% gas in air has been achieved at the purge pole, the ball valve at the purge connection is closed and the new service or main is commissioned in the usual fashion.

  (See Appendix C1 for a diagram of the purging arrangement)

2.2 Orifice at inlet

- The squeeze-off, rider and taping band/s are put in place as per usual under the network operator's own work procedures. For this arrangement to work, the orifice must be placed in a rider. If a squeeze-off is used as flow control, this method will not work and the orifice must be placed at the outlet as described in section 2.1.
- The differential pressure must be measured between the downstream and upstream side of rider, and delta 7kPa nominally maintained during the purge operations.
- The orifice / rider arrangement must be gas tight, made out of metal and be electrically bonded to earth.
- The purge pole is set up in the usual fashion in accordance with procedures. The purge pole must be bonded to earth.
- A hose connected to the tapping band at the end of the main through to the purge pole must contain an isolation ball valve and be initially closed.
- With the ball valve open at the purge connection, the rider is gently eased-off to generate flow observing the pressure difference at the orifice.
- If the operator on the rider can not see the differential pressure, the two operators must work together to maintain a purging pressure of delta 7 kPa for the duration of the purge.
- Once two readings of 100% gas in air has been achieved at the purge pole, the ball valve at the purge connection is closed and the new service or main is commissioned in the usual fashion.
- (See Appendix C2 for a diagram of the purging arrangement)

2.3 Branch purging

After the purging and commissioning of a main, there is often a requirement to purge the connected branches. Irrespective of the number of crew members present and the equipment available, each branch should be purged sequentially to ensure 100% gas is maintained in the newly commissioned mains.

Theoretically, branch connections can be isolated either using squeeze-offs or riders using the same methodology as for gas mains. However, branch connections have smaller diameters, so that controlling the purge from the outlet may well be the most practical and safest method (Appendix C3). The method employed will depend on the network operator's preferences, pipe material, tooling and procedures. In any case, the work methodology is suggested below:

A tapping band is installed at the end of each branch line.

For the case of ring mains or back-gassed branch mains, a flow stopping device will be required during the duration of the purge. In ring mains, the tapping band needs to be upstream of the flow stopping device, and the flow stopping device downstream of the tapping band, but upstream of the interconnector entry.

- The purge pole is set up in the usual fashion in accordance with procedures. The purge pole must be bonded to earth. The orifice is placed just before the entrance to the purge pipe. The orifice arrangement must be gas tight, made out of metal and be electrically bonded to the purge pole.
- One end of a braided or electrically bonded hose is connected to the orifice arrangement, the other end to the tapping band or other take-off method. The hose must contain an isolation ball valve, and a throttling valve and both must be initially closed.
- With the ball valve and throttling valve closed, the system is charged by operating the tapping tee
- The operator opens the isolation valve and gradually works the throttling valve to achieve a nominal flow 7 kPa.g at the orifice for the duration of the purge.
- Once two readings of 100% gas in air has been achieved at the purge pole, the ball valve on the hose connection is closed and branch connection is commissioned per the network operator's procedures

(See Appendix C3 for a diagram of the purging arrangement)

3 ORIFICE SIZING CALCULATIONS

Energy*Safety*'s orifice sizing calculation can be found in Appendix D. The Appendix contains a table which expresses the size of the orifice to the nominal diameter (ND) of the main to be purged. The table also lists minimum take-off sizes to ensure that hoses and taping bands are sufficiently large as not to significantly restrict the free-flow, and to ensure the velocity remains below the static electricity generating levels. The expected Reynolds number was also stated to ensure plug flow. i.e Reynolds Numbers will be greater than 4000.

The suggested work methodologies mentioned above and the orifice sizing calculations focus on the premises that:

- Sizing of an orifice is a function of pressure mains diameter. As the pressure will be closely monitored and controlled during the purging operation, the MAOP is irrelevant.
- The orifice upstream purging pressure is maintained at 7 kPa.g.
- Reynolds numbers were kept above 4000 to ensure turbulent or plug flow.
- Due to the requirement to rationalise orifice sizes for the interests of economics and simplicity for network operators, the pressure main velocity was kept as close to 2 m/s as reasonably practicable. This was not possible for the smaller and larger sizes and the velocity boundaries have been changed to suit, ensuring that Reynolds Numbers are above 4000. (see Appendix D, Calculation 1-1, Columns 9 & 10 and further notes below)
- Rationalising the number of orifices will lead to a greater variation in velocities in the mains. Too much rationalisation would lead to differences in perceptions of time to purge and is considered undesirable. EnergySafety believed it had reduced the total number of orifices to the minimum level. However, it will ultimately be the network operator's prerogative to rationalise and produce work procedures, etc. to suit.
- A column has been added in the calculation (see Appendix D, Calculation 1-1, Column 12) for the convenience of the reader that states pressure drop in kPa per metre of pressure main. The pressure drop can then be calculated for any length of pressure main by multiplying by the length (in metres). However, it should be noted that the effects of compressibility have been ignored. If pressure drops are calculated in the vicinity of 100% of the selected orifice operating pressure (i.e. 100% of 7 kPa = 7 kPa), then the effects of compressibility should be considered, as compressibility effects may reduce the actual flow. (A good source of related equations and when compressibility should be considered can be found in Crane 2013 which is listed in the references).
- The smaller the main, the lower the Reynolds number and hence, the higher the purge velocity required to maintain a plug flow. Conversely, in order to keep the velocities in the smaller take-off fittings to a minimum, the velocity in the main, in particular in the larger diameters, needs to be kept as low as possible. The calculations have taken this balance into consideration.

4 CALCULATIONS

The calculations sheets can be found in Appendix D. Calculations are referenced where appropriate and supporting documentation is included in attachments. Refer to the in-calculation notes for further clarifications.

The following assumptions have been made in order to carry-out the calculations:

1. The effect of approach velocity onto the orifice is considered negligible in all cases because of the low pressures and subsequent velocities (see assumption 4 below).
2. Compressibility effects have been ignored due to small pressure loss relative to the (absolute) operating pressure. (However this does not apply to line flow calculations in the case of PE sizes 20 and 25 mm).
3. The pressure at the orifice is also taken to be the pressure in the line being purged. This is justified in the calculation by the low pressure loss in the tapping bands, hoses and fittings.
4. The discharge coefficient for a square shoulder (and sharp edge) orifice is taken as 0.60 (Daughert, R.L., et al 1997). According to Crane (1999 and 2013), it would vary in the range 0.60 to 0.64 with the approach velocities used. Therefore, it is conservatively taken as 0.60.

5 FINDINGS

5.1 Orifice Sizing

The following table is derived from the calculations described in Appendix D and the parameters discussed in this report.

Table 1– Orifice Sizing

Column:	**1**	**2**	**3**	**4**	**5**	**6**
Parameter:	**PE Main Size**	**Equivalent PVC/Steel**	**Orifice Size**	**Est. Mains velocity**	**Reynolds No.**	**Min. take-off***
Units:	mm	mm	mm	m/s	Re	mm
	20		6.0	14.1	13792	16*
	25		6.0	7.6	10114	25*
	32		6.0	4.0	7365	25*
	40		10.0	6.5	15585	32
	50		10.0	4.2	12453	32
	63	50	10.0	2.6	9902	50
	75	65	10.0	1.8	8289	50
	90	80	15.0	2.9	15534	50
	110	100	15.0	1.9	12724	50
	160		25.0	2.5	24280	80
	200	155	25.0	1.7	19762	80
	225		35.0	2.5	33838	80
	250	195	35.0	2.0	30446	80*
	315		50.0	2.6	49222	100*
	355		50.0	2.0	43665	100*
	No. of orifices		6			

NOTES:

*Tapping bands may not be suitable for sizes below NB32 and over NB250. In these cases, consider the use of branch connections and cap-off after the purging operations.

6 CONCLUSION

This report has demonstrated that the accumulation of static electricity is a real danger in plastic gas mains.

By using this report and accompanying calculations as a guide for its own development and deployment of relevant procedures using an orifice, a network operator will make the activity of purging safer by providing a means to carry out purging in a controlled manner.

Energy*Safety* accepts that most fires caused during purging operations are short lived as the personnel operating the control point can shut-off the flow of gas quickly once the presence of fire is known. If however, gas escapes from the main or fittings during a purging operation, the discharge velocity can be controlled with an orifice in the system to reduce the accumulation of static electricity at the leak site. The leak or fault can be then be rectified and the purge continues with vastly reduced risk of fire or incident.

7 RECOMMENDATIONS

Energy*Safety* recommends the following:

- Confirm the methodology with actual purging and adjust this procedure as required prior to submission to Standards Australia for consideration by committee AG008.
- EnergySafety to provide a revised appendix E based on the contents of this report. The revised appendix will have an orifice sizing table, new figures to replace the old ones and revisions to the descriptive text. It will also have a reference to the ENA and or GTRC websites that will host this report and orifice calculations.
- Using the revised AS4645.3 Appendix E as a guide, network operators to develop their own procedures for purging operations in accordance with the findings of this report implementing an orifice based system or other means to achieve the improved methods of control for purging.

8 REFERENCES

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The Institute of Gas Engineers (IGE) 1992, *Distribution Mains - Recommendations on Transmission and Distribution Practise IGE/TD/3,* Edition 3: 1992, Communication 1514, London UK.

APPENDIX A – AS 4645.3:2008 – GAS DISTRIBUTION NETWORKS PART 3: PLASTICS PIPE SYSTEMS

APPENDIX E

DIRECT PURGING METHODS.

(Informative)

E1 GENERAL

This Appendix provides further guidance on in-field purging operations and addresses a number of issues that are not dealt with by codes such as IGE/SR/22. Extensive reference is made to IGE/SR/22 and the paper: *The explosion hazard associated with direct purging* by Sarah Darby.

There are two methods of purging; direct and indirect. Please refer to IGE/SR/22 for detailed information about indirect purging. Paragraph E2 discusses direct purging. Whilst indirect purging has a definite safety advantage, the procedure is more involved and costlier than direct purging. In many cases a correctly applied direct purge can achieve a similarly good safety outcome.

E2 DIRECT PURGING

E2.1 Overview

Direct purging is the introduction of gas into a main or service filled with air (usually during mains or service installation) or the introduction of air into a main or service filled with gas (usually when de-commissioning) without inter-stage inert gases being introduced.

In general, the direct purging methods and safety issues are the same for either scenario. However, when introducing air into a gas main or service, consideration should be given to a back-up air source i.e. spare compressor.

E2.2 Staged and gradual approaches

Direct purging can be achieved by introducing the gas either in two stages or gradually.

The staged approach typically means that the valve, squeeze-off or cutter T as shown in Figure E1 is gradually opened. Once the service or main's extension is under the same pressure as the main or service, the purge discharge is opened and flow is maintained until the gas has completely filled the main or service being purged.

The advantage of a staged approach is that this work can mostly be done by a single operator or crew.

The disadvantage is that in most cases, the boundary conditions of flow (between 1 and 20 m/s) are exceeded. As a result, there is an increased risk of ignition and main or service failure particularly in the case of plastics mains or services. Generally, this method is only suitable for MAOPs of 100 kPa or below. This method may also be acceptable for operations above 100 kPa and smaller than 25 mm NB.

The gradual approach (see Figure E2) means that the valve, squeeze-off or cutter T remains closed and a bypass provides a known input. In the case of a lateral connection to a transmission pipeline (see Figure E3), the metering skid and/or pressure regulation skid may allow opening of the isolation and provides an ideal entry condition. The preferred input for gradual purging is controlled by a meter which can be readily converted to read velocity and adjusted accordingly. The purge discharge is open during the entire purge and monitored accordingly.

Alternatively, as shown in Figure E4, the flow can be converted to a required pressure and the pressure controlled from the upstream section into the new main or service via the meter or gas pressure regulating skid. The purge discharge is open during the entire purge and monitored accordingly.

The advantage of this method is that it has a very positive safety outcome as the gas is introduced gradually and the main or service does not reach MAOP until it is entirely purged. Internal ignition is highly unlikely because the safe boundary conditions of 1 to 20 m/s are met, the velocity remains between 1 and 20 m/s.

The disadvantage is that more staff is needed as both the entry and exit points need to be monitored and parties need to be able to communicate with each other. If branches are connected, the flow and/or pressure may have to be adjusted during the purging as these branches are purged. This method requires calculation and detailed procedure writing by a professionally qualified engineer.

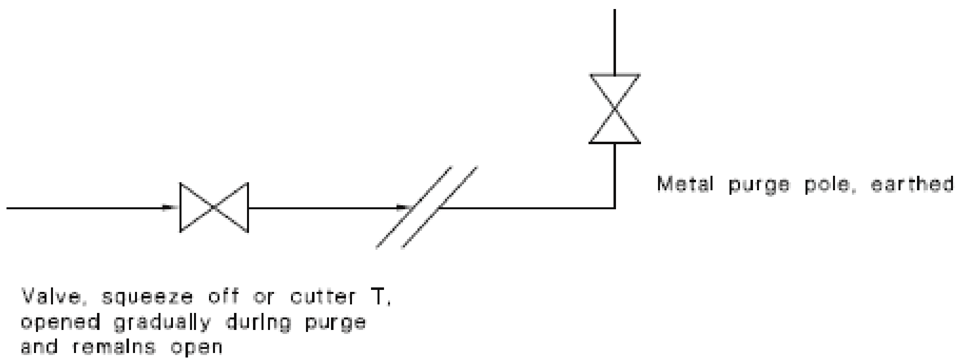


FIGURE E1 STAGED PURGE FOR MAINS AND SERVICES BELOW 100 KPA

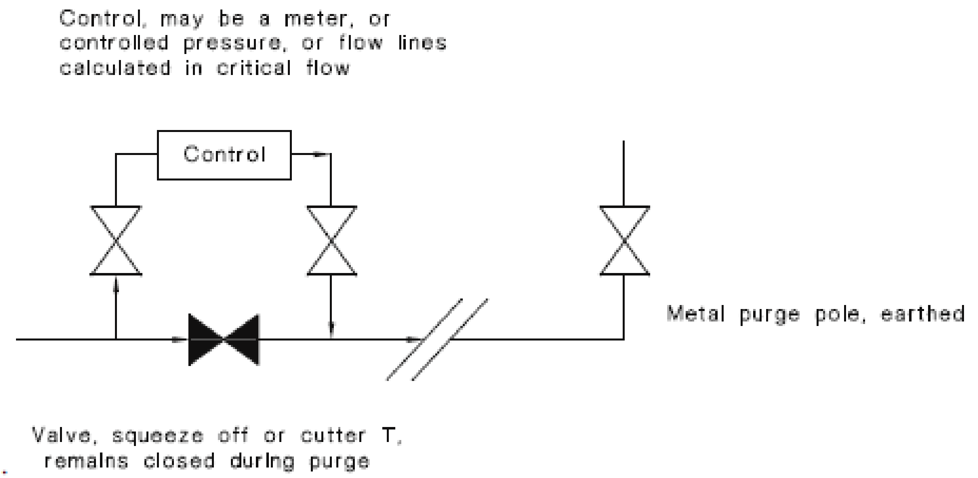


FIGURE E2 GRADUAL PURGE FOR MAINS AND SERICES ABOVE 100KPA - BYPASS CONNECTION MAY MAKE USE OF CURRENT OR FUTURE SERVICE T'S

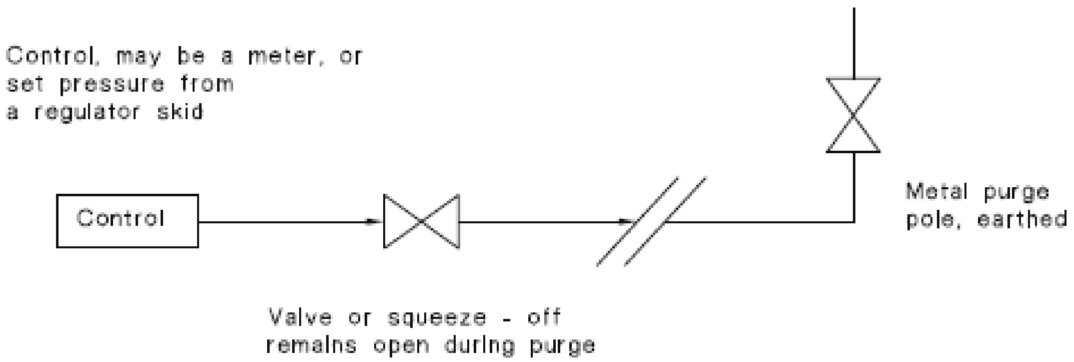
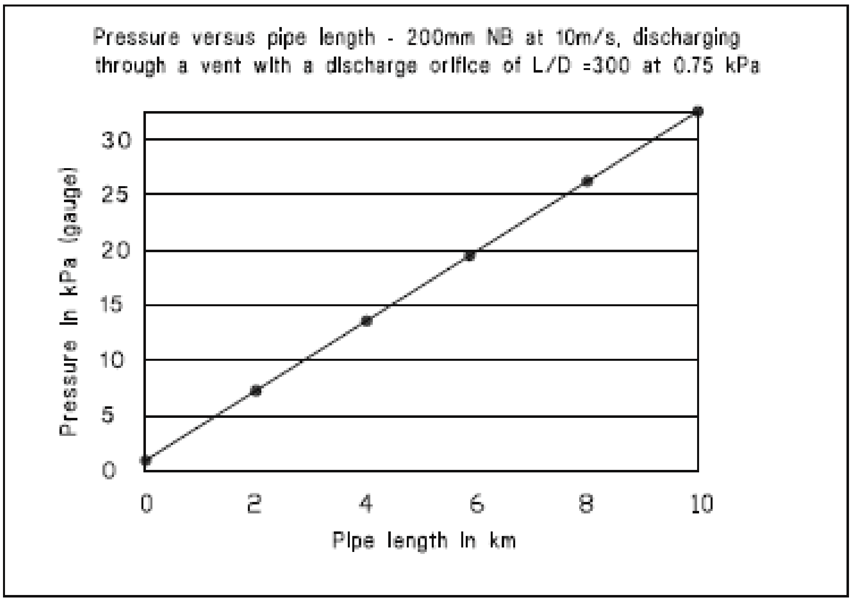


FIGURE E3 GRADUAL PURGE FOR MAINS AND SERVICES ABOVE 100 KPA—CONTROL CONNECTION MAY MAKE USE OF A METERING OR PRESSURE REGULATION SKID



Conditions for Figure E4:

Internal Diameter D Main or service Roughness	212mm 45 micron
Vent Internal Diameter with an orifice	154mm
Length of vent	4.0 m

FIGURE E4 CALCULATED INLET PRESSURE (LHS) FOR A GRADUAL PURGE FOR 200 mm NB TO ACHIEVE A VELOCITY OF AROUND 10.0 M/S THROUGH OUT THE ENTIRE PURGE

APPENDIX B – LITERATURE REVIEW - STATIC ELECTRICITY CHARGING IN PLASTIC PIPES SEPTEMBER 2014

1. Introduction

Following an incident in which gas escaping from a broken line caught fire without any obvious source of ignition, the question of the hazard presented by static electricity was revisited.

2. Literature Review

2.1 General

The issues associated with generation of static electricity in plastic piping in gas reticulation networks is well recognised and include the potential of sparks to ignite vented or escaping gas [1-12] and "pinholing" of the pipe [3, 5, 7, 12-14].

It is generally accepted that, with the possible exception of hydrogen [15], the movement of "single phase" gases through pipes does not create a significant build-up of static electric charge [16, 17], though Campoli et al [9] state that charges can be generated by "*extremely high velocity gas*" flowing through a rupture. This is also the concluded in Reference 11, AGA Purging Principles and Practice. The mechanism of such charging is attributed to frictional effects (or tribocharging) between particulates or droplets carried in the gas and the pipe inner walls [1-6, 16-18]. However, Smith [3] warns that it probably only requires minute amounts of particulate material to generate charges within a pipe.

Problems associated with static charges are commonly seen as being associated with plastic pipes, particularly polyethylene (PE), though other plastic materials, such as polyvinyl chloride (PVC), are also susceptible [3]. However, static charges may also be produced in metallic pipes if they are not earthed. Smith [5] reported measuring 10,000 volts of static on a steel line. The difference between conductive and non-conductive pipe material is that in conductive pipe material electric charges move freely the charges move freely and, provided the pipe is bonded to earth, do not build up to significant voltages. In contrast due to the extremely high surface and bulk resistivity of plastic materials such as PVC [19] and especially PE [16, 19, 20] charges are immobile and do not dissipate [3, 6, 7, 12]. Lyall [4] reported the generation of static charges exceeding 100 kV in an experimental loop made from 100 mm PE pipe.

The hazards associated with static charge on gas piping include shocks to personnel [1, 6] and the possible ignition of escaped or vented gas [1-3, 5, 6, 8] as well as pinholing [3, 5, 6, 7, 13]. It is reported [2, 3, 5, 6, 7, 12] that static charges are particularly prone to develop during "squeeze off" operations with PE due to the increased velocity of the gas near the squeeze off point. Reference 2 also cautions that the presence of particulate matter in the gas and highly turbulent flow, such as might occur at elbows and other fittings, "squeeze off" points and substantial leaks (escapes). Impingement points of a leak into dry soil or against an isolated metal fitting are also areas of risk.

Problem with static charge development on plastic pipes has led to various charge neutralisation techniques ranging from the traditional approach of using wet soapy (surfactant) and "burlap" wrap or tape to neutralise exterior charges [4, 6, 8] and sprays [21] to internal discharger (in addition to external) charge neutralisation to a proprietary "Ionix" system that is claimed to prevent the gas from giving rise to static charges [3, 5, 12].

2.2 Factors Related to Charge Development in a Gas Stream

According to Hearn [17], conditions which influence the development of static charges in gas streams are:-

- The presence of particulate matter in a gas stream
- The nature of the material
- Flow velocity
- Particle size
- Composition of duct walls
- Turbulence due to bends and constrictions etc.
- Temperature and humidity

References 9 and 11 report that the passage of high velocity *"clean"* gases can also produce static charges in plastic pipe, though at much lower potentials than would occur if particulate matter was present in the gas. Reference 11, AGA Purging Principles and Practice, states *"The steady flow of clean gas at 30 psig, free of particles, does not produce voltages of significance (400 to 500 volts)".* However, it also says that *"Up to 5,000 volts c*an *be produced by pulsing gas from no flow to full flow quickly"* Reference 11 continues *"The presence of particles in the gas stream, such as rust, sand, or dirt produce charges as high as 24 kV. The voltage is especially high in areas of turbulence, such as elbows."* Furthermore according to reference 11 *"Application of a wet cloth over the outside of the pipe causes an instantaneous reduction in the charge on both inside and outside surfaces."* The latter claim that the application of a wet cloth over the outside of the pipe causes an instantaneous reduction in the charge on both inside and outside surfaces appears to be in disagreement with references 3, 5 and 6, in which the view is expressed that neutralising charge on the outside surface of a plastic pipe does not eliminate the internal charge. In fact, Tranbarger and Stephens [6], explicitly state in relation to external charge removal practices *" ….however, this exterior treatment of the pipe does not reduce the interior charge."*

The GRI Report [6] into the occurrence of electrostatic charging of PE pipe used test loops to simulate field conditions. In these tests strong electrostatic fields were produced using gas (nitrogen or methane) containing particulate material, of which the most effective was found to be "Poly-grit" a blasting material, which is comprised of approximately 30% iron oxide. This material was also preferred because of its iron oxide content, which is similar to materials found in gas distribution pipes.

The GRI Report [6] included the following findings:-

- Squeeze-off operations increase charging of the pipe (due to increased gas flow velocities)
- Pinholes occur near tees and elbows (due to greater turbulence)
- Particulates must be present for significant flow-induced charging of PE pipe
- Neutralisation of the external charge on a PE pipe does not reduce the internal charge
- Neutralisation of the internal charge on a PE pipe does not reduce the external charge
- The presence of opposing charges in and on the pipe make quantitative measurement of charge build-up impractical with field instruments
- Field instruments measurements are also affected by moisture and contamination
- In tests charges of both polarities were generated, though when elbows were included in the rig only positive charges were observed.
- In a test loop the development of charge was unaffected whether the gas used was nitrogen or methane

- Peak voltages generated in tests were -131 kV with 100 mm pipe and -123 kV with 50 mm pipe.

Unfortunately the GRI Report [6] does not give velocities of the gas (nitrogen or methane) in the test loops. However, in one field test report with 100 mm PE pipe, of which the exposed section had been externally treated with anti-static fluid, a charge of +18.6 kV was generated by a flow of 2,832 scmh when the pipe was partially squeezed and when the Poly-grit@ was blown through the pipe. The gas appears to have been at a gauge pressure of 420 kPa (60 psi). The flow velocity of gas under the above conditions would be some 20 m/s.

The velocity of natural gas flow through an orifice at various pressures is given in Appendix B, where it is seen that even at low pressures the velocity far exceeds the abovementioned 20 m/s.

According to the Kansas Corporation Commission Utilities Division [8], the exposed ends of the plastic piping (such as at the point of a break) is the area with the greatest potential of internal static electricity (see Appendix A).

Another instance where significant static charges can be developed is where escaping gas impinges into dry soil or onto an isolated metal fitting [2]. This effect is suspected to be a significant contributor to ignitions occurring with high pressure leaks where the gas impinges onto soil.

The occurrence of pinholing [3, 5, 12-14], in which the generated charge becomes so great as to overcome the dielectric strength of the pipe material, should be taken as evidence that high levels of static electricity are being generated within network piping [3]. Reports of pinholing have only been with pipe material made from polyethylene (no reports found concerning PVC). According to Staker [14] *"The majority of occurrences have taken place when a squeeze-off unit was being used to control the flow of gas. Purging or filling of new piping systems accounted for approximately 90 percent of our failures. Discharges have occurred in a variety of sizes and manufacturers of pipe - ½-inch C.T.S. through 4-inch I.P.S. pipe with S.D.R. ranges of 10.0 to 11.5."*

2.3 Relevant Material Properties

2.3.1 Surface Resistivity

As noted above, static charges can develop in conductive pipe as well as non-conductive. However in the former case, when the pipe is earthed, the charges simply flow to ground and the pipe is effectively at zero potential. However, in highly resistive material the charges are immobile and remain for significantly long periods even after the gas flow, which generated them, has ceased.

Both uPVC and HDPE have very high surface and bulk resistances [19]. Groop *et al* put the surface resistance of HDPE at >10^{16} Ω/sq while Luttgens and Wilson [16] quote 10^{16} to 10^{17} Ω for HDPE and 10^{15}-10^{16} Ω for uPVC, both at 50% relative humidity. Vinidex [22] give the surface resistance of HDPE as >10^{17}Ω and 10^{13} to 10^{14}Ω for PVC [22]. By comparison the surface resistivity of copper is <1 Ω/sq [20].

Luttgens and Wilson [16] show a graph of developed electrical field strength vs the logarithm of surface resistivity at a separation speed of 1 m/s. The graph shows zero charge at less than 10^{12} Ω but climbs rapidly to 800 V/m for surface resistivity 10^{14} Ω. Note that some authors use Ω as the unit of surface resistivity, however, this is taken as intending Ω/sq (ohms per square) [21].

It may be noted that in some of the above references the unit of surface resistivity is given simply as ohms (Ω), while in others it is given in the units ohms per square (Ω/sq). The significance of these units are explained in reference 21.

2.3.2 Dielectric Strength

Dielectric strength of the pipe material is a measure of its resistance to pinholing. Staker [14], in reporting on instances of pinholing, reported measuring electrostatic potentials in medium density of up to 70 kV. Smith [5] and Ward [13] found pinholing to occur in PE pipe of 3.1 mm (0.122 inch) nominal wall thickness. They reported the dielectric strength of PE to be 510 V/mil (over 20 kV/mm). Plastics International report the dielectric strength of PVC to be 544 V/mil (21.5 kV/mm) but do not give a value for PE. By comparison Vinidex [22] report the respective dielectric strength of HDPE and PVC as 53 and 14 to 20 kV/mm. Given the value reported by Plastics International and the absence of pinholing in PVC pipes, the Vinidex dielectric strength for PVC value seeming surprisingly low.

A Typical channel of an electrostatic discharge which gave rise to a pinhole [5] is shown in Appendix A.

2.4 Pipe Repairs

Pipe repairs are a prime areas of concern for the development of static charges. The high flow velocity that accompanies an uncontrolled escape as well as the “squeeze off” technique used to bring the leak under control are known to be sources of serious static charges [2, 3, 5, 6, 8, 10]. Also, a large escape, in which the gas is drawn at a rate well in excess of that used in normal operation may be expected to mobilise particulate matter in the pipe and so exacerbate any static electricity problems.

2.5 *Venting*

It is recommended practice to vent gas from an earthed metal pipe or tube [1, 2, 10]. However, it is also cautioned venting of gas containing high levels of dust or scale could generate sufficient static electricity for *“an arc”* to occur from the dusty gas cloud back to the earthed pipe. [2, 10]. Australian/New Zealand standard AS/NZS 4645.1 [23] requires that a formal safety assessment shall consider the “Safe discharge of any static electricity” in relation to venting.

2.6 Handling

Apart from the flow of particulate containing gases, the handling are cleaning of plastic pipe (PE in particular) can produce electrostatic charges. According to the AGA Plastic Pipe Manual [2] charge may be generated *during “…. physical handling, of plastic pipe, during storage, shipping, installation and repairing.”* Reference 11 quantifies these charges as *“Contact between hands or clothing and the pipe can produce voltages of about 9 kV. The charges on the human body or clothing can be produced by normal walking or sliding down the sides of a ditch; these charges can then be transferred to the pipe. Removal of dirt and dust prior to joining can produce voltages of 14 kV”.*

2.7 Counteractive Techniques for Static Electricity Build-up

As noted above the traditional approach to neutralising static charges on plastic pipe in operations such as replacement or repair has been to wet the pipe and the general area preferably with a detergent containing water to improve wetting and wrap exposed pipe with conductive tape [8].

However Smith [3] and Tranbarger and Stephens [6] have pointed out the neutralising the external charge does not affect the internal charge, though this is somewhat contradicted in reference 11, as noted earlier. Tranbarger and Stephens [6] report, in GRI-92/0460, the development of equipment and procedures to neutralise internal charges. The report details a step by step procedure for repairing a section of damaged PE pipe with the recommended measures to avoid electrostatic hazards.

A spray is also marketed under the name “Statikill” that appears very effective in neutralising external charges [24], though it is not clear what its effect on internal charges is.

Smith [3, 5] reports on the *“Ionix Static Eliminator”* which is proprietary device (cartridge) installed in the gas stream and is claimed to *“change the electrical characteristics of the gas so that it no longer builds up static during passage”.* While it is not clear how such a device could in fact change the electrical characteristics of the gas, a report by Nicor Technologies indicated that it was effective in reducing the build-up of static charges [25].

3. References

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2 Plastic Pipe Manual For Gas Service, American Gas Association, 2001 p 68-70

3 D S Smith, Static electricity in PE fuel gas pipe, Pipeline & Gas Journal, December 2001

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5 D S Smith, Static Control in PE Fuel Gas Pipe http://ionixgastechnologies.com/Static%20Control%20in%20PE%20Fuel%20Gas%20Pipe.pdf

6 O Tranbarger and K W Stephens, Electrostatic discharger system for polyethylene pipes in distribution, Phase 1, GRI-92/0460, Gas Research Institute, October 1992 (includes originally separate Phase 2, showing step by step procedures)

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http://www.thefreelibrary.com/Static+electricity+in+PE+fuel+gas+pipe.+(Reducing+Danger).-a081597957

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18 Australian/New Zealand Standard AS/NZS 1020:1995 “The control of undesirable static electricity”

19 Plastics International, Material Properties http://www.plasticsintl.com/sortable_materials.php

20 E E Groop, A W Nowicki, C I Calle, C R Buhler, J G Mantovani Comparison of Surface Resistivity and Triboelectric Charge Generation Characteristics of Materials http://empl.ksc.nasa.gov/Publications/Comparison%20of%20Surface%20Resistivity.pdf

21 http://www.esdjournal.com/techpapr/ohmmtr/ohm.htm

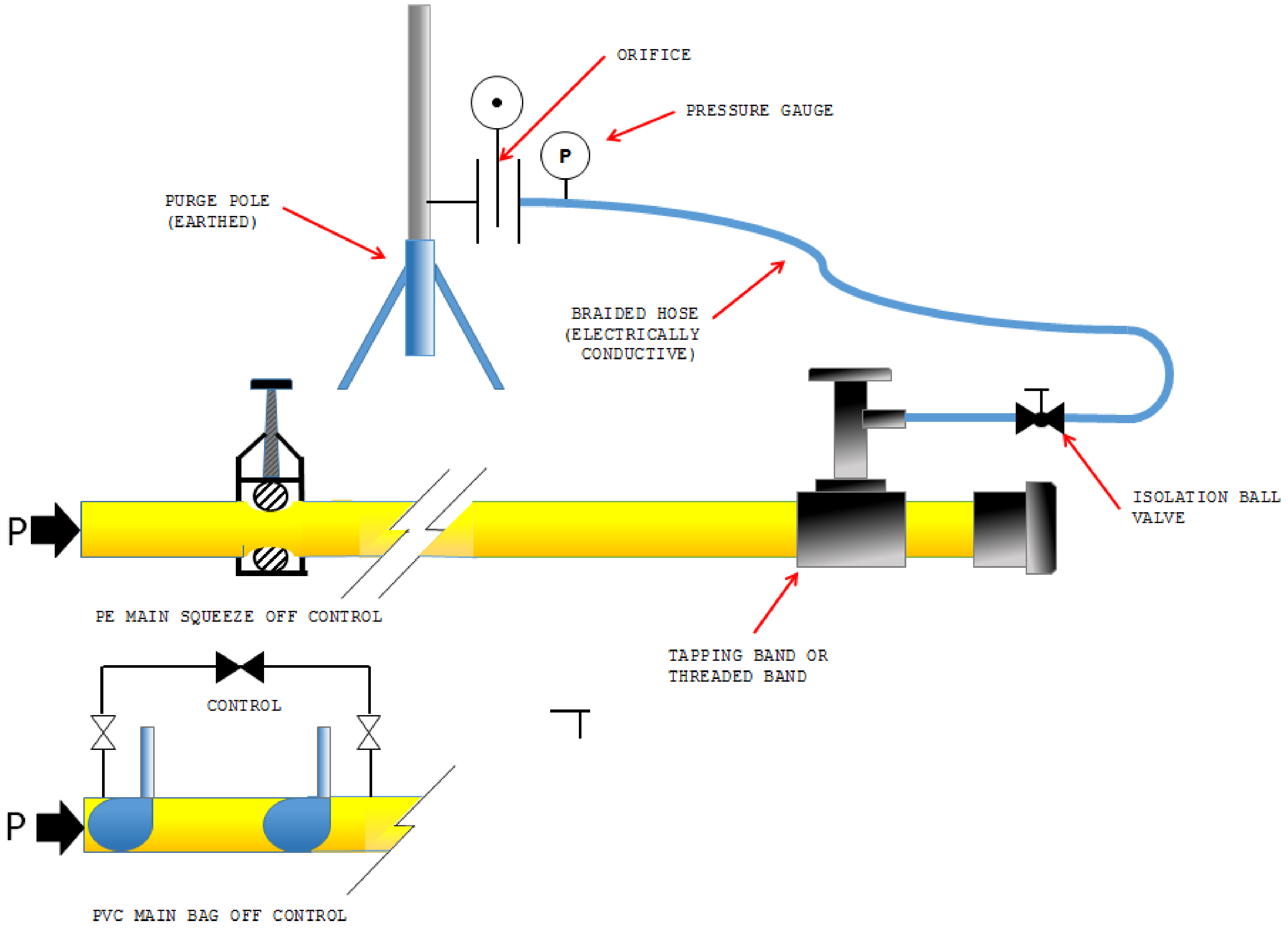
22 Vinidex specifications for PE and PVC http://www.vinidex.com.au/technical/material-properties/polyethylene-properties/ http://www.vinidex.com.au/technical/material-properties/pvc-properties/

23 Australian/New Zealand Standard AS/NZS 4645.1:2008 “Gas distribution networks Part 1: Network management” p 52

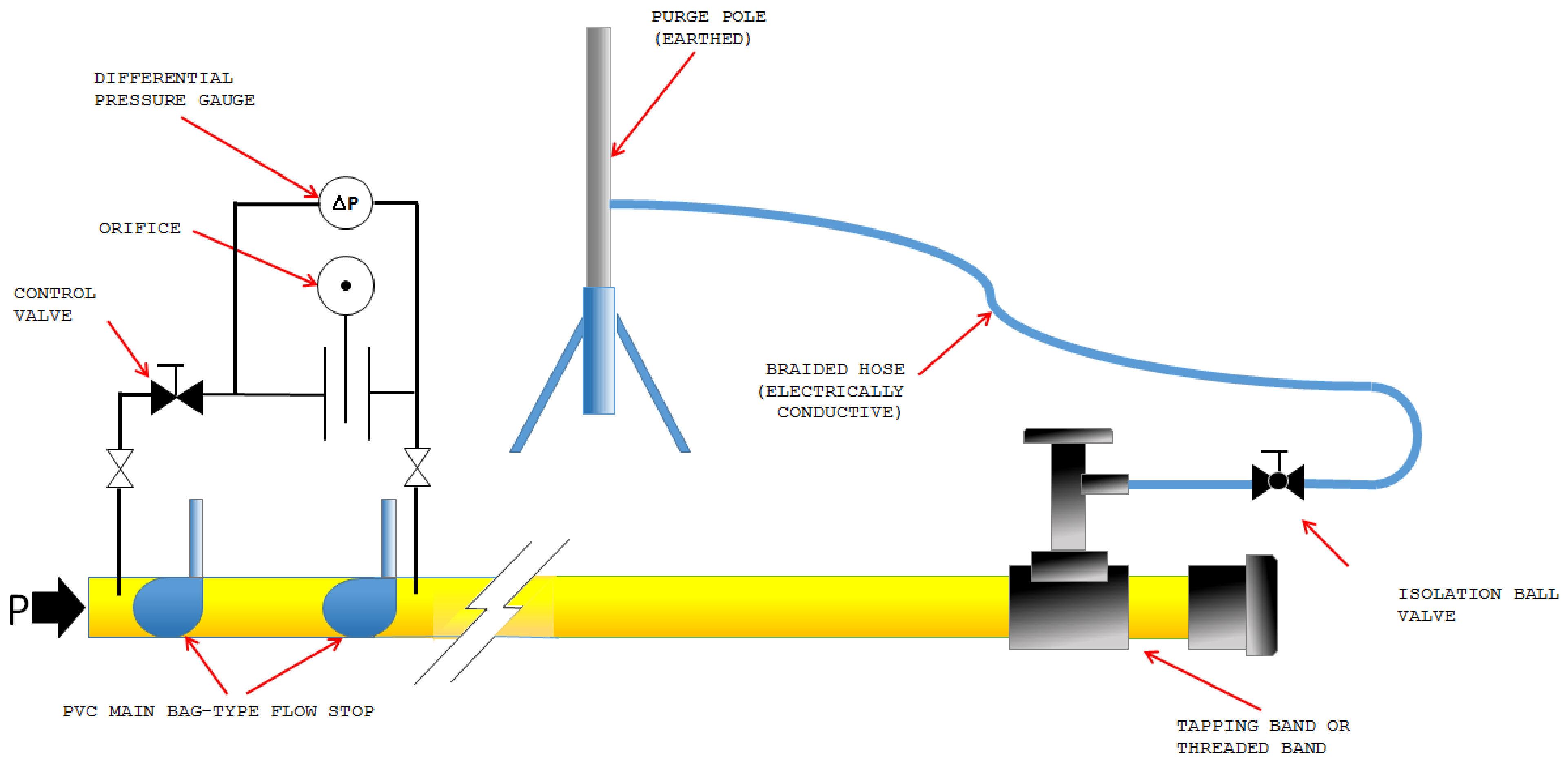
24 PERC Statikill http://statikil.com/

25 Nicor Technologies http://ionixgastechnologies.com/naturalgas_nicor.html

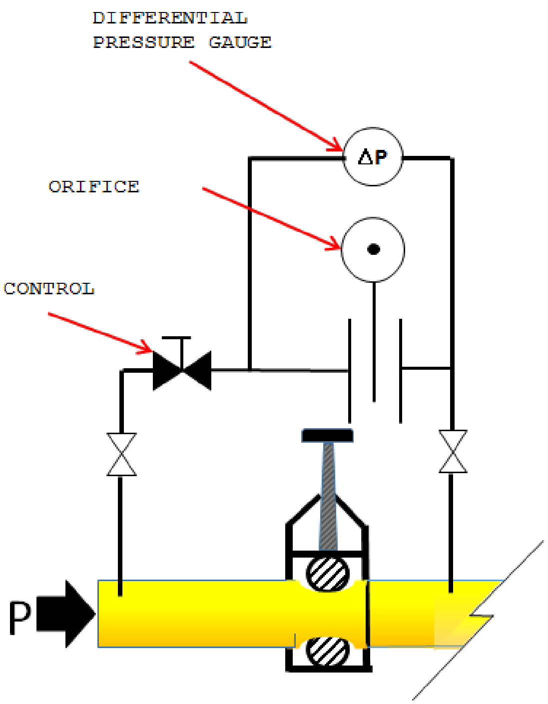
APPENDIX C1 – CONFIGURATION DIAGRAM - ORIFICE AT PURGE POLE



APPENDIX C2 – CONFIGURATION DIAGRAM - ORIFICE AT INLET

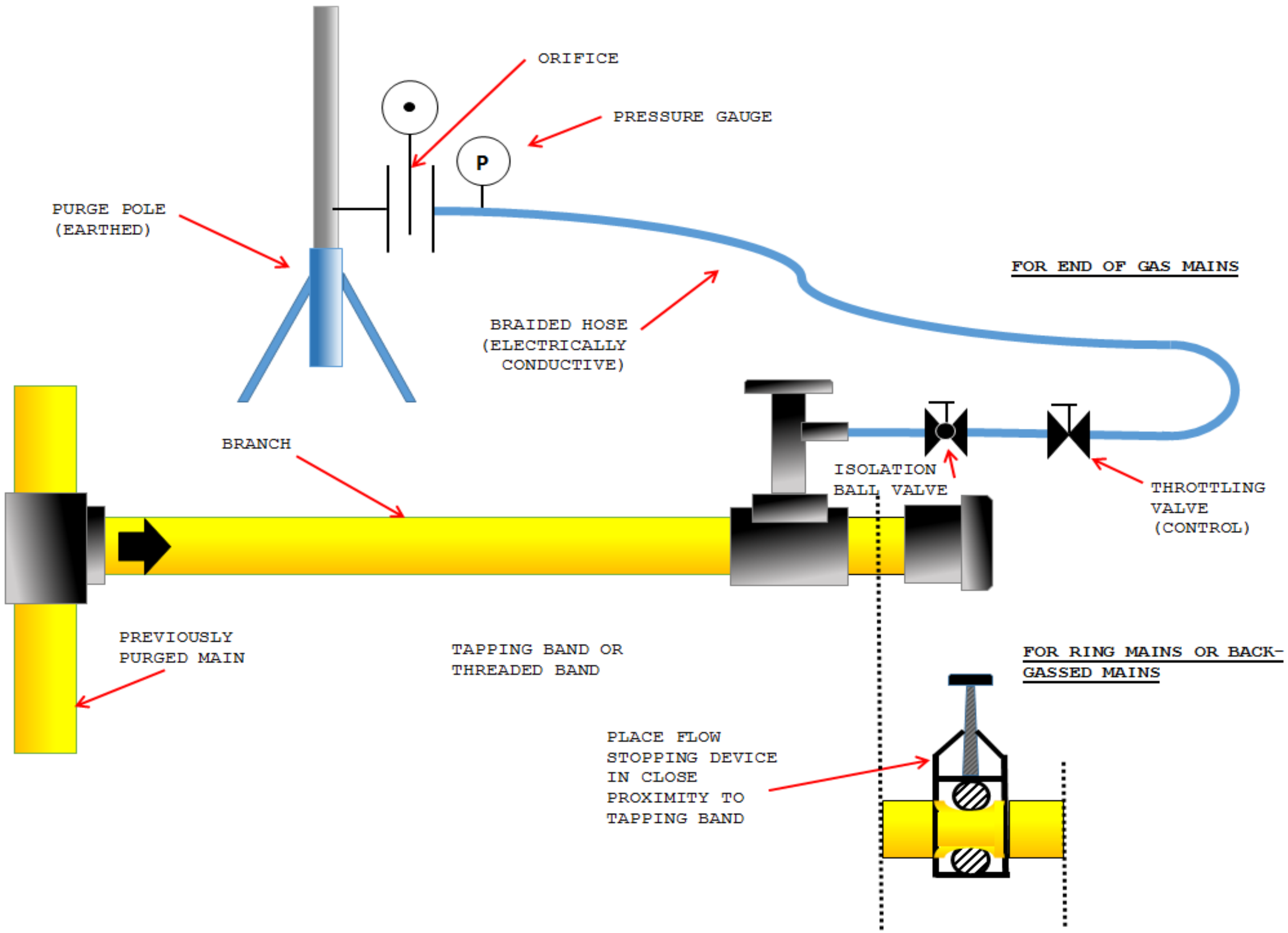


(See Overleaf for Squeeze-off arrangement)



PE MAIN SQUEEZE-TYPE FLOW STOP

APPENDIX C3 – CONFIGURATION DIAGRAM – BRANCH PURGING - ORIFICE AT PURGE POLE



APPENDIX D – ORIFICE CALCULATIONS

REFER file name: *APPENDIX D Purging Velocities ver13 (21-09-2015) - Branch Connection Added*