Assessment Tasks

Project

Introduction

Compressed air is commonly used in factories for a great variety of purposes e.g.: driving hand held pneumatic riveters, screwdrivers, wrenches, drills, grinders, polishers etc; spray painting; operating forging hammers; air jet cleaning; agitation of liquids; operation of hoists; driving linear actuators in automatic machinery; operating clutches and brakes; operating control valves. Air motor driven hand held tools, although in some cases not very energy efficient, have some advantages over their electric equivalents. These small air motor advantages include: being lighter and smaller for a given power output; being free of shock risk; and being able to stall without overheating.

In this project you will consider a factory's compressed air requirements and produce a system design to supply the compressed air. The overall project will be divided up into modular assignments, which will be progressively dealt with. For some of the plant items you will need to determine required capacity and such like and then make a catalogue selection, but for at least one item of plant, namely the air receiver, you will be designing the component itself.

Students are to work in pairs, submitting joint reports with clearly identified individual contributions. The required subdivision of contributions will be given in the assignment questions (these subdivisions are intended to give a reasonable distribution of work load and learning experiences). Some of the questions call for discussion of: the issues involved; the decisions made; and the consequences of various courses of action. These considerations are an important part of the design process and an important part of the assessment, <u>do not neglect them.</u>

Design of a Compressed Air Supply System for a Factory

Assessment Task	Assessment (%)	Submission
Part A	20%	Monday of Week 6
Part B	30%	Friday of Week 12

Project (Part A)

Load Definition and Sizing of Principal Components.

LOAD DEFINITION

The factory to be considered requires compressed air in several areas of operation: forge, fettling shop, machine shop, paint booths, assembly, and packaging. There is also a requirement for hot water in the electroplating department.

Forge

The forge contains one large pneumatically operated hammer driven by 1 double acting cylinder, piston rod at one end only, bore 500mm, piston rod diameter 125mm, stroke 1075mm. The piston executes 10 up strokes and 10 down strokes in 100 seconds then does nothing for 200 seconds, then repeats the cycle. The air is regulated to enter at 590 kPa.g. and in this machine the pressure in the cylinder may be taken to be this for the full stroke.

The tools used in the other workshops in the factory are named below together with their load factors.

Fettling Shop

30	grinders with	25% load factor
12	chippers with	75% load factor
8	medium hoists with	25% load factor

Machine shop

Blowguns, air chucks, air vices 50% load factor

Assembly shop

25	small screwdrivers with	40% load factor
8	nut setters with	25% load factor
12	steel drills with	50% load factor

Paint Shop

22 polishers with 50% load factor

20 spray painting guns with 50% load factor

20 spray painting masks with 50% load factor

Electroplating shop

No compressed air is used here but there are baths requiring hot water. The requirement is 9.0 m^3/hr of water at 55°C. Water enters the premises at 15°C.

Packaging Department

10 wood borers with 30% load factor

8 large screwdrivers with 25% load factor

3 heavy hoists with 10% load factor

The air consumption rates of the various tools, **<u>if they are operating at full load,</u>** are as given below.

- One of the grinders uses 24.0 + (Y/7.5) litres/sec of "free" air if operating at full load, where Y is the last digit of the student number of the partner whose family name has the first letter nearest the end of the alphabet. Thus Jill Zorro's student number is 3426543 therefore Y=3 hence the grinder uses [24.0 + (3/7.5)] litres/sec if at full load.
- One of the chippers uses 13.0 – (Y/9.0) of "free" air if operating at full load
- One of the steel drills uses 14.0 - (X/6.0) litres/sec of "free" air if operating at full load, where X is the last digit of the student number of the partner whose family name has the first letter nearest the start of the alphabet. Thus Bob <u>A</u>ardvark's student number is 3467314, therefore X=4.
- The woodborer uses 15.0 litres/sec of "free" air if operating at full load
- The large screwdriver uses 13.0 litres/sec of "free" air if oper'g at full load
- One of the small screwdrivers uses 7.0 litres/sec of "free" air if operating at full load.
- One of the nut-setters uses 16.0 + (X/2.0) litres/sec of "free" air if operating at full load.
- One of the spray guns uses 4.0 litres/sec of free air if operating at full load
- One of the spray masks uses 3.0 + (Y/10.0) litres/sec of free air if operating at full load.
- One of the polishers uses 10.0 - (Y/11.0) litres/sec of free air if operating at full load
- One of the medium hoists uses 16 litres/sec of "free" air if operating at full load whereas one of the heavy hoists uses 20 litres/sec of "free" air

Machine Shop

If all operating at full load, the blowguns, air chucks and air vices would use 70 litres/sec of free air, in total.

Forge

Air consumption in "free" air units is to be calculated from data given earlier.

Overall leakage

In the well maintained plant 5-10% of the supplied air is lost through leakage. For this factory a value of 70 litres/sec free air is thought to be a reasonable estimate by the factory manager.

Question 1

[Partner 1 and Partner 2 do jointly – 3.0 marks]

Clearly identify who is partner 1 and who is partner 2, underlining the first letter of your family name and the last digit of your student number.

From the data given, prepare an air consumption rate load profile graph for a typical 30 minute period. The only consumption figure that need be considered as a peak is that caused by the forge's operation. Sample calculations, showing how the figures used to generate the graph were obtained, must be provided.

COMPRESSOR SELECTION

Selecting a compressor to equal the peak flow requirement, when it is only for short duration, obviously implies a larger capital expense as far as the compressor is concerned, and larger electrical supply facilities.

Selecting the compressor on the assumption that every tool in the factory will be used at the same time and at full power will have similar consequences. Power authorities offer tariff structures to encourage reduction in peak electrical demand, and may even have penalty tariffs if the demand exceeds what was negotiated as the requirement, because demands that exceed what the local supply system was designed to handle may cause voltage drops, or may open overcurrent circuit breakers in the mains, either of which would annoy and inconvenience other nearby electricity customers.

The manager of the factory you are designing the compressed air system for is keen to have a low maximum electrical demand and has requested that a compressor and receiver combination be designed to achieve this.

Question 2

[Partner 1 and Partner 2 do jointly – 3.0 marks]

a) Determine the minimum capacity compressor that can cope assuming a storage receiver will be used. **Clearly explain your reasoning** including appropriate references to your graph in Question 1. Express your answer in terms of required free air delivery capability.

b) From the sample table of compressors provided at the e-reserve address given in Chapter 2 Appendix 2A, select a compressor that will satisfy (a) allowing for 5% possible future decay in free air delivery capability as the compressor wears. The normal working pressure required from the compressor is 690 kPa.g. The factory manager states that no future extra tools, or increase in load factor need be considered. **Discuss** the reasons for your choice including any advantages and disadvantages and any warning you think you should give the factory manager about the capacity of the machine you have chosen in compliance with his/her aforesaid statements.

c) Calculate the volumetric efficiency of the compressor you have chosen and **comment** on what other efficiency figure it would be useful to have from the makers in order to compare their product to others.

RECEIVER SIZE

The air receiver in a compressed air system has several functions namely: to reduce pressure pulsation in the piping system; to help separate water and oil mist from the air; to provide reserve capacity for times of peak load (during which time a small fall in pressure will occur); and, in the event that compressor capacity exceeds demand, to provide a buffer so that the compressor's unloading or stop/start system does not cycle too often. Your design work will concentrate now on the latter two functions.

The following pressure operating regime is to be designed for

kPa.g.	psi.g.	
?	?	Safety valve(s) discharge [? determined in a later question]
790	115	Compressor cycles off, or ceases to pump, if pressure rises to this level.
690	100	Compressor cycles on or recommences to pump if pressure falls to this level.
620	90	Pressure in receiver should not fall below this level for proper functioning of tools (given that some frictional pressure drop will occur in the piping)
590	85.5	Pressure arriving at tools should not fall below this level. (i.e. maximum pipe frictional pressure drop = 30kPa)

kPa.ab.	psi.ab.	
101.3	14.7	Atmospheric pressure

From this profile it can be seen that the compressor will normally be operating with discharge pressures ranging from 620 to 790 kPa.g. For the purposes of this assignment the volumetric efficiency can be assumed, within this pressure range (620-790), to be the same as that achieved at 690 kPa.g.

Question 3

[Partner 1 and Partner 2 do (a) jointly – 1.0 mark]
[Partner 1 and Partner 2 do (b) jointly – 3.0 marks]

a) Determine what volume receiver is necessary to cope with the peak caused by the forge. Carry out this volume determination for the compressor you have chosen in 2(b). As a preliminary to this, recall the statement above that the pressure in the receiver should not fall below 620 kPa, and carefully consider what the compressor might be doing when the forge peak commences. **Clearly explain the reasoning you have used in this volume determination, including appropriate references to the graph you prepared in Question 1.** This determination of the necessary receiver volume is to be done for:

   i. when the compressor is new

   ii. when its delivery capability has decayed by 5%

b) Consider now the receiver's ability to prevent the compressor's stop/start system from cycling too often. We are assuming for the purposes of this question that simple on/off motor control is being used – (another possibility is to "unload" the compressor by holding the suction valve open so the compressor ceases to compress the air and hence ceases to pump it through to the receiver). Large currents flow during motor start up and hence too frequent starting can lead to motor burn out so it is particularly important if the method of motor on/off control is being used, to ensure that start-ups are not too frequent.

   i. For a fixed size of receiver, comment on what would happen to the length of time between compressor starts and stops as the compressor's volumetric efficiency decays due to wear

   ii. Using the **larger** of the values of volume determined in (a) as the fixed size of receiver, determine if the receiver has sufficient capacity to ensure that the number of compressor starts in an hour is no more than 12 when the compressor is **new**. As part of this aspect of receiver volume determination: calculate the compressor's on time span and off time span. Initially you will find it helpful to consider an appropriate type of mean air demand with the forge peaks smoothed out, and then consider behaviour with the forge peaks present. Draw a graph of receiver pressure versus time for 30 minutes for the compressor in the as new state, starting with the combination of conditions of pressure at 690 kPa.g., the compressor just restarted and the forging just commenced.

COOLING OF THE AIR AND RECLAIMING OF THE ASSOCIATED HEAT

In order to minimise the work of compression compressors are usually cooled either by air or water. To improve the volumetric efficiency compression is often done in several stages and to further reduce the work the air is cooled between stages using an “intercooler.” Cooling the air also reduces the likelihood of spontaneous combustion of the hot air and carried over lubricating oil.

Due to steam and dry air partial pressure effects, the warm air leaving a compressor may reach 100% relative humidity as it cools and, and as it cools further, significant quantities of water may precipitate out. If this happens in the pipe work the water can be a nuisance with tools, so efforts are made to cool the air and separate out much of the water before it enters the pipe-work. This cooling is usually done with an “after cooler” positioned between the compressor and receiver.

All this heat that has been removed from the air can be either discarded or used for some useful purpose nearby. In this particular factory there is a demand for some hot water in the electro-plating shop which may be met to some extent by the “waste” heat from the air plant. In “Compressed Air Savings Manual” published by the Energy Conservation Programs Unit of the State Electricity Commission of Victoria, the advice is given that heat energy equivalent to up to 80% of the compressor’s electrical energy input can be recovered when it is operating on load; and using this heat water can be heated to temperatures up to 80°C.

Question 4

[Partner 1 and 2 do jointly - 2 marks]

a) From the sample table of after-coolers provided at the e-reserve address given in the Chapter 2 Appendix 2B, select an after-cooler to match the chosen compressor, and confirm that it is suitable and safe to use under the conditions you believe it has to.

For this after cooler, if water enters it at 15°C, at what temperature will the air leave it?

b) Assuming the large electric motor driving the compressor is 93% efficient determine approximately what percentage of the electroplating hot water demand can be met by heat scavenging. Determine the minimum kW rating of any supplementary heater that may be required.

PRESSURE RELIEF DEVICES

Pressure vessels filled with compressible gases or vapours can suddenly release large amounts of destructive energy if they explode due to over pressurisation or weakening of the vessel due to overheating.

Control systems aim to ensure that the source of energy causing the rise of pressure is deactivated when the pressure has reached the desired upper limit. (e.g. the compressor feeding air in to an air receiver or the gas flame heating a boiler are turned off.) However, such control systems can fail and should be backed up with pressure relief valves that will allow excess gas or vapour to escape when the pressure is getting too high. Such pressure relief valves must be able to handle the full flow being generated by the compressor or boiler.

A pressure vessel may also experience rising pressure if exposed to an unintended source of heat such as a fire and must be fitted with a pressure relief valve system that is capable of releasing sufficient air or vapour to prevent the pressure rising excessively due to this cause. In the event of an extreme fire the temperature rise of the metal from which the vessel is made may be sufficient to cause that metal to significantly weaken. To prevent explosion in such a situation a temperature activated relief device needs to be fitted, which will open at a temperature before the vessel has become too weak.

Question 5

[Partner 1 and Partner 2 do (a) jointly – 1.0 mark]
Partner 1 to do (b) (i) – 2 marks, Partner 2 to do (b) (ii) – 2 marks]

Before doing detailed calculations for this question, confirm with the lecturer or tutor that your choice of compressor and receiver size are acceptable.

From the sample table of safety valves provided at the e-reserve address given in Chapter 3 Appendix 3B select a safety valve suitable for protecting the receiver from the excessive pressures that could occur if the compressor's pressure controls failed to deactivate the compressor appropriately. Fully identify the valve and its pressure setting, and give reasons for your selection.

Relevant Clauses from AS1210 2010 include: 3.2.1.1; 8.2.1; 8.4.3; 8.4.5; 8.6.1; and 8.7.1.

(b) In the event of a fire occurring near the receiver the heat input to the vessel would cause the pressure of the air in the vessel to rise. If the compressor has also failed to turn off, the discharge capacity of the valve chosen in (a) may be inadequate to deal with this situation.

(b)(i) For the situation of a 'mild' fire, where the design strength of the vessel has not deteriorated, determine: the required rate of discharge (in kg/sec) of a pressure activated relief valve to deal with this situation; the pressure at which this flow may occur; the pressure setting at which this valve is to open, and from the sample table of possible safety valves provided at the e-reserve address given in Chapter 3 Appendix 3B, select a suitable safety valve to deal with the aforementioned flow. To carry out such a selection it will be necessary to convert the mass flow to free air volume flow in units consistent with those in the sample catalogue.

[Relevant clauses for (b) (i) from AS1210-2010 include 8.2.2; 8.7.3; 8.6.2.1; 8.6.2.2 and 8.6.2.4(c) and eqn 8.6.2.3(2).]

Assume the thickness of the corroded vessel is 10 to 12 mm for the purposes of this question. This assumption may require revision when more detailed vessel design is carried out in part B. Assume the minimum operating temperature T_0 is 12°C (285K). The vessel will be made of low carbon manganese steel boiler quality plate manufactured in accordance with AS 1548 PT 460 NR (L0) [See Table B1(B) in AS1210 2010]

(b)(ii) In the situation where the fire has caused the temperature of the vessel to be raised sufficiently to cause the design strength of the metal to be weakened, a pressure activated relief device may not provide adequate protection. Clause 8.6.2.4(b), addresses this issue, giving a method for determining the discharge capacity of <u>temperature</u> activated relief devices. Determine the required rate of discharge (in kg/sec) for such a device for your air receiver using this method. Also determine the value of the free air flow capacity that you would look for in a catalogue of such devices, were one provided, where such data was given, as is usually the case, for flows at 15°C upstream temperature.
Assume, for the purposes of this question, that the thickness of the corroded vessel is 10 to 12 mm and that there may be some flanges whose thickness is in the range 22 to 48 mm. These assumptions may require revision when more detailed vessel design is carried out in part B. Assume the design temperature T is 100°C (373K). The vessel will be made to Class 2A of low carbon manganese steel boiler quality plate manufactured in accordance with AS 1548 PT 460 NR (L0)grade.[See Table B1(B) in AS1210 2010]

DISTRIBUTION OF AIR TO TOOLS

Mechanical, civil and chemical engineers frequently have to design piping or ducting systems to distribute steam, water, air etc. Decisions that the engineer designing piping may have to address include:

(a) Deciding on pipe internal diameter.

(b) Deciding on the pipe material, and associated joining methods and materials,

(c) Deciding on the pipe thickness

(d) Deciding on the appropriate location for the pipe

(e) Deciding on the method and frequency of supports, including allowance for expansion/contraction.

(f) Deciding if the pipe should have a slope.

(g) Deciding if expansion joints are necessary for the pipe material, and expansion vessels for the fluid.

(h) Decide if thermal insulation is required

(i) Deciding on what control and processing fittings should be incorporated

Question 6 will give you practice at considering some of these issues.

Question 6

Partner 1 do (a) – 1.0 mark,

Partner 2 do (b) – 1.0 mark.

X and Y are defined below the next diagram.
If X + Y = odd number then Partner 1 and Partner 2 do (c) together – 4 marks and skip (d).
If X+Y= even number then Partner 1 and Partner 2 do (d) together – 4 marks and skip (c)

The route of the main compressed air line is shown on the next page.

a) Transfer the sketch given on the next page to your report and show on it appropriate drain positions. On a larger scale sketch show the arrangement of piping and fittings you propose using at a typical drain.

b) Noting the design pressure determined in Question 5, and referring to the data on some sample steel pipe sizes and associated pressure ratings provided at the e-reserve address given in the Chapter 4 Appendix 4 establish a suitable “class” of pipe, and state the range of sizes for which threaded fittings may be used, above which welded fittings must be used.

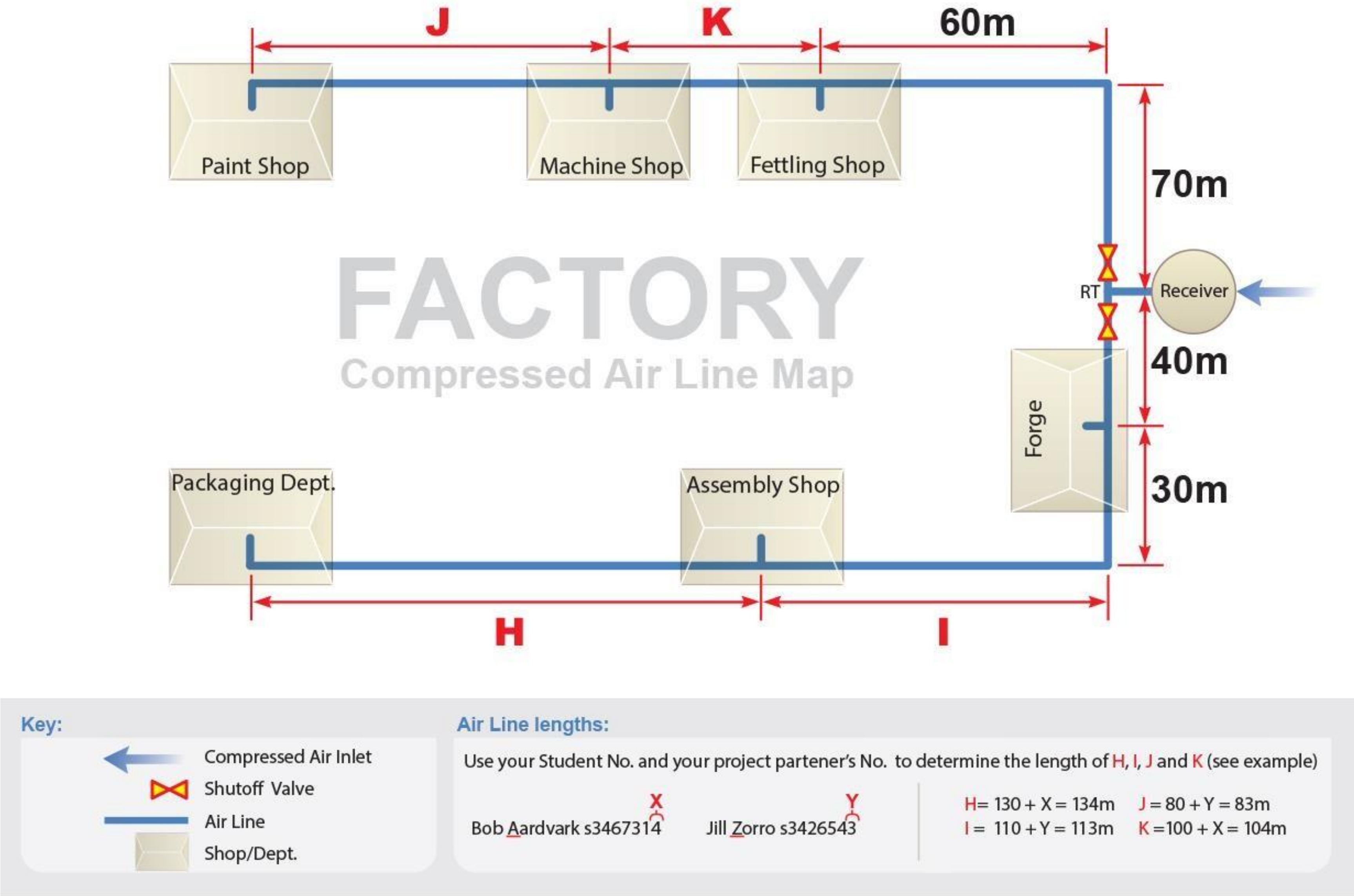

Figure 1.00 Factory Compressed Air Line Map © RMIT University, 2015

X is the last digit of the student number of the partner whose family name has the first letter nearest the start of the alphabet. Partner Bob Aardvark's student number is 3467314, therefore X=4 and hence the distance 100+X is 104 metres. Y is the last digit of the student number of the partner whose family name has the first letter nearest the end of the alphabet. Partner Jill Zorro's student number 3426543 therefore Y=3 and hence the distance 80+Y is 83metres. On your sketch clearly write your names and student numbers, underlining the first letter of your family name and the last digit of your student number.

The objective in questions (c) and (d) below is to determine appropriate internal diameters of the various sections of the main pipe. Leakage in each workshop is estimated at 11.7 litres/s free air, i.e. 70 litres/s overall.

Two commonly accepted guides for compressed air piping in factories are:

(1) The velocity in the main pipe should not exceed 6m/sec to avoid entrainment of water;

(2) The frictional pressure drop between the compressor plant and the furthermost point of use should not exceed about 30kPa, (or alternatively expressed as ~ 5% of the applied pressure.) For this assignment you are to size the pipe so that when the pressure at the branches of the receiver outlet T piece "RT" is 620 kPa (gauge), the frictional pressure drops between "RT" and the branches to packaging and paint shops are no more than 20kPa. (The remaining 10kPa of allowable pressure drop is allocated to occur within the branch lines in the various workshops). Making the pipes bigger than need be increases capital cost; making them too small means that to give the required pressure downstream at the tools, a higher upstream pressure will be necessary to compensate for the frictional losses, and this will in turn mean increase in compressor running cost. The advice at (2) represents a compromise between these two issues.

Within workshops the pipes usually terminate at chest height with an isolating valve, combined filter/water/separator/ pressure regulator/pressure gauge unit and then a hose connection fitting. If the driven machine requires lubricant to be added to the air, a drip feed lubricator is also fitted.

(c) Determine the minimum acceptable nominal bore pipe sizes for the three sections of main pipe between the relevant outlet of the tee "RT" and the branch to the packaging department. The three sections are indicated schematically on the next page. Sample calculations must be given.

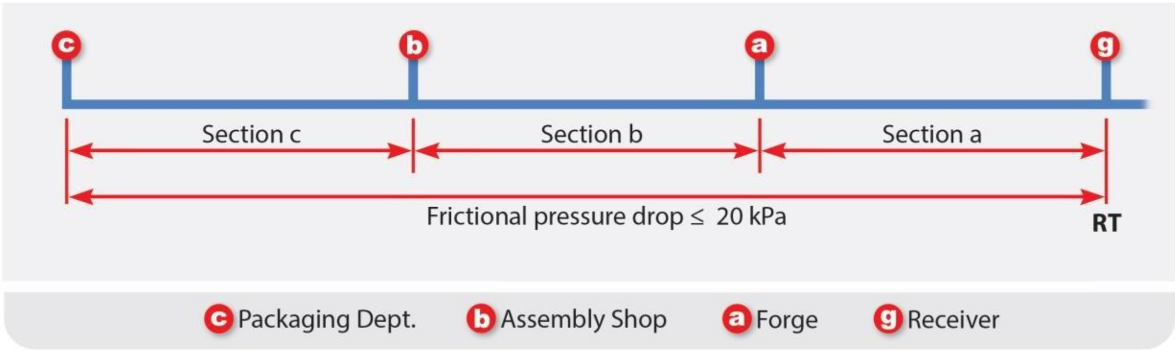

Figure 2 Main Pipe Run from Receiver Tee (RT) to Packaging Dept. © RMIT University, 2013

(d) Determine the minimum acceptable nominal bore pipe sizes for the three sections of main pipe between the relevant outlet of the tee "RT" and the branch to the paint shop. The three sections are indicated schematically below. Sample calculations must be given.

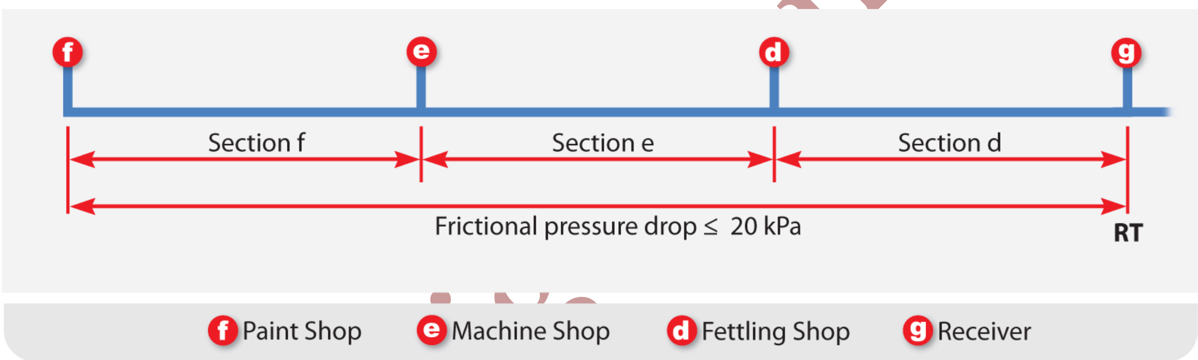

Figure 3 Main Pipe Run from Receiver Tee (RT) to Paint Shop © RMIT University, 2013

- Your report on Part A, prepared jointly with your partner and indicating on the front page who is partner 1 and 2 respectively, is to be submitted by deadline announced in Canvas. te marks will be deducted thereafter.

Logic must be clearly shown, reasons for decisions clearly stated, and sample calculations must be given (It can be dangerous to believe spreadsheets and computer programs, without doing sample calculations to check them, and results from spreadsheets alone are difficult for other engineers to check).
Writing must be clearly legible but typing is not compulsory.

<u>This concludes part A of the project-.</u>

Photocopy your report for part A of the project before you submit it, and retain the photocopy as you will need to refer to it while doing part B of the project

Project (Part B)

Detail Design of the Pressure Vessel (Air Receiver)

Students are to work in pairs, and are to submit a joint report, parts of which they are jointly responsible for and parts of which they are individually responsible for. The **Required** subdivision between partners 1 and 2, are indicated at the start of each question.

On the front of the report **clearly indicate who is partner 1 and who is partner 2 and include your student numbers.**

Submission: "Validating" calculations and flat drawings are to be submitted by **Friday, end of week 12 of semester**. Late marks will be deducted thereafter.

Broad statement of Design Requirements to be met:

- Design pressure: *** MPa
- Upper design temperature: 100°C.
- Volume: *** m^3.
- Orientation: longitudinal axis of cylinder vertical.
- Class of construction and associated inspection: 2A.
- Material: AS 1548 PT 460 NR (L0)

***: After all students have submitted part A, confirm with your lecturer/tutor that you are using the correct receiver design pressure and receiver volume.

The information in [ ] indicates some, but not all, relevant clauses from AS1210, 2010 Pressure Vessels.

Question 1

Considerations of Class and Testing of Vessel.

[Partner 1 - 2 marks].

a) What weld efficiencies may be assumed on longitudinal welds in a cylinder if class 2A construction is adopted? [Table 1.6 Row 3.3.1, Table 1.7B Row A1 and Note 1 below table; and Table 3.5.1.7]

b) Give the title and number of the two Australian standards that need to be referred to, to find out more about the testing of weld test plates and to find the required extent of non destructive examination of the welds on the vessel [Clause.5.2, Clause. 5.3, Appendix R].

c) Determine the required hydrostatic test pressure given that it will be carried out at 20^{o}C [Clause. 5.10.2.1]. For the purposes of this assignment you may assume for this steel that the design strength at 20^{o}C is the same as at 50^{o}C.

Question 2.

Considerations of Material Suitability.

[Partner 2 - 2 marks]

a) Is the design tensile strength data provided in Table B1 (B) for Carbon-manganese steel to AS1548 PT 460 at 50^{o}C consistent with the mechanical properties in the sample steel plate data provided at the e-reserve address given in Chapter 5 Appendix 5A, when this property data is combined with the factors of safety implicit in Appendix A Clauses A3 and A2 of AS1210?

b) (i)What is the upper limit of design temperatures that may be used with this steel for thicknesses less than 80mm? [C1ause.2.7.1 and Table B1 (B)]

(ii)What is the lower limit of design temperatures that may be used with this steel when it is used in an as welded and non impact tested assembly? [Fig 2.6.2A, Table 2.6.2 noting the Note 2(d)].. When determining material reference thickness, refer to Clause.2.6.4 and Table.2.6.4 row (d) (ii) and assume for the moment the shell and pipe thicknesses are in the range 10 - 16mm and flange thicknesses are in the range 22 - 48mm.

Question 3

Determination of Vessel Diameter, Length and Thickness

[Partner 1 & Partner 2 do jointly - 8 marks]

a) (i) Take the equations developed for the volume of metal in a cylindrical pressure vessel with 2:1 semi ellipsoid heads and prepare a family of graphs showing volume of metal versus cylinder diameter for a vessel of total contained fluid volume (including within heads) of *** m^3, with your design pressure of ***MPa, using a weld efficiency of 85%, with design tensile strength "f" of 115, 120, 125, 130 and 135 MPa, and with corrosion allowance of 1.0, 2.0, 3.0, 4.0 and 5.0mm. Discuss these graphs.

(ii) If corrosion internally is estimated at 0.125mm per year because of frequent wetting, determine the corrosion allowance for a 30.X year life, where X is the last digit of the student number of the partner whose family name is nearest to the start of the alphabet. (e.g. If Bob Aardvark's number is 3467314 then the design life is 30.4 years). Check if this corrosion allowance is sufficient to comply with the minimum corrosion allowance permitted by the standard for compressed air [*Cl.* 3.2.4.2].

Taking again the equations developed for the volume of metal in a cylindrical pressure vessel with 2:1 semi ellipsoid heads and prepare a graph showing volume of metal versus cylinder diameter for a vessel of total contained fluid volume (including within heads) of *** m^3, with your design pressure of ***MPa, using a weld efficiency of 85%, with design tensile strength "f" appropriate to the specified material, and with a corrosion allowance for 30.X years as found above. You may use a spreadsheet program or similar to prepare this particular graph however you must provide a sample calculation at the optimum diameter showing determination of the volume of metal and the length of cylindrical portion and the thicknesses of the cylinder and heads. This sample calculation must use the same equations that are incorporated in your spreadsheet as it is to act as a check on your spreadsheet.

(iii) Height restrictions in the factory dictate that the length of the vessel from the top of the upper semi-ellipsoid to the bottom of the other, cannot exceed 7.0 meters (some extra space below the vessel has been allowed for in setting this limit). Comment on other issues that may affect a designer's choice of diameter and length, and comment on how the graph in (ii) can help the designer in his/her deliberations on such issues.

b) From the sample table of available semi-elliptical heads provided at the e-reserve address given in Chapter 5 Appendix 5B, select semi-ellipsoidal heads that will give close to your optimal diameter. Determine the required thickness of the cylinder and head for the commercially available diameter chosen (including corrosion allowance but assuming for the purposes of this question that wind, earthquake and suchlike are not present). These calculations for the commercially available diameter may differ slightly from the optimum diameter earlier determined. From the sample table of catalogue data select a semi-ellipsoidal head thickness. The selection of thickness from the catalogue may be a stock size or a size readily manufactured to order.

You will also need to recalculate the length of the vessel appropriate to the commercially available diameter and check the length is not excessive. From the sample steel plate sizes provided at the e-reserve addresses given in Chapter 5 Appendix 5A select sheet sizes for the cylinder. Note that the semi-ellipsoidal heads from the catalogue incorporate a small cylindrical straight "flange" portion ("SF").

Question 4

Longitudinal and Circumferential Welds

[Partner 1 & Partner 2 do jointly - 1 mark]

Decide on an appropriate type of weld for the longitudinal and circumferential seams given that a weld efficiency of 85% is to be achievable and provide a dimensioned cross-sectional sketch.
[Table 1.6 (Item 3.3.1), C1ause 3.5.1 and tables and figures therein , C1ause 3.12.6]

Question 5

Inspection Opening.

[Partner 1 (a), (b), (c), (d) - 8 marks];
[Partner 2 (e), (f), (g), (h) - 8 marks];

{Note that some information on chosen flange size generated in (e) by partner 2 is required to be given to partner 1 for use in (b) in allowing for gravity loading when checking the nozzle thickness}
[Partner 2 (i) - 6 marks]

You are to design a circular inspection opening into the cylindrical portion of the vessel, with a reinforcing ring if necessary, and with a short pipe stub to crawl through, sealed at the outside with a flat cover plate bolted to a flange using **a full face gasket on the flange, and the gasket material is to be an elastomer (rubber) with fabric insertion.** Confirming calculations as to the strength of the branch pipe (a.k.a. nozzle), opening in the vessel wall, bolts, flange and cover plate are to be carried out as per the relevant clauses in AS1210. Some brief guides are as follows:

a) It is proposed to have one person-hole for the inspection opening. Is one such opening sufficient? [*Cl* 3.20.1, 3.20.4, *Ta* 3.20.4]. It is proposed that the inspection opening be via a short pipe of 610+Y mm outside diameter, where Y is the last digit of the partner whose family name is nearest to the end of the alphabet

(e.g. if Jill Zorro's student number is 3426543 the pipe outside diameter is 613mm). Is this a sufficiently large inspection opening size for a vessel of this size? [*C1* 3.20.4 and *C1* 3.20.9] It is possible to have an inspection opening of bigger diameter than the "preferred" sizes but in any case: can a hole of this size be dealt with by the rules for reinforcement given in AS1210 [*Cl* 3.18.4.1]?

b) Read clauses 3.20.10 and 3.19.10 taking particular note of 3.19.10.2 and determine the minimum nozzle thickness permitted. Assume for this assignment, that the pipe will be made of the same steel as the vessel, and that the pipe has been specially made to your diameter from a manufacturer working to Class 1 as regards any longitudinal seam in the pipe and its associated allowed weld joint efficiency. Select an appropriate pipe thickness (not necessarily the minimum permitted [see discussion in *Cl* 3.19.10]). If possible this thickness selection should be from the thicknesses of ANSI B36.10 pipe near to your diameter. ANSI pipe size data has been provided to you (refer to Chapter 6 Appendix 6C). Note that **<u>your pipe is of special individual diameter dependent on student number, and is NOT to be rounded to the nearest standard commercial diameter,</u>** however it is to be of some standard wall thickness if possible.

c) Regarding reinforcement of the opening:

(i) Calculate the "missing" area A to be compensated for [*C1*. 3.18.7.2]

(ii) Sketch on A4, and include <u>as part</u> of the calculations (i.e. not as a separate appendix), a cross section of the pipe going through the wall, with some reinforcing pad tentatively in position, (D.R. Moss in "Pressure Vessel Design Manual" recommends the thickness of reinforcing pad to be between ¾ & 1 ½ of the vessel wall thickness) Show relevant thickness T_1, t, T_{b1}, t_b, T_{r1} (in actual mm) and areas A_1 etc as per Fig 3.18.10, also include a sketch showing weld dimensions t_c, E_2, B, & F_r as defined in *Fig* 3.19.3 C (d) and determined from the legend accompanying this Figure. **<u>Take care with the differing definitions of "t"s</u>** that may occur from section to section in AS1210.

(iii) Determine the limiting distances for reinforcement [*Cl*.3.18.10.2 and 3.18.10.3], and then the available reinforcing area [*Cl.* 3.18.10.4] in the wall (A1), in the branches (A2 & A3), and the welds (A4) and hence the cross sectional area (A5) of reinforcing pad required (if any).

(iv) Determine the strength in tension (in Newtons) of the combination of all the elements contributing reinforcement to the shell, whose contribution can only be made if the welds holding them to the shell are adequate (ie those areas of reinforcing metal that are separate from the main vessel wall).

(v) Determine the strength (in Newtons) of the welds on failure path (3). ....(3) on *Fig* 3.19.2(a) or if this path is not quite relevant for your case, then on the failure path associated with "letting go" the combined elements in (iv). Sketch the failure path as part of your calculations. Check that these welds' combined strength is adequate, i.e. not less than (iv). For allowed stress in weld types refer to *C1* 3.19.3.5 and *C1* 3.5.1.4.3 paragraph 2.

d) The inspection opening is to be in the cylindrical shell as low as is permitted to enable ease of access. Establish how low it may be [*C1* 3.18.5.1, and *Cl* 3.5.1.3]

e) Refer to the Temperature/Pressure ratings table for steel flanges provided in Table 2.1 of AS2129 and to the sample tables of flanges manufactured to AS2129 provided in Chapter 6 Appendix 6D, and hence select an appropriately sized slip on plate flange, blind plate and associated bolts. Note that the slip on flange will have to be bored **to suit your pipe's special outside diameter.** This may weaken the flange a bit compared to the standard size and may reduce spanner room. The strength of your specially adapted flange and its associated bolts and cover plate are to be confirmed using the calculation methods in AS1210, as outlined below.

f)

(i) Check that the centre to centre spacing of the bolts on the pitch circle is not too great. [end of *C1* 3.21.4.1 referring to *Cl* 3.21.6.2 and *Cl* 3.21.11.2 for notation, *Table* B3 assuming flange steel is same steel as vessel, and *Table* 3.21.11.4 for properties of gasket materials when used on flanges with full face gaskets].

(ii) Check that there is adequate spanner room. (refer to the tables for spanner {a.k.a. wrench} clearances given in the e-reserve reference in Activity 6F of Topic 6)

(iii) Determine the required bolt forces both for the operating condition, and for the gasket seating condition [*C1* 3.21.11.4.1].

(iv) Confirm the adequacy of the total bolt core area assuming precision metric steel bolts to AS4291 of grade 5.6 or 8.8 are used *[C1* 3.21.11.4.2, *Table* B2, and the table in *Cl* 3.21.5.4.6]

(v) Determine the required tightening torque for the bolts. (Refer to the equation for torque in the second paragraph on page 16 of Topic 6)

g)

(i) Regarding flange stresses, determine the bolt force that may exist during seating, *[C1*.3.21.11.4.3 – *eqn* 3.21.6.4.4. (2)] and hence the radial flange stress during gasket seating [*eqn* 3.21.11.6(2) and *eqn* 3.21.11.5]. Check that the stress is not excessive [*C1* 3.21.11.7].

(ii) Regarding flange stresses, determine the bolt force allowed for during operating conditions [*Cl*.3.21.11.4.3 ⇒ *eqn* 3.21.6.4.4(1)] and hence the radial flange stress [*eqn* 3.21.11.6(2), *eqn.* 3.21.11.5]. Determine the overall tilting moment M_O [*Cl* 3.21.11.5, noting that C. Dixon's opinion, based on earlier versions of the standard, is that M_G and M_O are different. M_G is as defined in *eqn* 3.21.11.5, and M_G is used to get S_R in *eqn* 3.21.11.6(2). M_O is the sum of M_D plus M_T, and M_O is used to get S_T in *eqn* 3.21.11.6(1)] and hence the tangential flange stress [*eqn* 3.21.11.6(1)]. Check these two stresses are not excessive [*C1* 3.21.11.7].

(iii) Determine an appropriate welding arrangement for attaching the slip on flange to the pipe piece [*Cl*. 3.21.3, *Fig* 3.21.3]

h)

Confirm the adequacy of the cover plate [*C1*.3.15.3]

i)

Provide dimensioned drawings, for construction purposes, on A3 paper as follows:

(i) Local front view of the inspection opening (not the whole vessel) looking towards the cover plate and the local part of the vessel wall, and showing the sectioning plane used to generate (ii) below.

(ii) Cross section of the branch, flange, cover plate and local part of the vessel wall, showing the welds. Since the opening is symmetrical only one side need be shown.

Question 6

Supports

[Partner 1 and Partner 2 jointly do (a) (i) – 1 mark,
Partner 1 does (a) (ii) – 4 marks,
Partner 2 does (b) – 4 marks,
Partner 1 does (c) - 6 marks]

Design the lug and column part of a support system similar to that shown in *Fig* 3.24(a) using 4 lugs [*C1auses* 3.24.1, 3.24.2, 3.24.3.1, 3.24.7, 3.25].

a) Lugs with pads

Refer to the lug selection and local stress checking procedure provided at the e-reserve address given in Chapter 5 Appendix 5C. The vessel will be tested hydrostatically when new with an hydraulic oil of a density of 910 +X0 kg/m^3, where, as mentioned before, X is the last digit of the student number of the partner whose family name is nearest to the start of the alphabet. (e.g. If Bob Aardvark's number is 3467314 then the density is 910 +40 = 950kg/m^3.)

(i) Select an appropriate sized lug and pad

(ii) Check that local stresses are not excessive in the new condition when full of oil at the design pressure, which state of affairs will occur part way through the pressure build up part of the hydrostatic test. Use the limiting stress values suggested at the e-reserve address given in Chapter 5 Appendix 5C (Another check which is not part of this assignment would be in the corroded state, full of air at the design pressure. A further check which is not part of this assignment would be checking the stresses when the pressure has reached the full hydrostatic test pressure - pressure vessel codes usually allow higher stresses to exist during the hydrostatic test than during operation at the design pressure. However for simplicity in this project we will not analyse that situation and will restrict ourselves to analysis when full of liquid at the design pressure).

b) Columns.

Using square hollow section from the catalogue extracts provided to you at the e-reserve address given in Chapter 8 Appendix 8, design a column that matches the lug and satisfies the required "unity" equations for combined loading {see also AS3990 Mechanical equipment—Steelwork, *eqn's* 8.3.1.} This check will be done for the as new condition with the vessel full of the hydrostatic test oil. (Note that if a hydrostatic test was done late in the vessel's life stress check calcs on the vessel and the columns would have to be done allowing for corrosion inside the vessel and column.) The column is to have a height, measured from the base plate to the bottom plate of the lug, of 2247 + XY mm (e.g. 2247 + 43mm for Bob Aardvaark and Jill Zorro). The detailed base plate design is not part of this assignment but in real life would have to be dealt with in consultation with the civil engineer responsible for the slab/footings.

c) General Arrangement Drawing.

(i) On A3 paper, or larger if necessary, draw, showing principal dimensions of interest to the purchaser and installer:
The front view of the whole vessel looking at the inspection opening.

(ii) A side view of the whole vessel

Notes:
For this assignment loads due to wind, earthquake and unsupported or expanding pipe are taken as zero.
Other connections to the vessel which you do not have to consider for this assignment include: lifting lugs, air inlet and outlet pipes, sockets to mount safety valves, socket for pressure gauge, and socket for draining.