## CEM | CEA

# AN INTRODUCTION TO COMPRESSED AIR SYSTEMS

Learning Facilitator:

## Learning Objectives

- Explain basic compressed air terms and concepts
- Define the supply and demand sides of a compressed air system
- And identify the components of a compressed air system and explain what they do
- List the main types of compressors and identify the differences in their function
- Compare the capacity and efficiency of different types of compressors
- Identify the system performance improvement opportunities

## INTRODUCTION

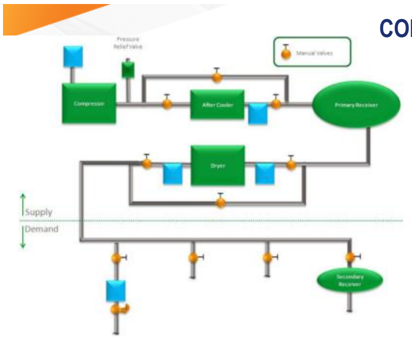
- Compressed air is widely used throughout industry.
- It is sometimes called the **"fourth utility"**, after electricity, gas and water.
- From mining, lumber and paper mills, petroleum, chemical, textile and glass production to small manufacturing plants and hotels, **compressed air** provides critical services and can often represent the majority of the facility energy costs.

## INTRODUCTION

- Many facilities cannot function without compressed air, **reliability** is paramount, but given that sound operating practices can reduce energy consumption by **20%** to **50%**, efficiency is high on the agenda.
- Compressed air is one of the most expensive utilities. There are many different types and designs of air compressors. Each is suited for different applications in buildings and industry.

J3 TRAINERS & CONSULTANTS INC.

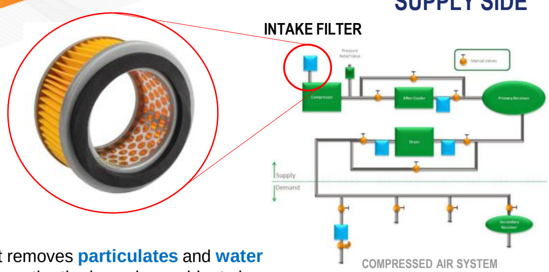
## COMPRESSED AIR SYSTEM




## SUPPLY AND DEMAND SIDE

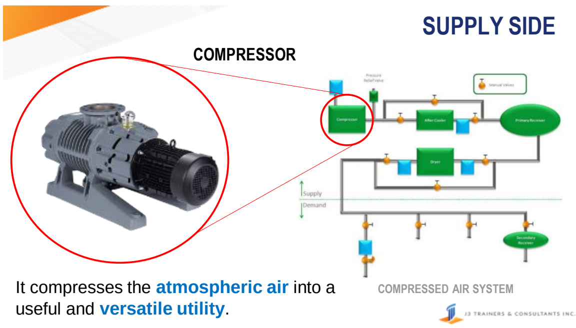
J3 TRAINERS & CONSULTANTS INC.

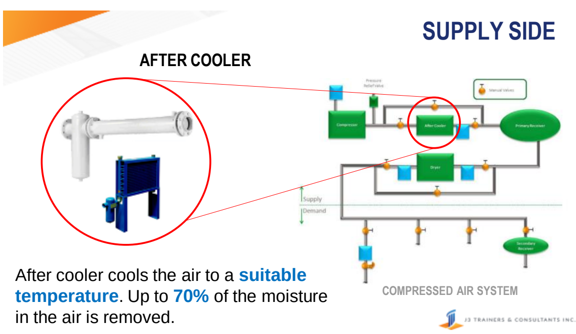
## SUPPLY SIDE

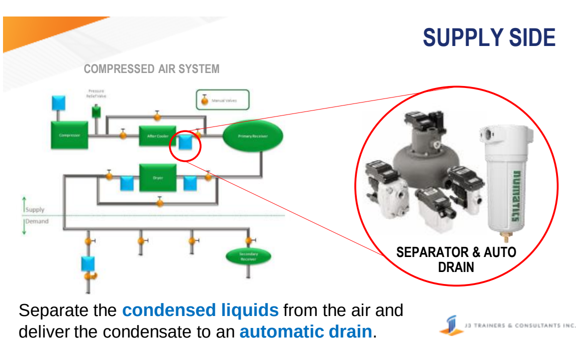



It removes particulates and water from the the incoming ambient air.

J3 TRAINERS & CONSULTANTS INC.

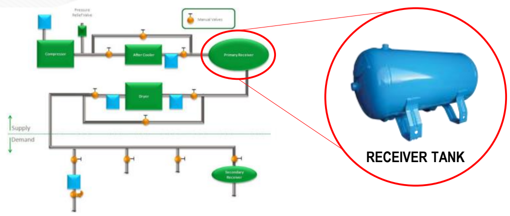

SUPPLY SIDE
COMPRESSOR
It compresses the atmospheric air into a useful and versatile utility.
COMPRESSED AIR SYSTEM
J3 TRAINERS & CONSULTANTS INC.


SUPPLY SIDE
AFTER COOLER
After cooler cools the air to a suitable temperature. Up to 70% of the moisture in the air is removed.
COMPRESSED AIR SYSTEM
J3 TRAINERS & CONSULTANTS INC.


SUPPLY SIDE
COMPRESSED AIR SYSTEM
SEPARATOR & AUTO DRAIN
Separate the condensed liquids from the air and deliver the condensate to an automatic drain.
J3 TRAINERS & CONSULTANTS INC.

COMPRESSED AIR SYSTEM

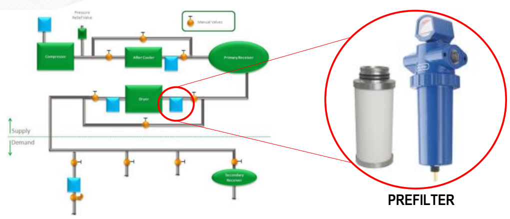
## SUPPLY SIDE




Primary receiver or tank is the **storage** for the compressed air supply. The air in this receiver has been **cooled**, and any moisture that condensed out has been removed.

COMPRESSED AIR SYSTEM

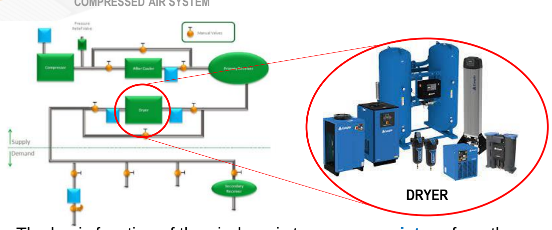
## SUPPLY SIDE




Prefilter can improves the **performance**, **reliability** and **service life** of the air dryer.

COMPRESSED AIR SYSTEM

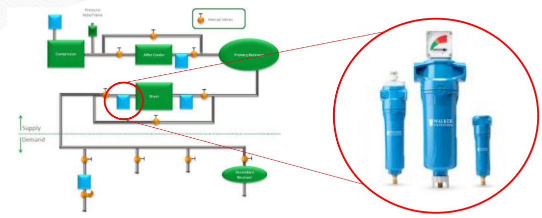
## SUPPLY SIDE




The basic function of the air dryer is to remove **moisture** from the air by cooling it with a refrigerant. Thus, the water vapor is **condensed**, and the air can be compressed.

COMPRESSED AIR SYSTEM

## SUPPLY SIDE



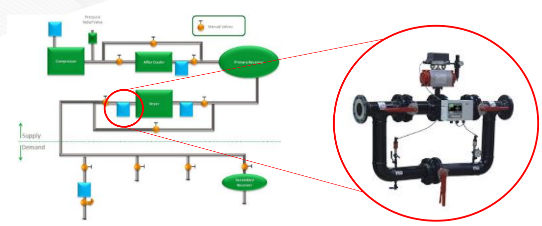
COALESCING FILTER

Coalescing filter **condenses** and removes **oil vapors**.

J3 TRAINERS & CONSULTANTS INC.

COMPRESSED AIR SYSTEM

## SUPPLY SIDE



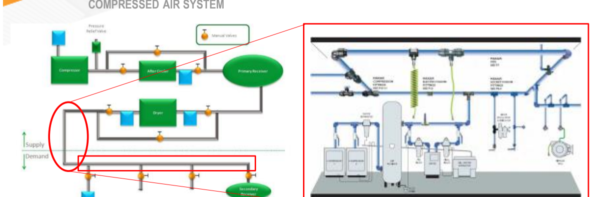
CONTROL RECEIVER/ PRESSURE FLOW CONTROLLER

A control receiver and pressure flow controller can provide **fine** pressure regulation at **minimum** pressure.

J3 TRAINERS & CONSULTANTS INC.

COMPRESSED AIR SYSTEM

## DEMAND SIDE

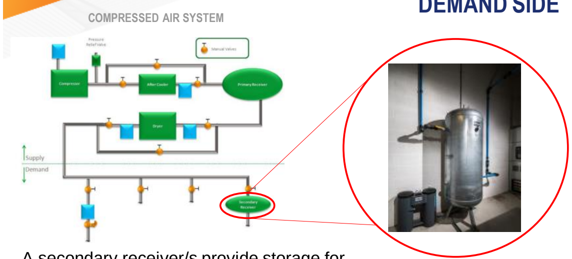


DISTRIBUTION SYSTEM/ PIPING

**Distribution system** is designed to deliver an uninterrupted supply of compressed air right where you need it.

J3 TRAINERS & CONSULTANTS INC.

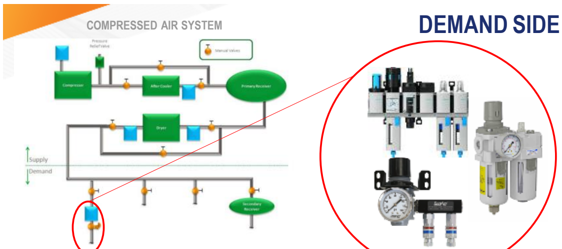
## DEMAND SIDE




SECONDARY RECEIVER

A secondary receiver/s provide storage for short-term **intermittent demand loads** in the plant.

## DEMAND SIDE




FRL's

Point-of-use FRLs (**filter, regulator, and lubricators**) are needed to ensure that every tool or process receives a clean, lubricated supply of compressed air at the proper pressure to provide **peak performance**.

## INDUSTRIAL COMPRESSED AIR SYSTEMS

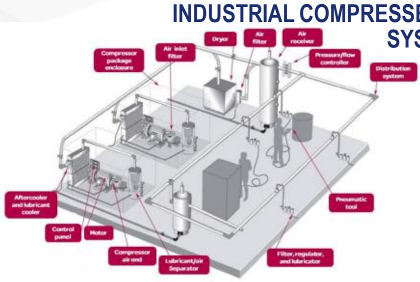
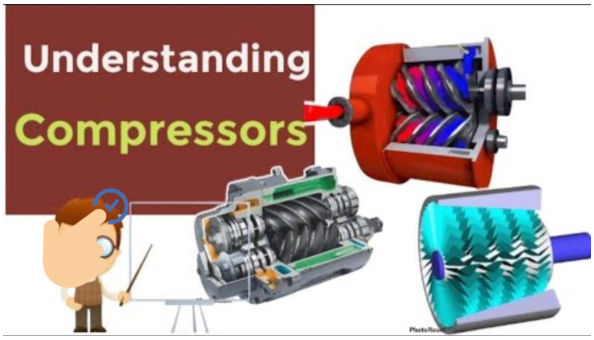
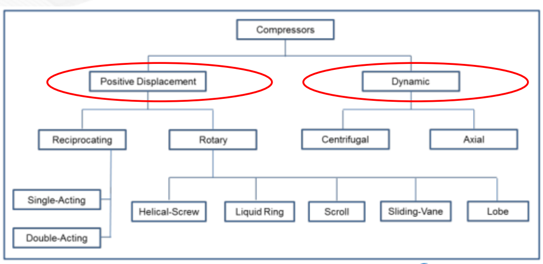



Diagram used with permission from the US Department of Energy and the Compressed Air Challenge.




## COMPRESSOR FAMILY TREE




## TWO COMPRESSOR TYPES

There are two basic compressor types: **positive-displacement** and **dynamic**.

**Positive-displacement**

**Dynamic**

## POSITIVE-DISPLACEMENT COMPRESSOR

At constant speed, the average air flow remains essentially **constant** with some minor pulsing or variations in **discharge pressure**.

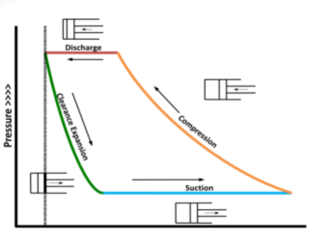
## WHAT ARE POSITIVE DISPLACEMENT COMPRESSORS

A bicycle pump is the simplest form of a positive displacement compression.

- **Single-acting compressor**
  - If only one side of the piston is used for compression.
- **Double-acting compressor**
  - If both the piston's top and undersides are used.

(The **pressure ratio** is the relationship between absolute pressure on the inlet and outlet sides).

## BASIC OPERATING CYCLE OF COMPRESSOR



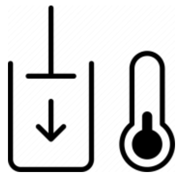

PRESSURE-VOLUME INDICATOR CYCLE

Four stages as shown in this Pressure-Volume indicator cycle:
- **Suction**
- **Compression**
- **Discharge**
- **Clearance expansion**

## HEAT OF COMPRESSION

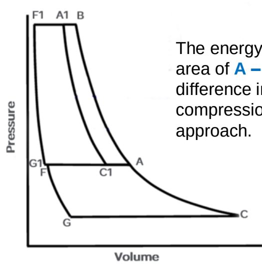
**Compressing** the air makes the molecules move more rapidly, which increases the temperature, this is called "**heat of compression**"

To improve compressor **efficiency** and limit internal temperature, the compressor package may contain more than **one stage** of compression.





## TWO STAGE COMPRESSOR




The energy saved is represented by the area of **A – B –A1 – C1**, which is the difference in profile between the **single** compression cycle and the **two-stage** approach.



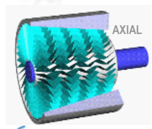
## DYNAMIC COMPRESSOR

**Dynamic compressors** impart velocity energy to **continuously** flowing air or gas by means of impellers rotating at **very high speeds**.

## WHAT ARE DYNAMIC COMPRESSORS

In a dynamic compressor, the pressure **increase** takes place while the gas flows. The flowing gas accelerates to a **high velocity** by means of the rotating blades on an impeller.

- The velocity of the gas is subsequently transformed into **static pressure** when it is forced to decelerate under expansion in a diffuser.
- Depending on the main direction of the gas flow used, these compressors are called **radial** or **axial** compressors.


J3 TRAINERS & CONSULTANTS INC.

## SELECTION CRITERIA OF A COMPRESSORS

Selecting the right compressor depends on requirements for:

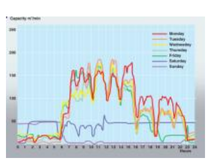
1. Capacity
2. Pressure
3. Efficiency at full, partial and no load
4. Noise level
5. Physical size
6. Water and Oil carry-over
7. Vibration
8. And Maintenance

J3 TRAINERS & CONSULTANTS INC.

## SELECTION CRITERIA OF A COMPRESSORS

Capacity

Choose a compressor that can handle the volume of air or gas needed for your application, measured in CFM or L/s, to avoid inefficiency or shortfall



J3 TRAINERS & CONSULTANTS INC.

Pressure

## SELECTION CRITERIA OF A COMPRESSORS

Select a compressor that delivers air or gas at the required force, in PSI or bar, to ensure it's neither too weak nor too strong for your tools or processes.

| Description | Pressure drop bar |
|---|---|
| End user | 6 |
| Final filter | 0.1–0.5 |
| Pipe system | 0.2 |
| Dust filter | 0.1–0.5 |
| Dryer | 0.1 |
| Compressor regulation range | 0.5 |
| Compressor max. working pressure | 7.0–7.8 |

J3 TRAINERS & CONSULTANTS INC.

Efficiency at Load

## SELECTION CRITERIA OF A COMPRESSORS

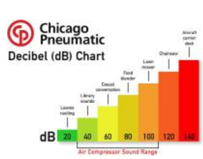
Opt for a compressor that uses energy effectively whether running at maximum, variable, or no load to save on electricity costs.

J3 TRAINERS & CONSULTANTS INC.

Noise Level

## SELECTION CRITERIA OF A COMPRESSORS

Consider a compressor with a low decibel rating to protect hearing and minimize disturbance in the workplace




J3 TRAINERS & CONSULTANTS INC.

## SELECTION CRITERIA OF A COMPRESSORS

Physical Size

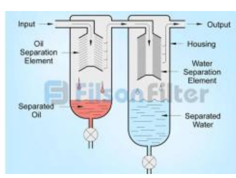
Ensure the compressor fits in the available space, with compact options for tight areas and larger models for more flexibility in capacity and features

J3 TRAINERS & CONSULTANTS INC.

## SELECTION CRITERIA OF A COMPRESSORS

Water and Oil Carry Over

To prevent moisture damage, systems include aftercoolers, dryers, and separators. To avoid oil contamination, especially in sensitive industries, oil separators, filters, and oil-free compressors are used.




J3 TRAINERS & CONSULTANTS INC.

## SELECTION CRITERIA OF A COMPRESSORS

Vibration

Go for a compressor with minimal vibration to reduce wear and annoyance, with proper installation to dampen any remaining vibration.

J3 TRAINERS & CONSULTANTS INC.

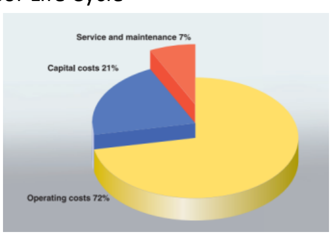
## SELECTION CRITERIA OF A COMPRESSORS

Maintenance

maintenance is the routine process of inspecting, servicing, and repairing equipment to ensure it operates efficiently and has a long service life. Good maintenance practices can prevent breakdowns, reduce energy consumption, and minimize the risk of contamination in the compressed ai

J3 TRAINERS & CONSULTANTS INC.

## Compressor Life Cycle




J3 TRAINERS & CONSULTANTS INC.

## 12 SYSTEM PERFORMANCE IMPROVEMENT OPPORTUNITIES

**1. Analyzing Compressed Air Needs**

Reviewing and understanding the specific requirements for compressed air in terms of volume, pressure, and quality for different uses within the facility.

**2. Potentially Inaappropriate Uses of Compressed Air**

Identifying processes where compressed air might not be the most energy-efficient or not properly used

J3 TRAINERS & CONSULTANTS INC.

## 12 SYSTEM PERFORMANCE IMPROVEMENT OPPORTUNITIES

**3. Compressed Air System Leaks**

Detecting and repairing leaks which can be a significant source of energy waste in compressed air systems.

**4. Pressure Drop and Controlling System Pressure**

Managing pressure levels throughout the system to ensure efficiency, as pressure drops can lead to energy loss and system stress

J3 TRAINERS & CONSULTANTS INC.

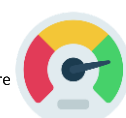
## 12 SYSTEM PERFORMANCE IMPROVEMENT OPPORTUNITIES

**5. Compressed Air System Controls**

Implementing and optimizing controls that can effectively manage the operation of compressors based on demand

**6. Compressed Air Storage**

Ensuring that there is adequate storage capacity to meet demand peaks without excessive compressor cycling or pressure variations.



J3 TRAINERS & CONSULTANTS INC.

## 12 SYSTEM PERFORMANCE IMPROVEMENT OPPORTUNITIES

**7. Proven Opportunities at the Component Level:**

Identifying and implementing improvements in individual components of the compressed air system that have been successfully used in the industry.

**8. Maintenance of Compressed Air Systems for Peak Performance**

Regular and proper maintenance to ensure the compressed air system is operating at its optimal performance.

J3 TRAINERS & CONSULTANTS INC.

## 12 SYSTEM PERFORMANCE IMPROVEMENT OPPORTUNITIES

**9. Heat Recovery and Compressed Air Systems**

Utilizing the heat generated by the air compressors for heating spaces or processes, which can improve overall energy efficiency

**10. Baselining Compressed Air Systems**

Establishing a performance benchmark for the compressed air system to measure improvements and efficiency over time.

J3 TRAINERS & CONSULTANTS INC.

## 12 SYSTEM PERFORMANCE IMPROVEMENT OPPORTUNITIES

**11. Compressed Air System Assessments and Audits and Selecting a Service Provider**

Conducting thorough assessments and audits of the system to identify areas for improvement and choosing the right service provider for these tasks.

**12. Compressed Air System Economics and Selling Projects to Management**

Understanding the financial aspects of operating and improving compressed air systems and effectively communicating these to management for approval and investment in optimization project

J3 TRAINERS & CONSULTANTS INC.

## KNOWLEDGE REVIEW

(Select the best answer)

1. What are the two basic types of compressors?

A) Positive-displacement and dynamic

B) Rotary and reciprocating

C) Axial and centrifugal

D) Single-stage and multi-stage

## KNOWLEDGE REVIEW
(Select the best answer)

2. Which of the following is a selection criterion for choosing the right compressor?

A) Temperature

B) Color

C) Humidity

D) Capacity

## KNOWLEDGE REVIEW
(Select the best answer)

3. What are the two basic sub-types of positive displacement compressors?

A) Rotary and axial

B) Reciprocating and dynamic

C) Centrifugal and screw

D) Reciprocating and rotary

## KNOWLEDGE REVIEW
(Select the best answer)

4. Which type of compressor resembles a bicycle pump or piston?

A) Centrifugal compressor

B) Axial compressor

C) Positive Displacement compressor

D) Dynamic compressor

## KNOWLEDGE REVIEW
(Select the best answer)

5. It removes particulates and water from the incoming ambient air

A) Intake Filter

B) Dryer

C) Air Receiver

D) Drain

## KNOWLEDGE REVIEW

A gas undergoes an isobaric (constant pressure) expansion from a volume of 3 cubic meters ($m^3$) to 8 cubic meters ($m^3$) at a constant pressure of 150 kPa. Calculate the work done by the gas during this expansion process.

Use the formula for work done during an isobaric process: $W = P \cdot \Delta V$

## Sample

Air is flowing through a horizontal pipe with a diameter of 8 cm at a velocity of 5 meters per second (m/s) and 6 bar working pressure. Calculate the volume flow rate of the air in cubic meters per hour ($m^3$/hr).
Use the formula for the volume flow rate: $Q = v \cdot A$,

## Sample Design :

Calculate the compressor capacity , tank capacity and pipe size for a production system that has a nominal capacity of:

$$V_N = \mathbf{55}\ \frac{\boldsymbol{m^3}}{\boldsymbol{min}}$$

Conditions:

Maximum ambient temperature: 35°C
Ambient pressure: 1 bar(a) Humidity: 60%
Pipe Length : 50 meters

J3 TRAINERS & CONSULTANTS INC.

## Sample Design

Convert the Nominal Volume to Free Air Delivery to total compressor capacity

$$\frac{P_N V_N}{T_N} = \frac{P_{FAD} V_{FAD}}{T_{FAD}}$$

$$V_{FAD} = \frac{P_N V_N T_{FAD}}{T_N P_{FAD}}$$

$$V_{FAD} = \frac{P_N V_N T_{FAD}}{T_N P_{FAD}}$$

$$V_{FAD} = \frac{1.013x\ 55x\ (273+35)}{(1)x(273+0\ )}$$

$V_{FAD} = \mathbf{63}\frac{\boldsymbol{m^3}}{\boldsymbol{min}}$ is the total compressor capacity **, around 11 unit of 37 kw compressor.**

J3 TRAINERS & CONSULTANTS INC.

## Sample Design

Calculate the Air Receiver Tank and Pipe Size

**AIR RECEIVER TANK SIZING**

**AS PER RULE OF THUMB : IS-7938-1976 :**

**TANK VOLUME** (Minimum - m3) = (1/10) x **AIRCOMPRESSOR CAPACITY** *(m3/min-FAD)*

**TANK VOLUME** (Maximum - m3) = (1/6) x **AIRCOMPRESSOR CAPACITY** *(m3/min-FAD)*

**AS PER ISO :**

**TANK VOLUME** = (0.25 x cmm x Pi x To) / [ $f_{MAX}$ x (Pu-PL) x Ti ]

**Where :**

cmm = m3/min (FAD)
Pi = Absolute inlet pressure of aircompressor (1.0 bar)
Ti = Absolute inlet air temperature of aircompressor (35+273 = 308 K)
To= Absolute outlet temperature of aircompressor or air temp at the tank (30+273 = 303 K)
Pu - $P_L$ = Difference of unload and load pressure (1.0 bar) Specs ; 0.5 - 1.0 bar
$f_{MAX}$ = maximum cycle frequency of load - unload (1 cycle / 0.50 minute)

**Pipe Size : D (Diameter-inch)**

$$= \left[\frac{cmm^{1.85} \times L}{129 \times \Delta P \times Po}\right]^{1/5}$$

cmm = $m^3$/min (FAD)
L = Total pipe length, m
Po = Abs.outlet press.,(Pg+1.0) bar
ΔP = Press.drop, bar

J3 TRAINERS & CONSULTANTS INC.

## Sample Design

Calculate the Air Receiver Tank

$$V_{tank} = \frac{0.25xV_{fad}xP_{inlet}xT_o}{f_{max}x(P_u - P_l)xT_i}$$

$$V_{tank} = \frac{0.25x63x1x(273+30)}{\frac{1}{0.5}x1x(273+35)}$$

$$V_{tank} = \frac{0.25x62.9x1x(273+30)}{\frac{1}{0.5}x1x(273+35)}$$

$$V_{tank} = \frac{0.25x63x1x(273+30)}{\frac{1}{0.5}x1x(273+35)}$$

$$\boldsymbol{V_{tank} = 7.7m^3 or\ 8m^3}$$

Calculate the Pipe Size

$$D_{pipe} = \left(\frac{V_{fad}{}^{1.85}x\ L}{129xP_{drop}xP_o}\right)^{1/5}$$

$$D_{pipe} = \left(\frac{63^{1.85}x\ 50}{129x0.05x7}\right)\text{^}0.2$$

$\boldsymbol{D_{pipe}}$ = **6 inches**

J3 TRAINERS & CONSULTANTS INC.

Thank You!