PUMPS and HYDRAULICS

Student Notes

Department of Fire Services
Massachusetts Firefighting Academy

Firefighter Skills Training Group
PO Box 1025 - State Road
Stow, MA 01775
978-567-3200

2 – (Parallel) 2-1/2" Lines

Divide total flow in half, calculate flow on one line.

1 – 2-1/2" and 1 – 3" Line

Divide total flow in half, drop the last digit, and subtract 15.

Example: 500 = 250
2 -15
10 PSI

Nozzle Pressures Hand Lines

Solid Stream	50 PSI
Combination	100 PSI
Low Pressure Comb.	50 PSI
Low Pressure Comb.	75 PSI

Heavy Streams

Solid Stream	80 PSI
Combination	100 PSI
Low Pressure Comb.	50 PSI
Low Pressure Comb.	75 PSI

STATIC PRESSURE: Pressure on the compound gauge with no water flowing.

RESIDUAL PRESSURE: Pressure on the compound gauge with water flowing. The remaining water available.

Static/Residual Rule

Pressure drop from 0 to 10%:
3 times the present flow available
Pressure drop of 10% to 15%:
2 times the present flow available
Pressure drop of 15% to 25%:
1 times the present flow available
Pressure drop of more than 25%:
Minimal flow available

Rating of Pump at Draft

100% @ 150 PSI
70% @ 200 PSI
50% @ 250 PSI

Flow From Solid Stream Tips Hand Lines

Tip Size	Flows
7/8"	150 GPM
15/16"	180 GPM
1"	200 GPM
1-1/8"	250 GPM
1-1/4"	300 GPM

Flow From Heavy Stream Appliance Tips

Tip Size	Flows
1-1/4"	400 GPM
1-3/8"	500 GPM
1-1/2"	600 GPM
1-3/4"	800 GPM
2"	1000 GPM

Appliance Losses

Heavy Stream start at	+10 PSI
Wyes	+5 PSI
Siamese	+5 PSI

RULE OF THUMB – FIREGROUND FRICTION LOSS

FLOW	FL/100'
1-1/2"	
50 GPM	10 PSI
80 GPM	20 PSI
100 GPM	30 PSI
125 GPM	50 PSI

FLOW	FL/100'
1-3/4"	
100 GPM	15 PSI
125 GPM	25 PSI
150 GPM	30 PSI
180 GPM	40 PSI
200 GPM	60 PSI

FLOW	FL/100'
2"	
125 GPM	10 PSI
150 GPM	15 PSI
200 GPM	25 PSI
250 GPM	40 PSI
300 GPM	55 PSI

2-1/2"

Drop the last digit of the flow, subtract ten from that number.

Example: 250 GPM
-10 GPM
15 PSI/100'

(Above 399 gpm, just drop the "0")

3"

Determine the flow in hundreds of gallons per minute and square the first digit.

Example: 300 GPM
3 x 3 = 9 PSI / 100'

FLOW	FL/100'
4"	
500 GPM	5 PSI
700 GPM	10 PSI
750 GPM	12 PSI
1000 GPM	20 PSI
1250 GPM	30 PSI

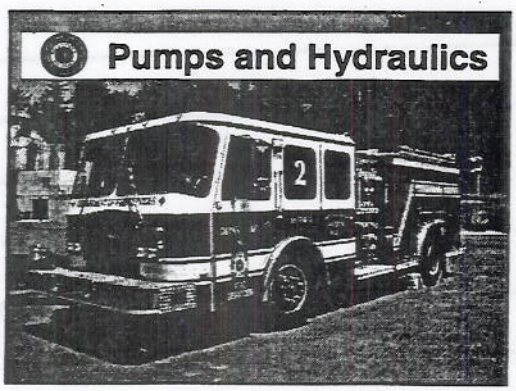
FLOW	FL/100'
5"	
500 GPM	2 PSI
1000 GPM	5 PSI
1250 GPM	10 PSI
1500 GPM	15 PSI
2000 GPM	20 PSI

Efficient Carrying Capacity

Hose Size	Flows
1-1/2"	100 GPM
1-3/4"	150 GPM
2"	200 GPM
2-1/2"	300 GPM
3"	500 GPM
4"	1000 GPM
5"	2000 GPM

Always maintain a residual pressure of no less than 20 PSI

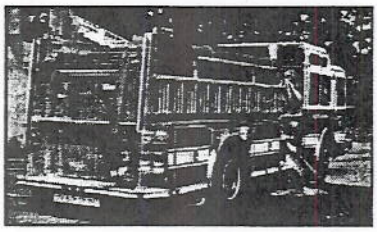
Forward Pressure –5 PSI per 10ft
Back Pressure +5 PSI per 10ft



Inspection, Maintenance, and Testing

This module will give the student an understanding of daily, weekly and annual testing and inspection of apparatus

Maintenance involves the apparatus and all equipment carried on the piece



Maintenance:

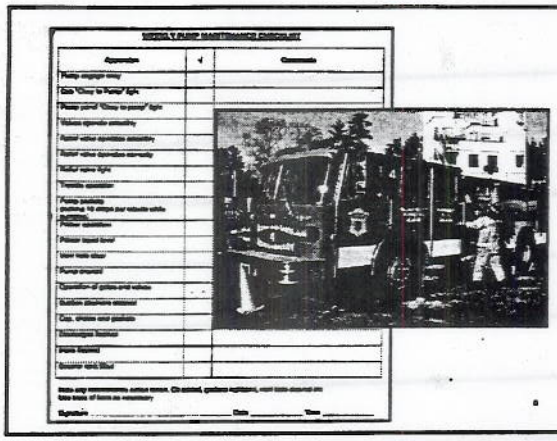
- Improves reliability
- Reduces problems
  - Repair costs
  - Downtime for repairs

Documentation

- Details the history of the apparatus
  - Identifies problems
  - Shows the need for repair or replacement
  - Tracks the cost of maintenance
- Inventory of equipment
- Records are required by ISO for rating purposes

Daily Inspection

Engine Oil Level	Fuel Level
Radiator Coolant	Water Tank Level
Batteries	Tires
All Lights	Air System Pressure
Horn and Siren	Equipment



Weekly Inspection

Transmission Oil Level	Check for Loose Nuts, Pins etc.
Power Steering Fluid	Start and Run Motor Driven Equipment
Hydraulic Brake System	Check Operation of Pump
Air Brake System	Equipment on Apparatus
Check All Engine Belts	Ladders
Battery Terminals / Cables	Tools
Operate Valves in Cooling System	SCBA
Check Drains and Hose Connections	Salvage Equipment

Pump Theory

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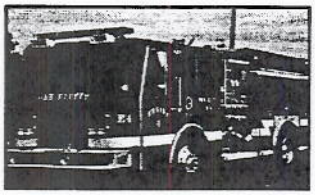
Functions of a Fire Dept. Pumper

- Provides Water for Firefighting
- Controls Water
- Source of water to supply pumpers at the proper pressure



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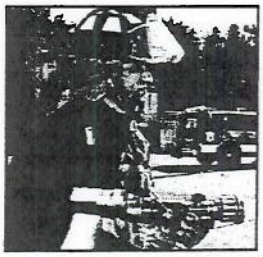

Provides Water for Firefighting

- Handlines
- Master stream appliances
- Supplement sprinkler system
- Supplement standpipe system
- Relay pumping to other apparatus

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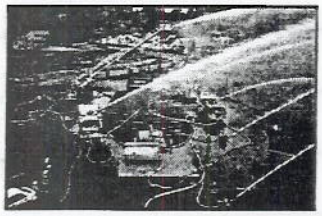
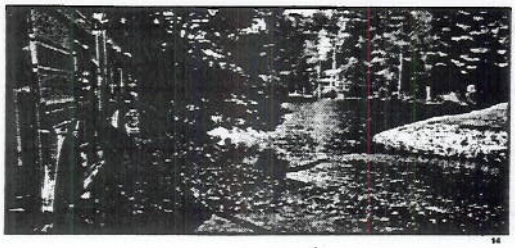
Controls Water



- Friction loss
- Back pressure
- Forward pressure
- Excessive line pressure when other lines shut down
- Increase pressure

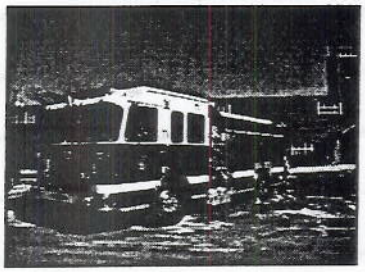
Water Sources

- Tank Supply
- Pressure Source
- Hydrants
- Dry Hydrants
- Static Sources



Types of Pumps

- Rotary Vane
- Centrifugal



Rotary Vane Pump

- Used as a priming device
- In a cycle, the rotor turns, and the vanes advance outward
- Space between the rotor and housing is filled with water
- Vanes then force air out the discharge

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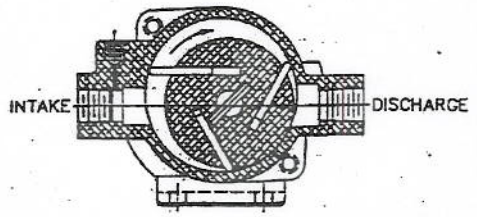
Rotary Vane Pump



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Centrifugal Pump

- Spinning action creates outward force
- An impeller is used
  - Water enters the eye and is thrown outward

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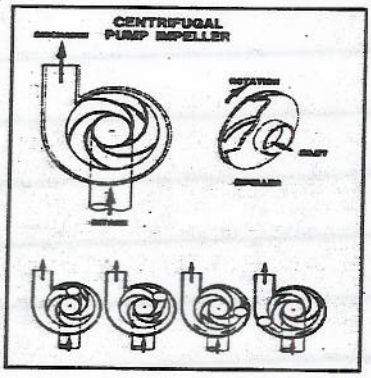


Single Stage Pump

- Has one impeller
  - Total flow and pressure depend on engine speed
- May have a single or double eye in the impeller
- Greatest efficiency is at or near capacity
- More common and simpler to operate, purchase, and maintain

Two Stage Pump

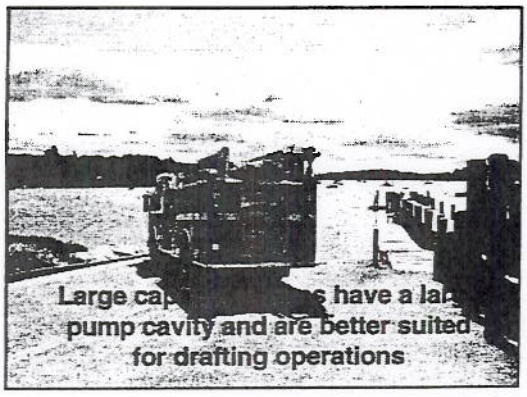
- Also known as series/parallel or pressure/volume
- Has two impellers on a single shaft
- Two modes of operation

Series/Pressure or Parallel

- Water flows through each impeller in series/pressure
- Pressure is increased by each impeller
- Results in higher pressure and lower volume
- Pressure setting is used for flows up to 50% to 70% of pump capacity

Parallel or Volume

- Both impellers are working, but not in series
- Water passes through either impeller, but not both
- Results in greater volume and lower pressure
- Used for flows greater than 50% of pump capacity



Class Ratings

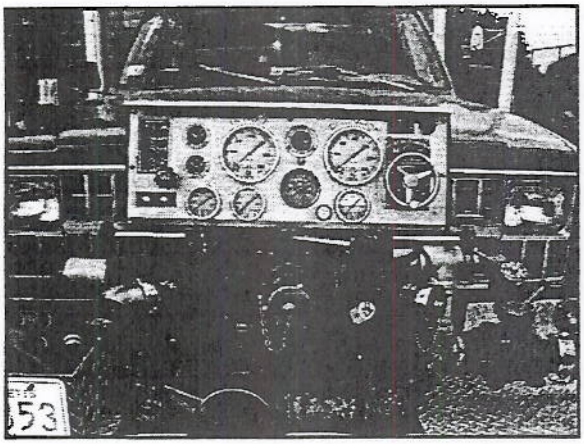
- Have a capacity of 750 to 2500 gpm
- Tested to pump:
  - 100% of capacity @ 150 psi net capacity
  - 70% of capacity @ 200 psi net capacity
  - 50% of capacity @ 250 psi net capacity
- Must be capable of pumping at capacity up to 2000 feet of elevation

Powering Pumps

- Front Mounts
- Power Take Off
- Midship
- Separate Engine
- Rear Mount

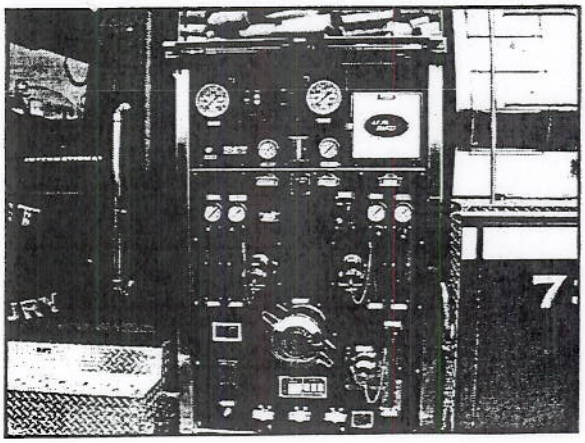
Front Mount

- Pump is driven through a reduction gear with a clutch on the front of the motor
- Pump is independent of transmission – pump and roll capability
- Location of pump makes it susceptible to freezing and collision damage
- Pump is engaged by a clutch lever most often found at the pump itself



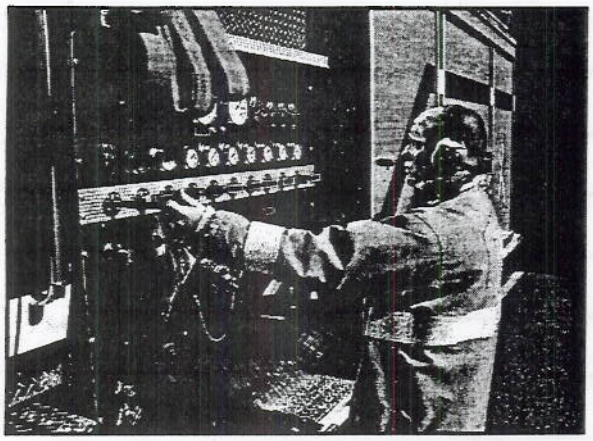
Power Take Off (PTO)

- PTO pumps are smaller (250 – 1500 gpm)
- Driven by gears within the transmission case (shaft)
- Pump is engaged by a PTO control
- Apparatus is normally stopped, but may be moved in a lower gear



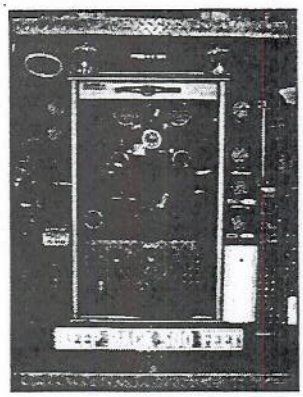
Midship

- Split-drive, shaft driven through a transfer case from the road transmission
- Transfer case allows selection of road or pump capability
  - Usually no pump and roll capability
- Allows for full power from engine to the pump
- Pump is engaged by shifting the transfer case lever from road to pump



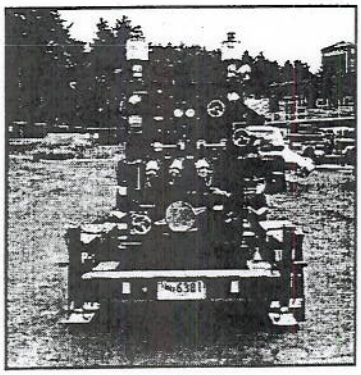
Rear Mount

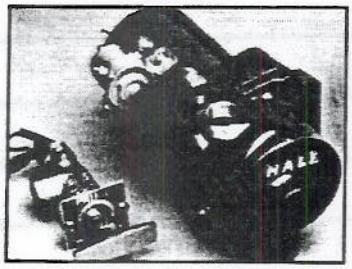
- Split-drive, shaft driven through a transfer case from the road transmission
- Transfer case allows selection of road or pump capability
  - Usually no pump and roll capability
- Allows for full power from engine to the pump
- Pump is engaged by shifting the transfer case lever from road to pump



Separate Engine

- Power is independent of the apparatus
- Examples:
  - Skid-mounted
  - Trailer mounted
  - Built into the apparatus
  - Crash truck





Priming Device

The Need for a Priming Device

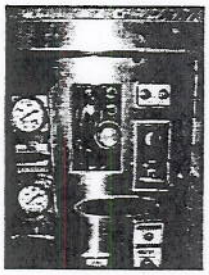
- Absolute negative pressure is impossible to achieve
- Open waterway found in centrifugal pumps
- Remove air from the pump cavity and suction hose creating a higher outside pressure that pushes water up into the pump

Types of Priming Devices

- Positive Displacement Rotary Vane
- These will expel air with or without a lubricant
  - Dry used on the newer pumps
  - Oil may be used to reduce wear and priming time
  - Oil is no longer recommended
  - Environmentally friendly anti-freeze

Pressure Relief Devices

- Pumps must be equipped with a device to control pressure
- The devices operate in a range of 90 – 300 psi
- When activated, the pressure rise shall not exceed 30 psi

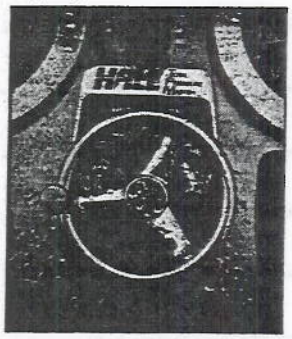


Types of Relief Devices

- Relief Valve
- Governor
- Gated Incoming Relief Valve
- Automatic Pressure Relief Devices installed on the pump

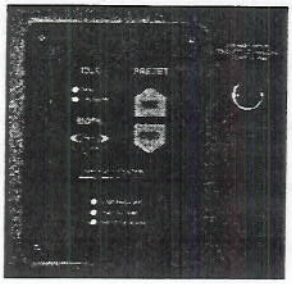
Relief Valve

Controls pressure by rerouting water from the discharge side of the pump



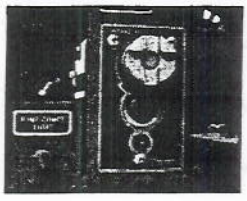
Total Pressure Master

Incoming / Outgoing relief valve made by Hale

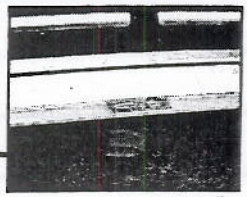


Governor

Controls pressure controlling engine speed which in turn affects pump pressure

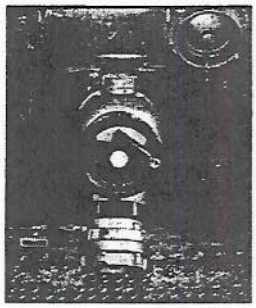


Manufacturer's Built In Relief Valve



Intake Pressure Relief Valve

Do Not Cap



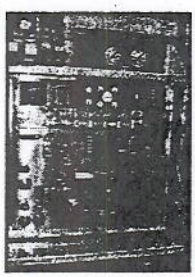
Gated Incoming Relief Valve

Pressure can be set for incoming LDH lines

ICV's must be adjustable from 90 psi – 185 psi

Pump Panel Components

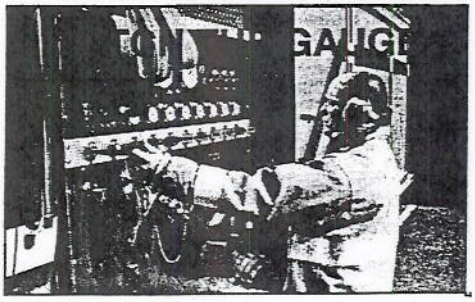
- Large Suction Intake
- Auxiliary Intake
- Discharges
- Compound Gauge
- Pressure Gauge
- Line Gauge
- Governor
- Tank Gauge
- Tank Suction
- Tank Fill



- Pump Power Indicator
- Primer Control
- Relief Valve
- Throttle
- Transfer Valve
- Drains
- Rating Tag
- Test Plugs
- Radio
- Engine/Transmission Lights

Engine / Pump Cooling System

Protects the engine from overheating

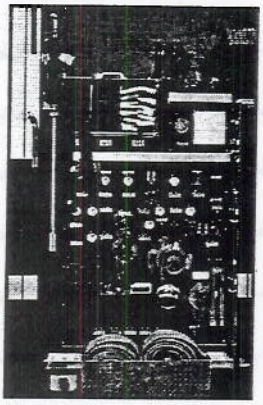


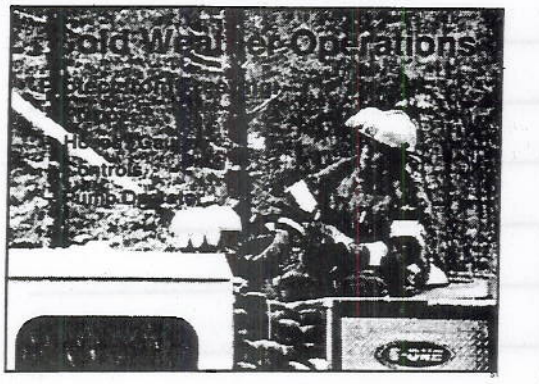
Methods to Cool the Engine

Open Hood	Thermostat
Radiator	Cooling Coil
Fan	Radiator Fill
Auxiliary Cooler	Pump Cooler Valve
Water Pump	

Where are the controls for these cooling lines?

- Auxiliary Cooler
- Cooling Coil
- Radiator Fill
- Pump Cooler



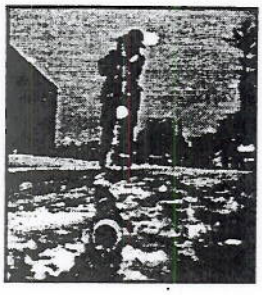


Speed of freezing depends on:

- Temperature of area where apparatus is stored vs. outside temperature
- Volume of water discharged
- Surface area exposed
- Duration of exposure
- Wind chill affects personnel only

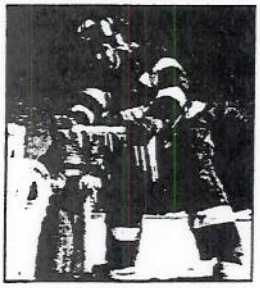
Freezing Prevention

- Do not shut down lines completely
- Moving water does not freeze as quickly
- Drain booster lines, monitors etc.
- Valves should be closed when no hoselines are connected
- Check antifreeze levels
- Circulate water
- All pumps leak – watch for icing



Freezing Prevention

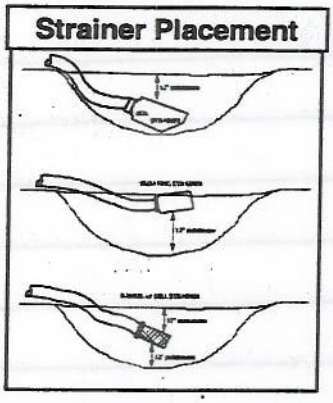
- Take time to dress properly prior to leaving the station
- Dress in multiple layers
- Move around – standing still slows the body down
- Drink warm fluids
- Use the pull-out platform step



Drafting Procedure

- Spot the truck
- Connect the hard suction
  - 12" off the bottom and from the surface
- Close all drains and discharges
- Prime until a steady discharge or constant pressure reading
- If no prime, check drains, discharges and suction hose
- When primed, increase throttle and open discharges slowly

Strainer Placement



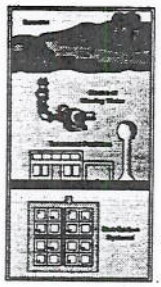
System Check When Pump Will Not Draft

- Primer Operation
- All Suction Connections
- All Discharge Connections

Water Distribution Systems

Water Distribution Systems

- Quality
- Quantity
- Reliability
- Economy



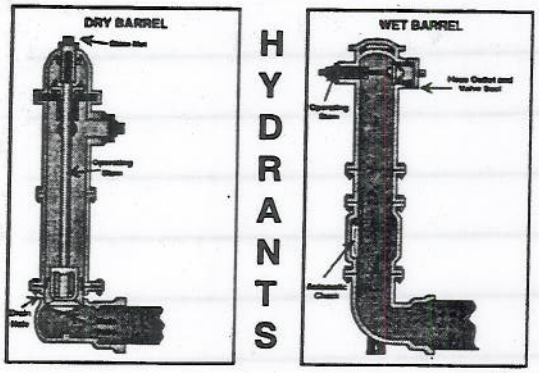
Water Distribution Systems

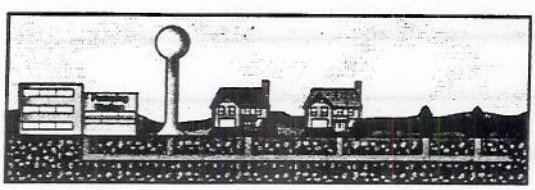
- **Supply Sources**
  - Reservoirs, tanks, in-ground wells
- **Treatment Facility**
  - Softens water, fluoride, cleans, removes bacteria and minerals
- **Delivery System**
  - Gravity
  - Pump
  - Combination

Mains

- **Primary**
  - 24" – 36"
- **Secondary**
  - 12" – 16"
- **Distributors**
  - 6" minimum for hydrants with 20 psi minimum pressure to prevent backup of contaminants into the system

HYDRANTS

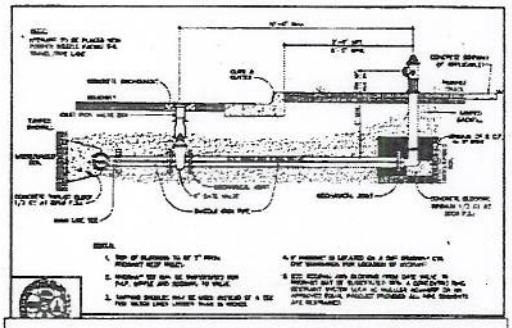




Distance Between Hydrants

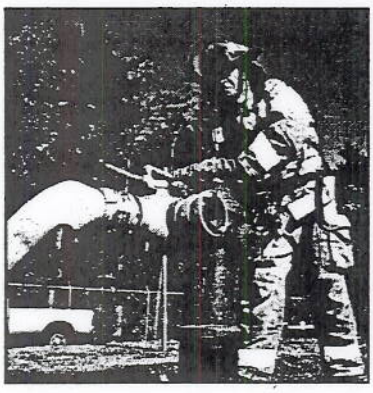
500' – High Value

800' – Residential



Standard Hydrant Installation

Proper opening of the hydrant requires 18 – 22 turns of the operating nut



NFPA Hydrant Color Code

Caps and Bonnet Color Code	
0 – 499 GPM	Red
500 – 999 GPM	Orange
1000 – 1499 GPM	Green
1500 and up	Light Blue

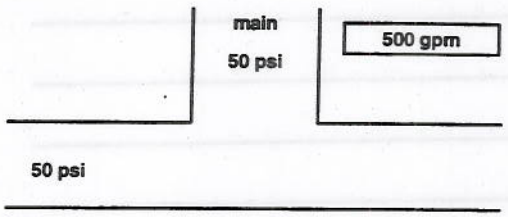
Markings

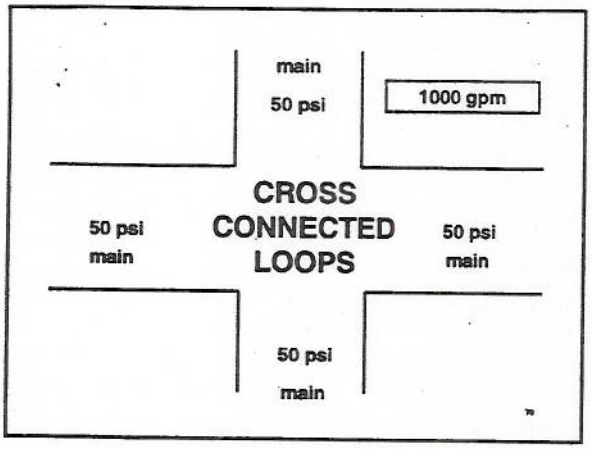
- Weather
- Time of Day
- Ease of Locating
  - Flags
  - Pole Markings
- Carrying Capacity Varies
  - Diameter
  - Pressure
  - Friction Loss
  - Age of Water System

Interconnecting Feed Distribution

- Helps Reduce:
  - Friction Loss
  - Sedimentation
  - Incrustation
- Higher Output Pressure
  - Residual

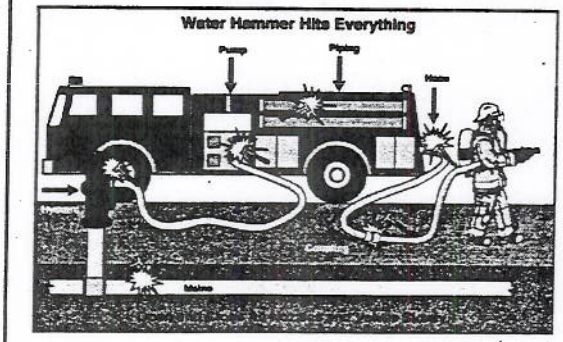
Single Feed





Water Flow Problems

- Water Hammer
- Nozzle Reaction
- Cavitation
- Dead End Mains
- Incrustation
- Sedimentation



Nozzle Reaction is equal to half the flow

Cavitation of a Pump
("the pump running away from the water")

- Water is discharged from the pump faster than it is coming in
- Air cavities are created in the pump and move from the point of highest vacuum into the pressurized section and collapse
- High velocity causes severe shock to the pump – usually resulting in damage

Dead End Mains

- Water mains that are not cross connected with other mains – low water flow
- Know your water distribution system

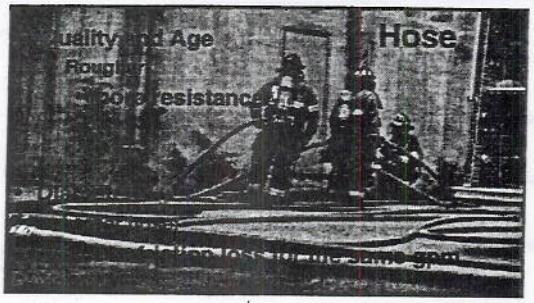
Incrustation

- Increases resistance for water flow by lining of pipe interior
- Caused by:
  - Tubercular corrosion of rust (iron pipe)
  - Chemicals in the water
  - Growth of biological or living organisms
- Water mains flushed each year reduces incrustation
- Flow test should be done to determine obstructions

Sedimentation

- Materials that settle to the bottom of a liquid
  - Mud, clay, leaves etc.
- Strainers in pump intakes
- Flushed water mains
- Flush hydrant prior to charging supply lines if possible

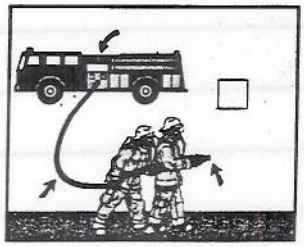
Basic Handline Hydraulics



Efficient Carrying Capacity of Hose

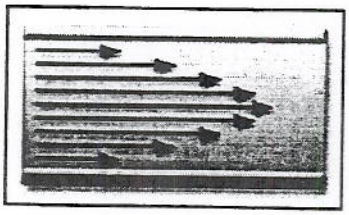
1-1/2"	100 gpm
1-3/4"	150 gpm
2"	200 gpm
2-1/2"	300 gpm
3"	500 gpm
4"	1000 gpm
5"	2000 gpm

Friction Loss is part of the total pressure that is lost while forcing water through pipes, fittings, fire hose, nozzles and adapters

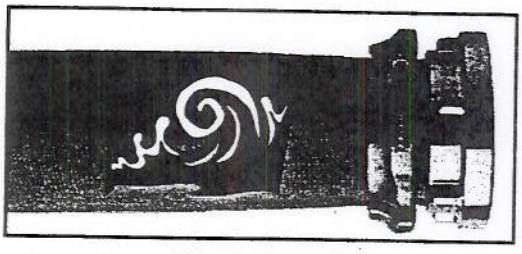


Friction Loss is lost energy!

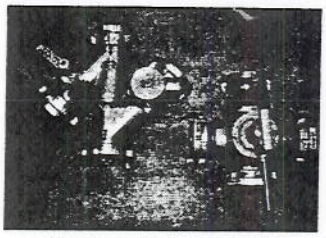
Quality of Flow



LAMINAR FLOW
Water is moving in a straight line



TURBULENT FLOW
Water is moving in a swirling motion

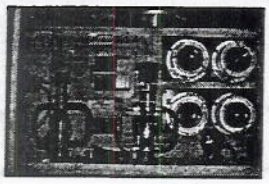


Appliances

- Varies with type and amount of flow
- Rule of Thumb: add
  - 10 psi for master streams and ladder pipes
  - 5 psi for wyes, siameses etc
  - 25 psi for standpipes

GPM's Delivered

- Varies with type of nozzle
- Combination (fog)
  - Varies with nozzle pressure
- Solid Stream
  - Varies with tip size



TIP SIZE	Solid Stream Master Streams 80 psi	Solid Stream Handlines 50 psi
	1-1/4" = 400	¾" = 100
	1-3/8" = 500	7/8" = 150
	1-1/2" = 600	15/16" = 175
	1-3/4" = 800	1" = 200
	2" = 1000	1-1/8" = 250
		1-1/4" = 300

Types of Pressure

Static Pressure:

stored energy that is available to move water through pipes, hoses and appliances.

- Shown on compound gauge with no water flowing
- Static pressure remains the same at any point in the closed system if elevation is the same

No matter what size hose or piping

Residual Pressure:

kinetic energy that is available perform work. Water pressure that was not used to overcome back pressure due to elevation or friction loss.

- Incoming pressure shown on compound gauge with water flowing
- Residual pressure is different at various points in the system due to friction loss and elevation

Negative Pressure:

any pressure created in the fire pump or hard suction hose which is less than atmospheric.

- Atmospheric pressure is 14.7 psi at sea level

Normal Operating Pressure:

pressure through water distribution system during normal consumption demands.

- **Fluctuates during day and night**
- **And also according to time of year**

Line Pressure:

pressure needed to provide proper nozzle pressure with a given layout.

Discharge Pressure:

in situations requiring multiple lines, the pump develops pressure for the highest line (greatest pressure).

- **Gate back for all others to get the proper line pressure**

Nozzle Pressure:

the pressure required at the nozzle to develop a proper fire stream from a nozzle.

- Nozzle pressure and the tip size determine flow capability
- Standard nozzle pressure
  - Combination: 100 – 75 – 50
  - Solid Handline: 50
  - Solid Master Stream: 80

Net Pump Pressure:

combined total pressure (psi) developed by the fire pump.

Net pump pressure = PSIG pressure + PSIG vacuum (inches of Hg.)

Flow Pressure:

forward velocity pressure at a discharge opening measured with a Pitot Gauge.

Forward Pressure:

pressure gained by water flowing, when the nozzle is lower than the pump.
Figured at 0.5 psi per foot.

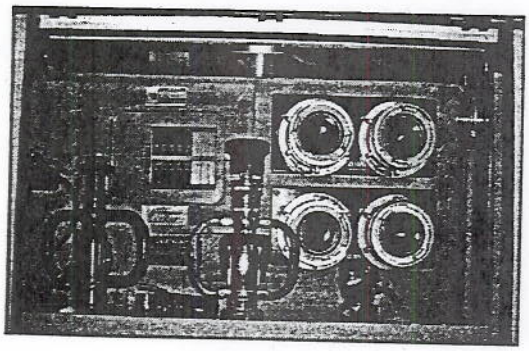
– 5 psi per floor below ground level

Back Pressure:

pressure that is must be overcome when the nozzle is above the pump.
Figured at 0.5 psi per foot

– 5 psi per floor above ground level

Nozzles and Appliances



Nozzles

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Solid Stream

- Fixed orifice, smooth bore nozzle which produces an unbroken stream
- Produces a stream that is compact and has little shower or spray
- Has good reach
- Made to operate in a range of 40 – 60 psi with 50 psi being the accepted standard

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Solid Stream

- **Advantages**
  - Greater reach
  - Greater penetration
  - Less likely to disturb normal thermal layering of heat and gases during interior attack
- **Disadvantages**
  - Set stream pattern
  - May not be used for foam application
  - Less heat absorption per gallon delivered
  - Must be fully opened to get full gpm/psi delivered

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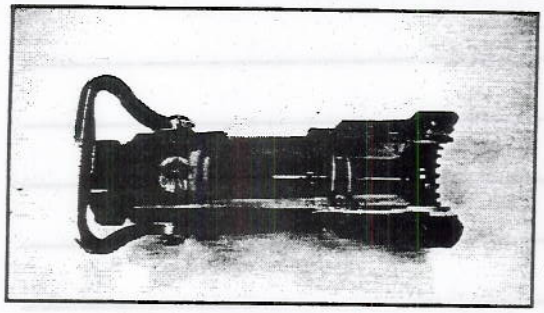
Combination Nozzle

- Produces a fog stream of fine water droplets
- Can be adjusted to different patterns
- The fog pattern is good for heat absorption
- Made to operate in a range of 50 – 100 psi
- Fixed gallonage
- Adjustable gallonage
- Automatic



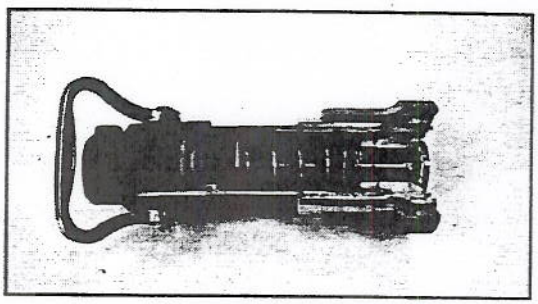
Combination Nozzle

Combination Nozzle

- **Advantages**
  - Discharge pattern may be adjusted
  - Gallonage may be adjusted
- **Disadvantages**
  - Does not have the reach or penetration power of solid streams
  - Fog stream is more susceptible to wind current
  - When improperly used during interior attack, can cause the spread of fire, create heat inversion and cause steam burns
  - Need to operate fully open to get full gpm/psi

Automatic Nozzles

- Combination nozzle with a sensing device that maintains a constant 100 psi
- May use slide valve or ball valve
- Automatic adjustable gallonage
- Requires minimum contact with pump operator
- Able to control nozzle reaction at the nozzle
- Handlines: 1-1/2" – 3" hose
  - 50 – 350 gpm (full range)
  - 60 – 200 gpm (mid range)



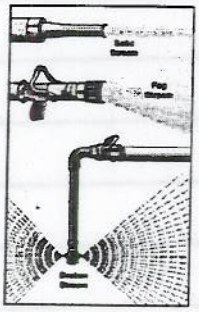
Automatic Nozzle

Automatic Nozzle

- Advantages
  - Nozzle operator has flow control
  - Consistent hard-hitting streams
  - Maintains optimum nozzle pressure at all times
  - Will adjust to the flow available
    - If flow is increased, the gpm's will automatically increase pressure
  - Will maintain maximum reach for available flow

Broken Stream Nozzle

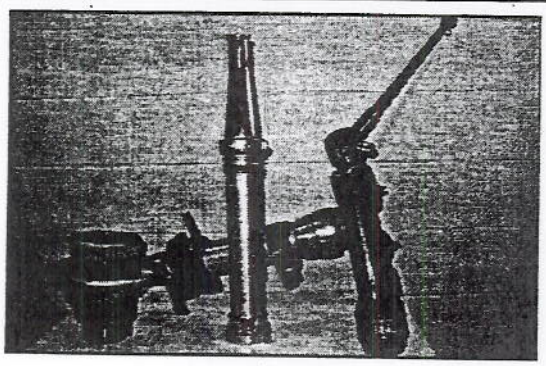
- Produces coarsely divided drops of water
- Good heat absorption
- Examples:
  - Piercing Nozzle
  - Water Curtain Nozzle
  - Bresnan Nozzle
  - Cellar Nozzle
  - Chimney Nozzle
  - Navy / Rockwood Nozzle



Master Stream Appliances

Master Stream Appliances

- Master streams are discharged from appliances using tips larger than 1-1/4"
- May be either solid stream or fog
- Solid tip master streams should be operated in a range of 60 – 80 psi
- Combination tip master streams are operated at 50 –100 psi
- Friction loss in master stream appliances starts at 10 psi
- The age of the appliance may require more psi with high flows at the tip



Ladder Pipe

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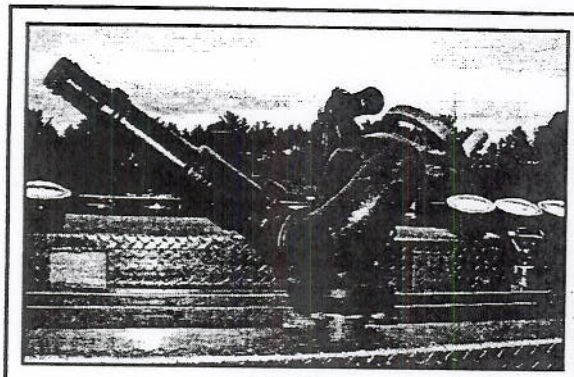
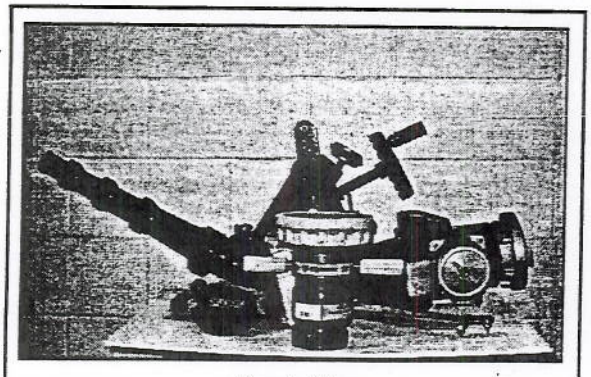


Monitor

113



Deck Gun

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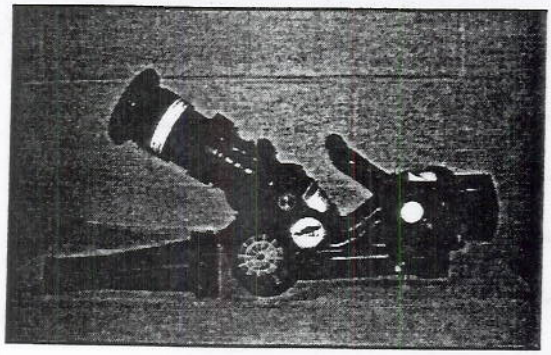
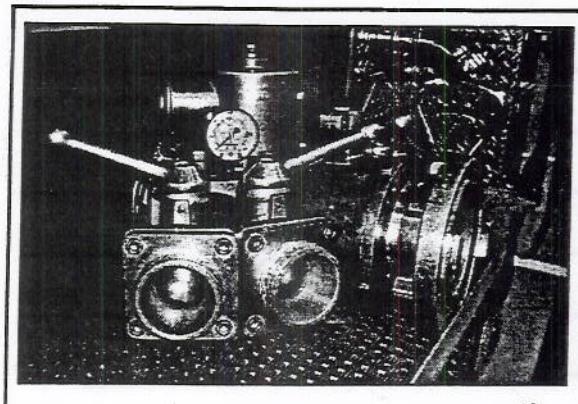


Portable Gun

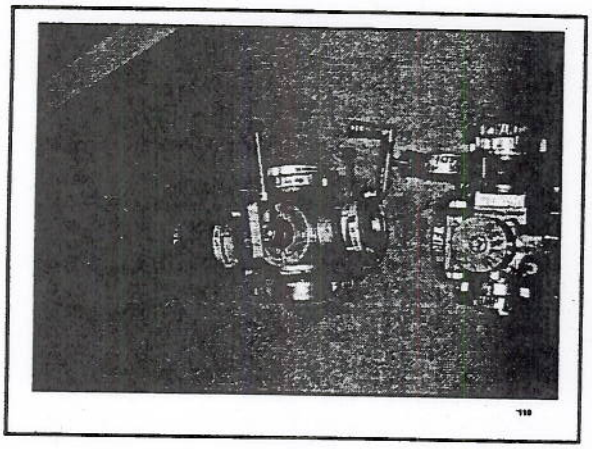
Ball Distributor Valve

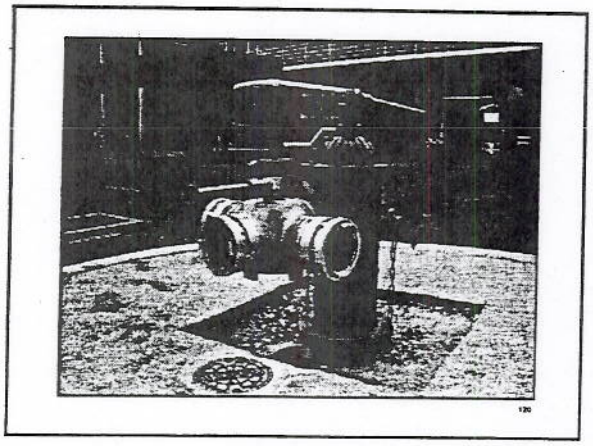
- Used with Large Diameter Hose
- Also called portable hydrant or manifold
- Principle is same as a wye appliance
- Generally have a 4" or 5" inlet with 2 or more smaller
- May also be an outlet that is same size as the inlet



Hydrant Assist Valve

- Makes pumping the LDH line accessible and does not require the shutdown of the hydrant in order to set the pump
- With these valves there is no stoppage of water flow





Wyes and Siamese Valves

- Wye
  - Divides one or more lines
  - Has one female and two or more lines
  - Used to divide a larger line into smaller or same size lines
- Siamese
  - Combines two or more lines into one line
  - Has one male and two or more female connections / Storz connections
  - Used to combine several lines into one larger one to supply a ladder pipe or ground gun

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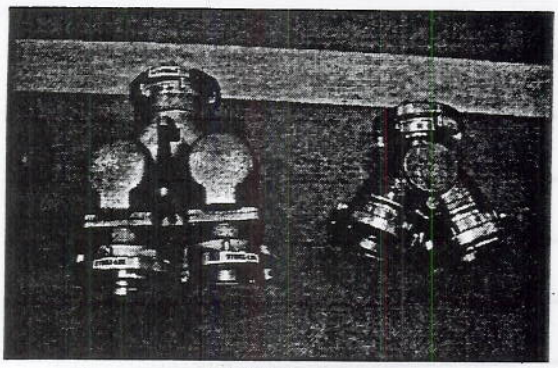

LDH Siamese

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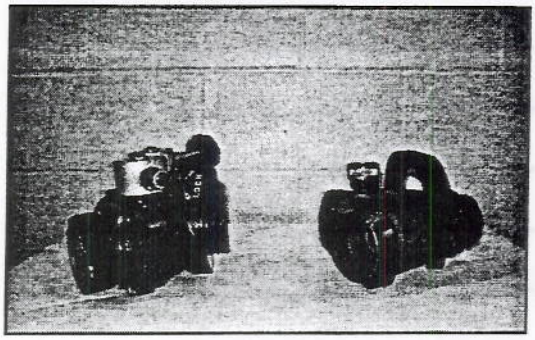

2-1/2" Siamese

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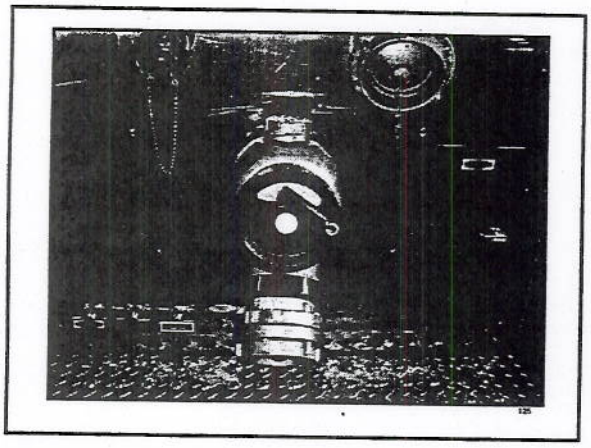
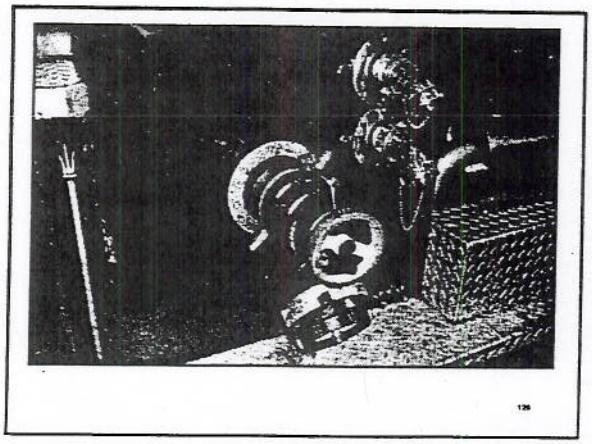
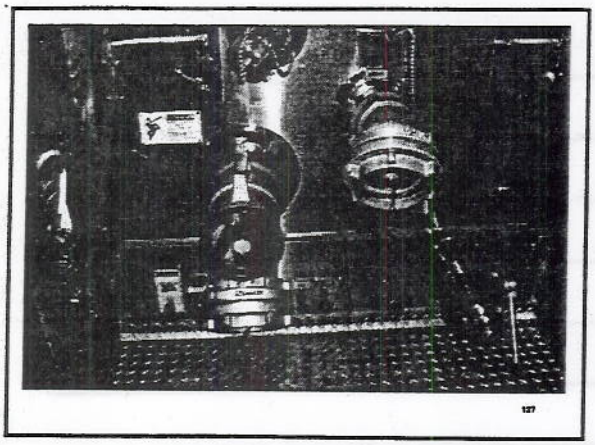
Gated Incoming Relief Valves

- Designed to release all air coming into the pump from LDH
  - Must be opened manually
- Should be left open when the pumper is put back in service
- Newer type are self-closing
  - Paddle wheel closes the bleeder valve
- Female end comes in 4", 4-1/2", 5" or 6"
- Storz side comes in 4", 5", or 6"
- Older type pressure relief is on the pump side, not the hose side

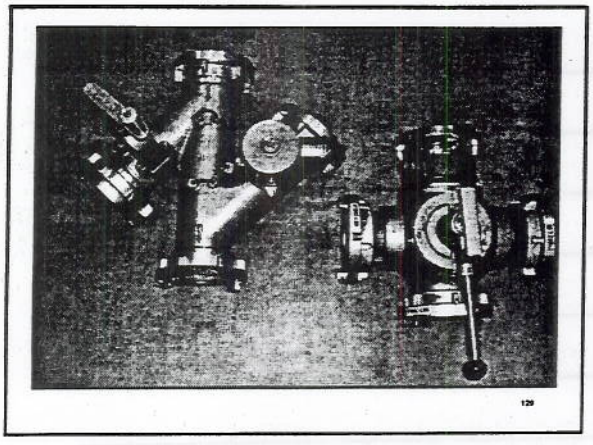


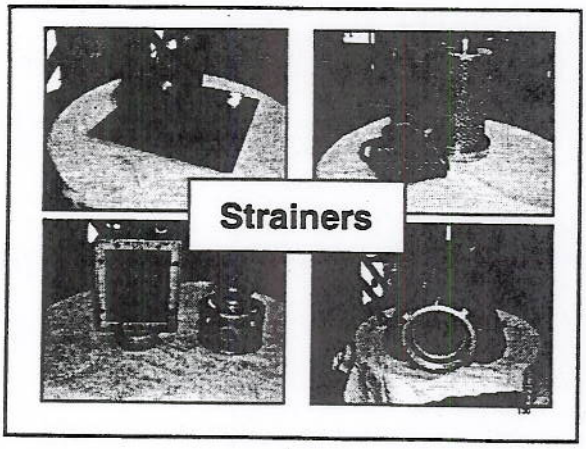




Relay Valves

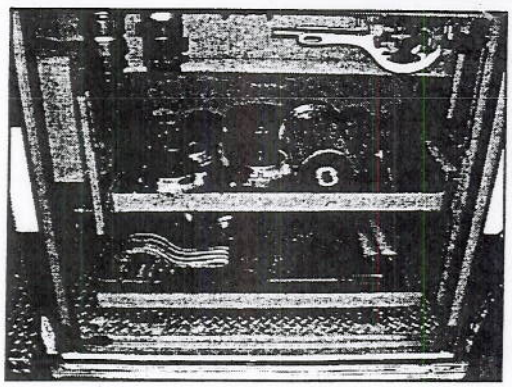
- Z-Valve
- LDH inlet and outlet with 2 gated LDH valves and 1 clapper valve
- Used to increase the pressure in a long LDH relay
- Adapter to convert a Harrington hydrant assist valve into a relay valve

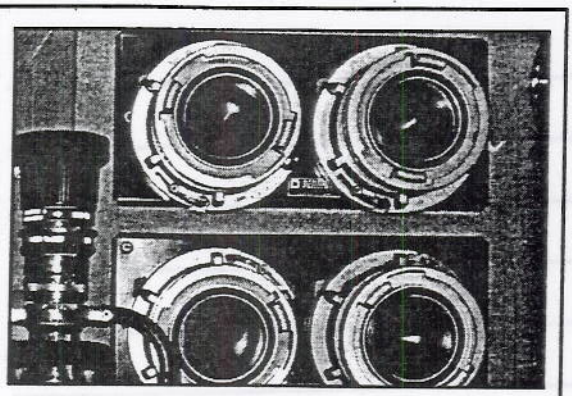




Adapters

NPT TO NST / or size	2-1/2" NST to 3"
2-1/2" NST to 4" Storz	1-1/2" Double Male
4" x 5" Stortz	2-1/2" NST to 5" Storz
4-1/2" NST Female x 4" Storz	4-1/2" NST Female x 5" Storz
2-1/2" NST Female x 1-1/2" Male	2-1/2" Double Male
2-1/2" Plug Cap	2-1/2" Cap
Suction Caps	Reducer Caps





Step 1	Position the apparatus in a safe position, and immobilize it by setting the parking brake and blocking the wheels.
Step 2	Engage the pump and select the proper gear in the road transmission. Lock the gear into place.
Step 3	Open the tank-to-pump valve.
Step 4	Set the transfer valve to the SERIES (PRESSURE) position if necessary.
Step 5	Increase the throttle setting to obtain the desir pressure, priming if necessary.
Step 6	Set the relief valve or pressure governor.
Step 7	Open the circulator valve or partially open the tank fill valve.
Step 8	When an external water supply becomes available, reduce the discharge pressure by 50 psi. Open the intake valve while closing the tank-to-pump valve. Check the discharge pressure and adjust as needed. Readjust the pressure relief device. (If equipped with an electronic governor, the reduction of 50 psi will be approximately the needed discharge pressure when the incoming water source valve is opened completely and the booster valve closed) Remember the tank fill valve was opened in Step 7. Adjust the flow of the tank fill as needed. Readjust the throttle and check the setting of the relief device.
Step 9	Check to make sure the tank to pump valve is closed completely. The older pumpers may not be equipped with a check valve in the tank-to-pump line, causing the tank to back fill.

Changeover Procedures

Worksheets

References

- Hale Pumps
- IFSTA
- NFPA
- Waterous Pumps

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For more information, contact:

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Massachusetts Firefighting Academy
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Stow, Massachusetts 01775
Phone: 978-567-3200
Fax: 978-567-3229
Website: mass.gov/dfs

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Thank You
&
Stay Safe

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