EEHPC 2012

Looking at the Return on Investment with Fluid Power Systems

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In discussing the issue of ROI, there are some primary things to consider:

1. Is this a new application where the customer is choosing between a fluid power solution and a prime mover/mechanical solution?
2. Is this a new application where the customer is choosing among several fluid power solutions?
3. Is this a retrofit where the customer wants to replace and/or improve an existing fluid power system?
4. Is this a retrofit where an existing electromechanical system is being replaced with a fluid power system?
5. Will the installation of this system simplify or complicate the job of the maintenance staff?
6. Is there funding available from the utility company?
7. Are *you* convinced that an efficient fluid power system is the *best* solution?

Each one of these points takes a slightly different approach when determining the return on investment. However, each needs to address the issues of:

- Installed cost
- Operating cost
- Repair cost
- Disposal cost
- Environmental impact
- Future value of money

It is also important to think about our own ROI. As we develop new or improved products, train and certify our people, we will be investing in the future of fluid power which is an investment in our own future.

Before we can be confident that there will be a return on investment for those who choose to upgrade to a new level of fluid power, we need to be certain we have the knowledge to help produce the savings.

So, we will be looking at ways in which we routinely waste energy and also some cures to overcoming the bad habits that produce waste.

We will be referencing articles written for the Fluid Power Journal. These articles are under the heading, "Watts It All About" and can be found in the binder you received when you arrived.

We will be specifically looking at the articles on Flow Controls, Efficient Hydraulic Systems, A Failed Experiment, Something is Missing, You Made the Mess … , and Quads and the EEHPC.

If we are going to show our customers that there is a reasonable ROI when using fluid power, we have to know how to design efficient systems and explain to our customers why we are choosing what we are choosing.

It is important to have customer involvement when choosing a hydraulic system so they can understand the impact of the decisions we help them make.

We will also then talk about the **"perfect"** hydraulic system.

- This **“perfect”** system will include the ability to store hydraulic energy at pressures much higher than what is usually expected.
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- This power will be released with minimal energy loss.
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- Multiple electric motors with varying loads can be replaced with hydraulic motors using this system and actually reduce the energy consumption.
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- The installed cost may be lower than when using all electric motors.
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- The style of reservoir allows for a reduced fluid volume and better filtration providing reduced installed cost, reduced disposal costs, and longer life for the components.
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- The overall higher efficiency will reduce the heat load, extending the life of the fluid, and minimize or eliminate the need for a heat exchanger.

So, let’s begin.

From **"Quads and the EEHPC"** page 59

When talking about very large amounts of energy, the insiders like to combine the two terms and just call them "Quads," meaning quadrillions of British thermal units. So, what's the point? Well, a recent study explored the use of fluid power in the agricultural, mobile, industrial, and aerospace industries. It found that fluid power is one of the leading consumers of energy in North America, using somewhere in the area of 3.1 quadrillion Btu's (Quads) per year. **The same study suggested that fluid power is, on average, only 21% efficient.** This is like good news and bad news. The good news is that we are recognized as a leader in the transfer of power and are likely to remain so for the foreseeable future. The bad news is that our systems are inefficient, and we are vulnerable to losing market share to other means of power transfer.

The amount of power consumed by fluid power systems in one year is enough to take all the icy water flowing over the (Niagara) falls for 33 days and bring it to the boiling point, an increase of 180° F. The *wasted* energy is enough to raise the temperature of that same amount of water 142° F. Given a cost of $.10/kWh, each year about **$88 billion is spent** powering fluid systems. Of that, about **$70 billion is wasted** due to inefficiency. Someone responded to this information and suggested that the fluid power industry could make a 5% improvement by simply using "best practices." If this is true, then we could **save about $3.5 billion** in energy costs just by doing what we already know how to do and know we should do.

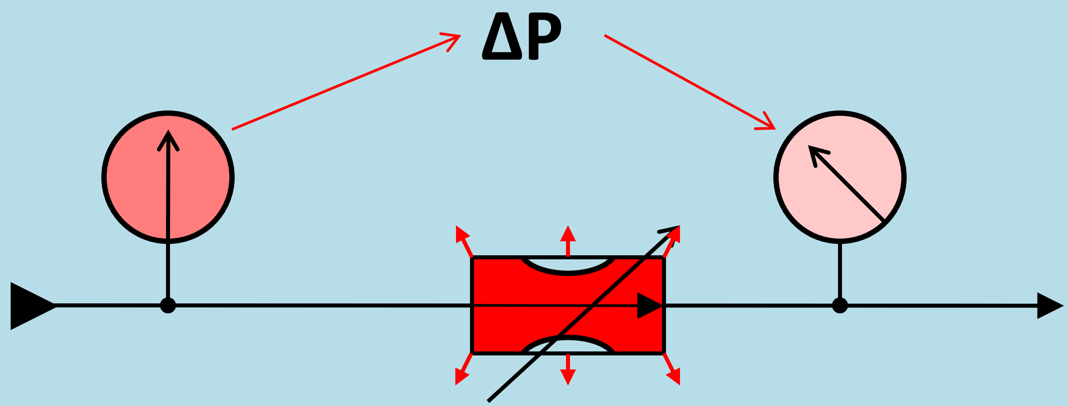
From “**Flow Controls, If in Doubt** …” pages 6-9

Now, I am not suggesting that we eliminate flow control altogether. One of the beauties of Fluid power is the fact that we can regulate the speed of linear and rotary functions from a single power source. This requires some type of flow modulation. What concerns me is that we may consider the energy consumed by the control as just part of the cost of using Fluid Power and not take into consideration the impact our choices may have on the cost of operation and on our industry.

<u>There is no such thing as an energy efficient flow control</u>. A system that requires flow control will ***always*** be generating more flow and pressure than is needed and the excess is wasted energy. The best we can do is to limit the waste. A pump pushes a volume of fluid at a pressure determined by the resistive load. By definition then, we charge the fluid with energy. If we require something less than the full flow at system pressure, **the excess energy will be lost**.

Daniel Bernoulli

Daniel Bernoulli informed us that, given a constant flow, there would be a discrete pressure drop (ΔP) through a fixed orifice.



To maintain a constant flow with a *varying* pressure, there will have to be a varying orifice.

The higher the upstream pressure, the greater the ΔP will be for a given flow.

The upstream pressure will ***always*** be higher than the downstream pressure.

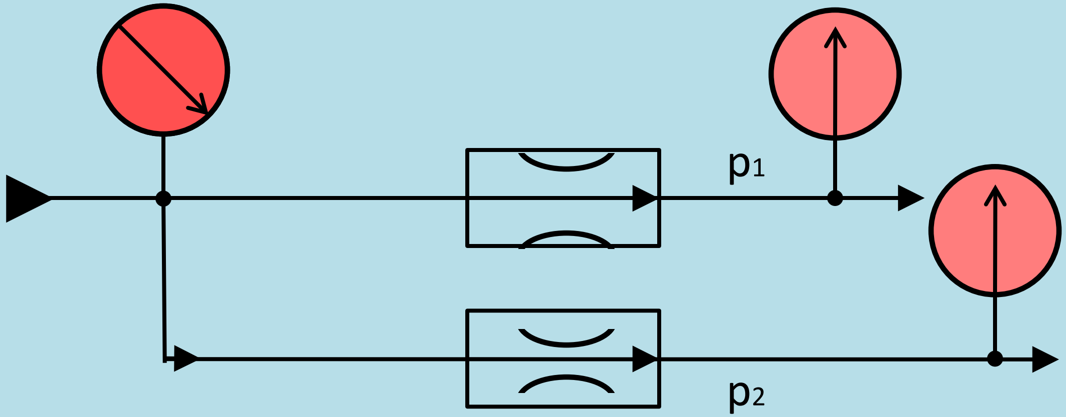
With hydraulics, a restrictive flow control will always be an energy consumer and will release the energy as heat.

When we use a restrictive type flow control as a flow divider we see the same kind of thing.

The upstream pressure will always be higher than the highest downstream pressure;

by at least 80 psi.

If the source is the stored energy in an accumulator, it will sometimes be substantially higher.

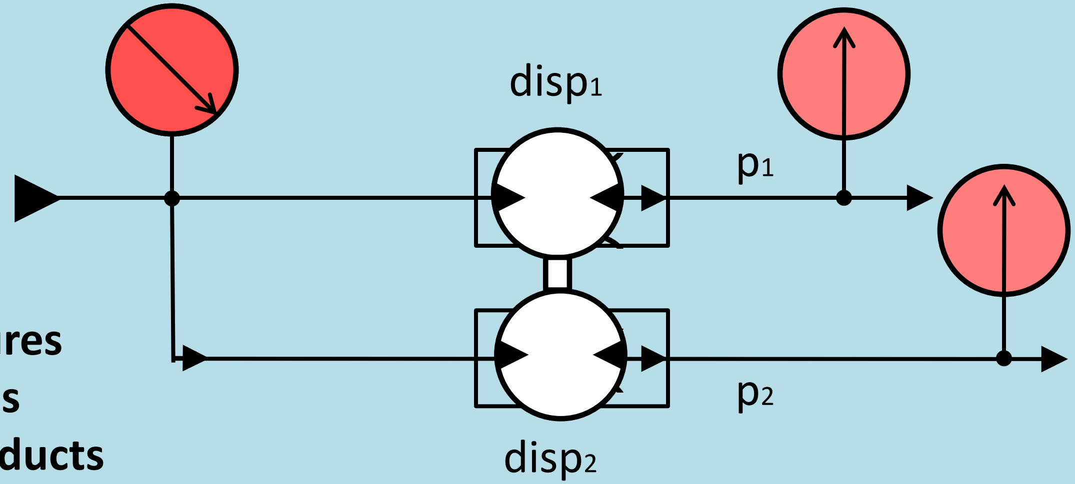


Something very different happens when we use an equal displacement flow divider.

The flow is divided evenly as before,

But the input pressure is much lower.

How can this be???



The input pressure is found by multiplying the downstream pressures (p1 and p2) times the displacements (disp1 and disp2), adding those products together, and then dividing by the total displacement (disp1 + disp2).

$$\frac{(disp_1 \times p_1) + (disp_2 \times p_2)}{disp_1 + disp_2}$$

We will assign some values to the flow divider and let the math show us the result.

$T = \text{Disp.} \times \text{psi} \div 2\pi$

$\text{psi} = T \times 2\pi \div \text{Disp.}$

$\text{psi} = 477.46 \times 6.2832 \div 4$

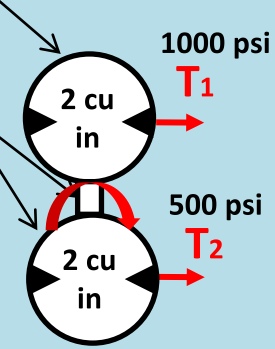
$\text{psi} = 750$

The displacement flow divider is essentially two or more positive displacement hydraulic motors that are connected by a common shaft.

They could be vane motors, piston motors, gear motors, or any combination.

The common shaft between the motors has to develop enough torque to push the exhausting fluid against the downstream load.

We know that torque is a factor of pressure and displacement so we can determine the torque load on the common shaft by adding the torque on the top (T_1) to the torque on the bottom (T_2).



The torque developed by the input pressure acting on the total displacement has to match the combined torque of the two outputs.

We will assign a displacement of 2 cubic inches to each motor.

We will assign a resistive pressure of 1000 psi to the upper motor and 500 psi to the lower motor.

$T_1 = 2 \times 1000 \div 6.2832$

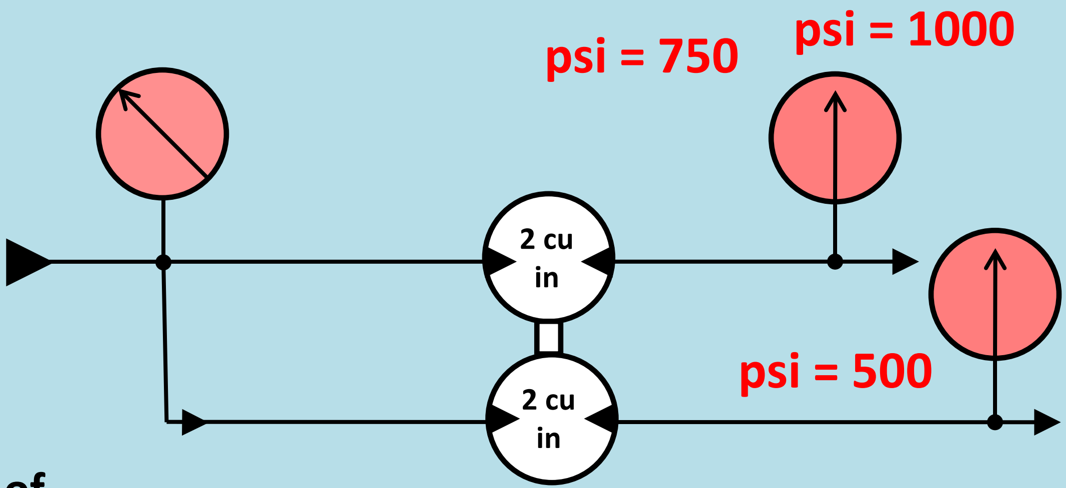
$T_1 = 318.31$ lb/in

$T_2 = 2 \times 500 \div 6.2832$

$T_2 = 159.15$ lb/in

$T_1 + T_2 = 477.46$ lb/in

Now, instead of a high pressure drop turning into wasted energy, all the pressurized fluid is being used for useful work.



There is no magic here.

We did not create some new source of power.

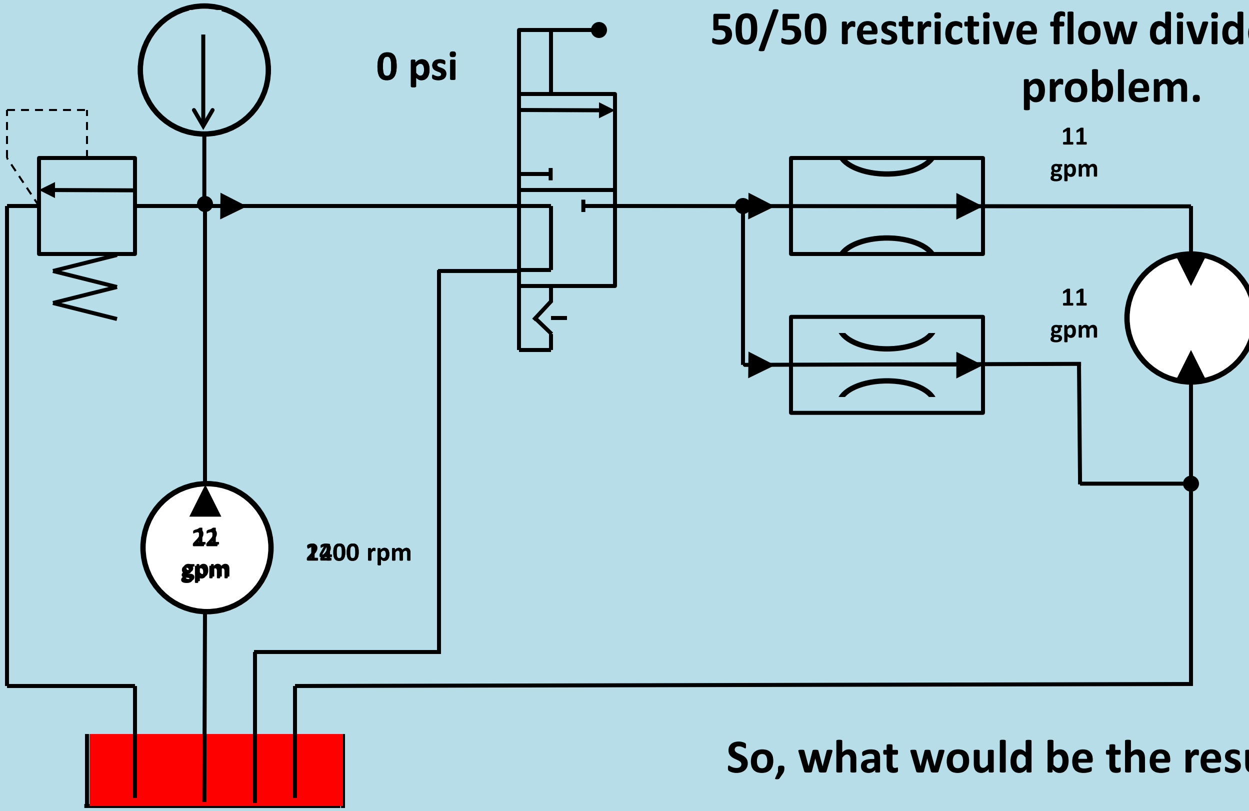
We just demonstrated that the simple displacement type flow control may be more efficient in converting an energy source into useful work than is a restrictive flow control.

This is from an actual application on a piece of mobile equipment.

The customer came to our counter and asked for an 11 gallon/minute pump.

[illegible]

Our counterperson gave the customer a 50/50 restrictive flow divider to cure the problem.

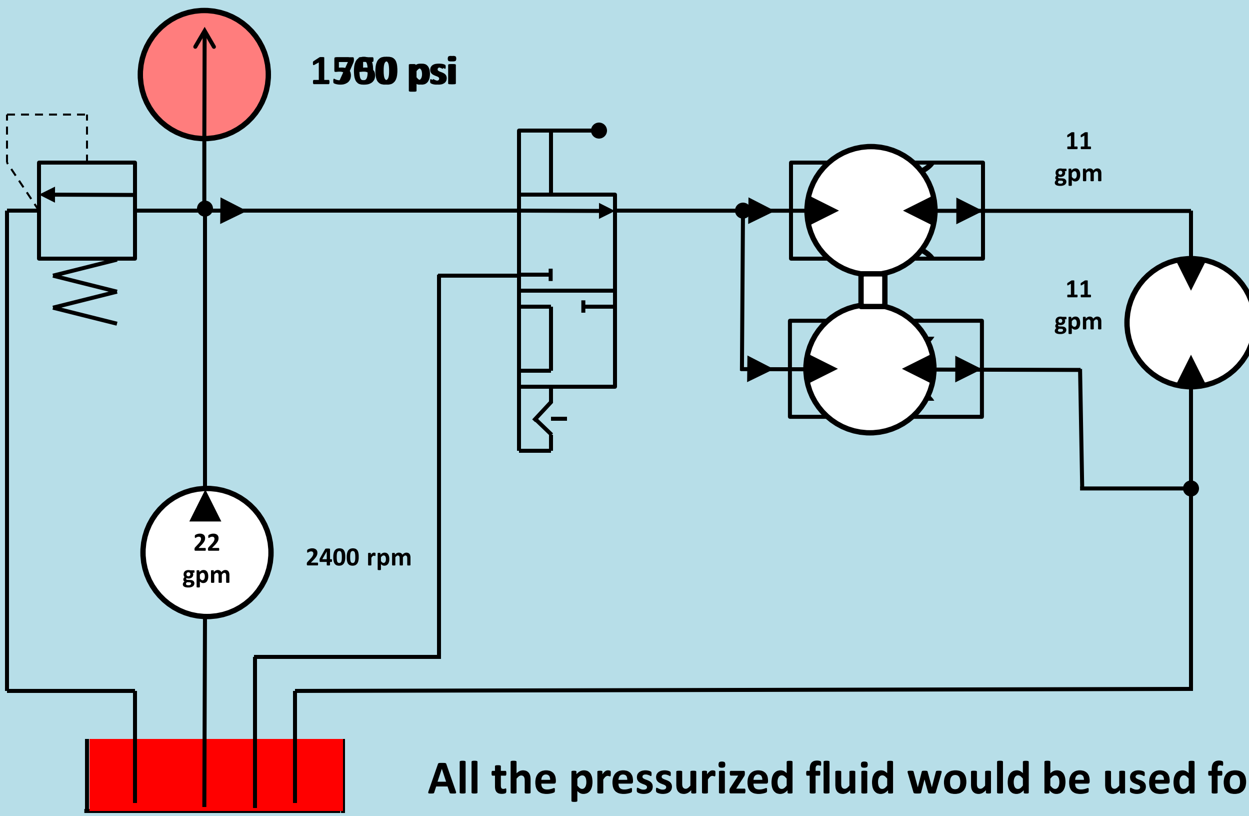


So, what would be the result?

22 gpm was being charged with 1500 psi but only 11 gpm was doing work.

The remaining 11 gpm had to release its energy as heat.

If we had added a 50/50 *displacement* flow divider, we would have had a very different result.



All the pressurized fluid would be used for useful work; either to drive the motor or else to assist in driving the motor.

We said that there is no such thing as an energy efficient flow control.

Even the displacement flow control has a pressure drop as flow passes through it.

Sometimes we do not need to divide flow but merely control flow.

Blaise Pascal

It was Blaise Pascal who informed us that pressure in a confined fluid is seen equally throughout the fluid.

In order for us to move a load, we have to have flow, and in order to have flow, we have to have a pressure differential.

This pressure differential times the flow rate is an energy loss that we can calculate.

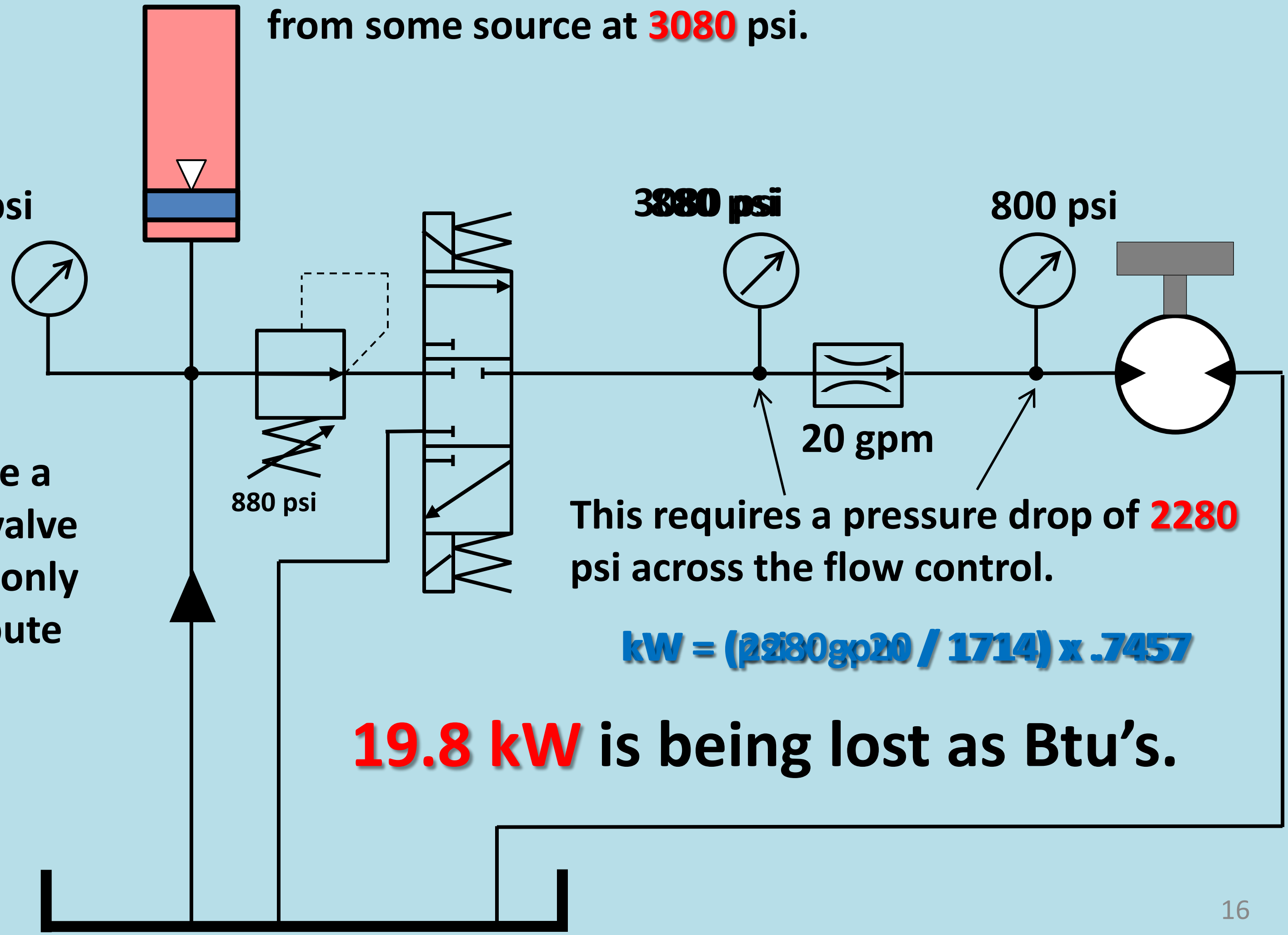
The question is; how much pressure drop is acceptable and what can we do to minimize it.

The following few slides will look at dealing with pressure sources that are higher that what is required by the load.

Using Fluid Stored at a Higher Pressure Than is Required by the Load

This application has a motor with a torque load that requires 800 psi and 20 gpm to rotate at the desired speed.

An accumulator stores the fluid it receives from some source at 3080 psi.



Even if we introduce a pressure reducing valve into the circuit, we only relocate and distribute the pressure loss.

This requires a pressure drop of 2280 psi across the flow control.

kW = (2280 x 20 / 1714) x .7457

19.8 kW is being lost as Btu's.

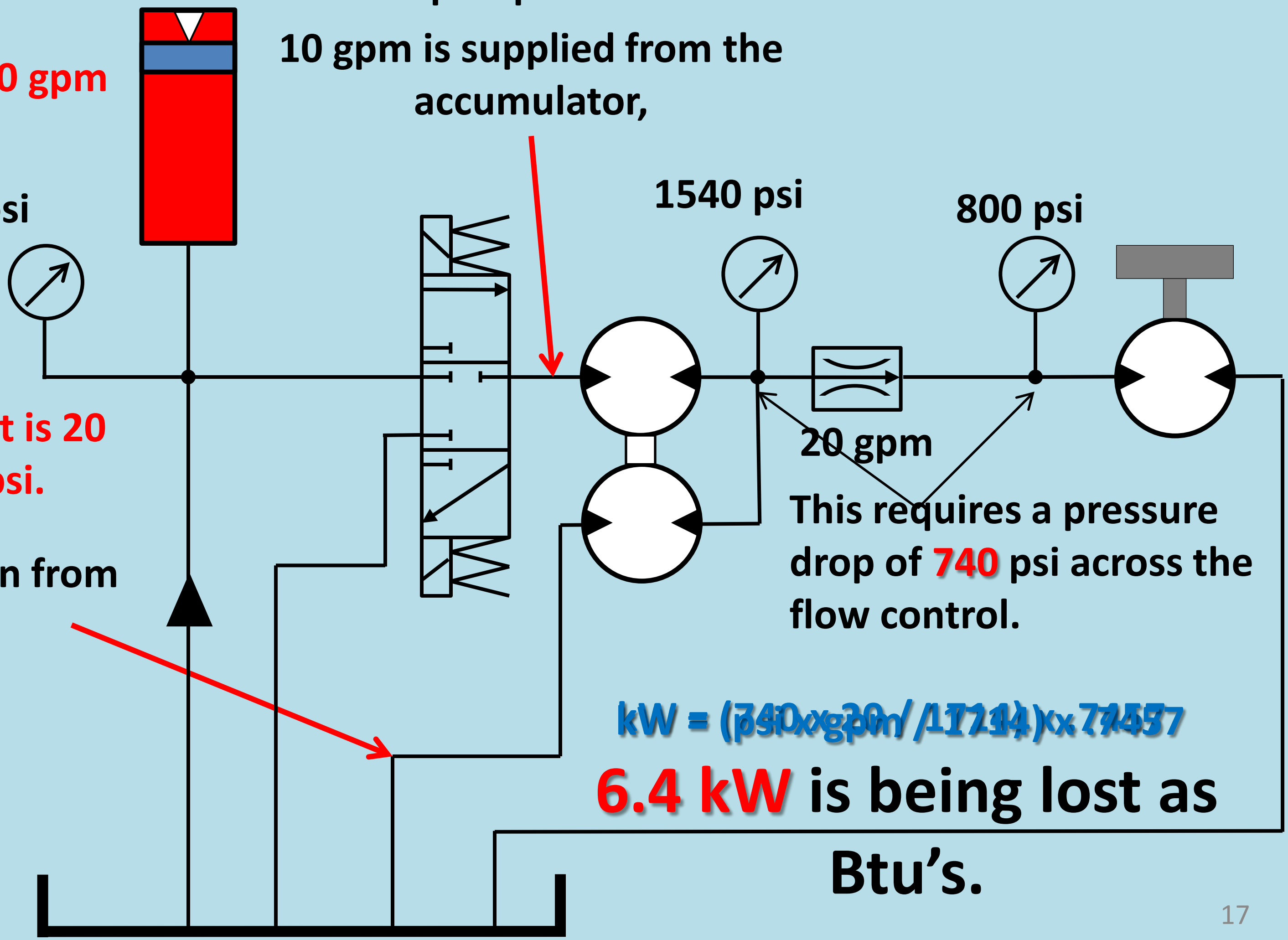
Now we will introduce a simple 50/50 displacement device.

When we shift the directional valve something very different happens.

One side of the displacement device is used as a motor driving the other side as a pump.

The power input is 10 gpm at 3080 psi.

10 gpm is supplied from the accumulator,



The power output is 20 gpm at 1580 psi.

and 10 gpm is drawn from the reservoir.

This requires a pressure drop of 740 psi across the flow control.

kW = (psi x gpm / 1714) x .7457

kW = (740 x 20 / 1714) x .7457

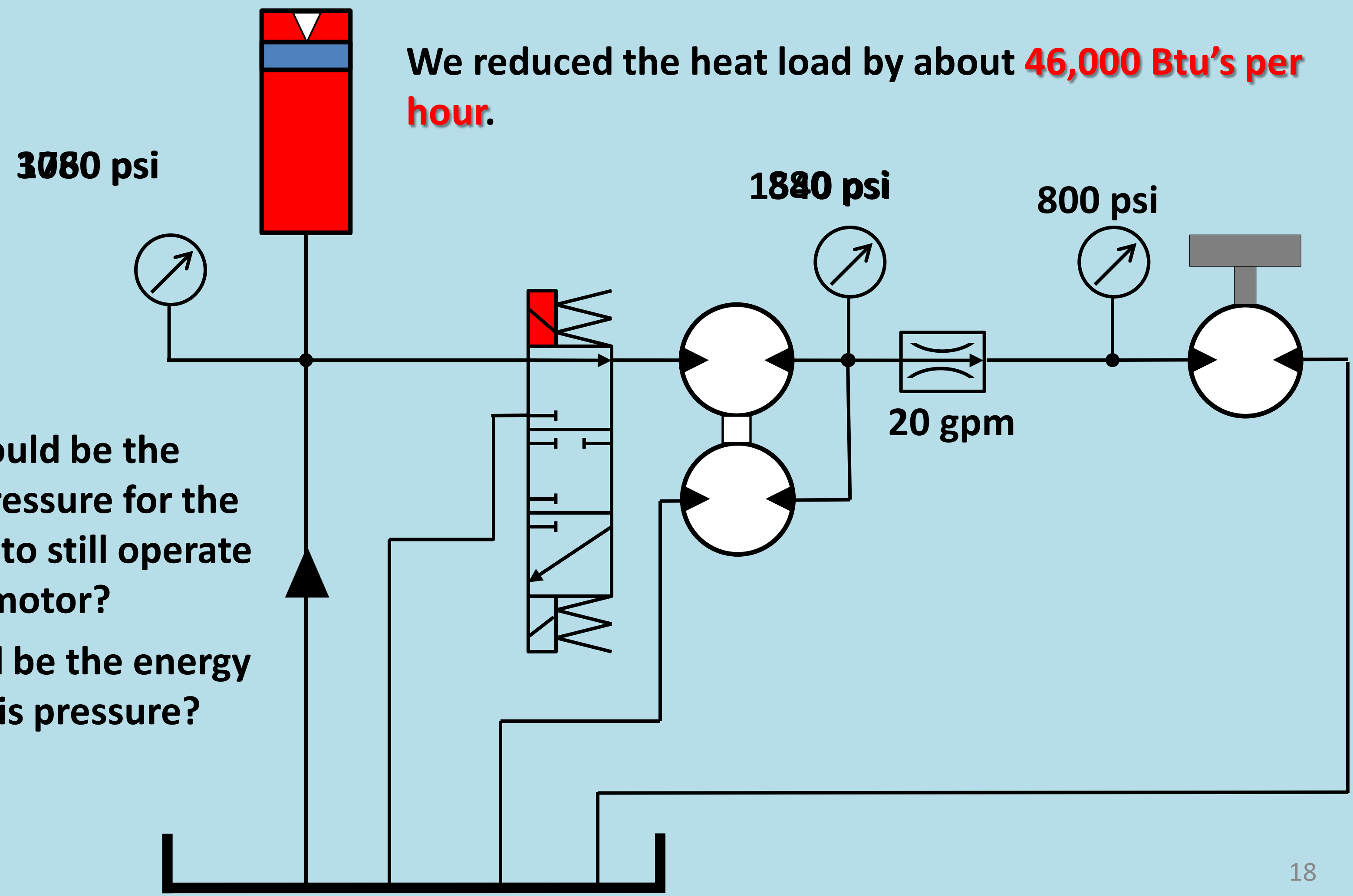
6.4 kW is being lost as Btu's.

We just made a Flow Augmenter / Pressure Transformer

By adding the displacement device we reduced the volume of fluid required from the accumulator by **50%.**

We reduced the energy loss by 13kW. / 7.4kW.

We reduced the heat load by about **46,000 Btu's per hour**.



What would be the minimum pressure for the accumulator to still operate the motor?

What would be the energy loss at this pressure?

From

Something Is Missing: pages 44 - 46

Using Alternative Energy

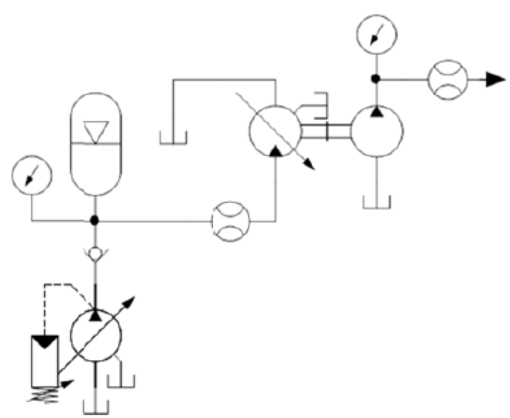
And

Use It or lose It: pages 49 - 52

Using Alternative Energy

Hydraulic Transformer									
Input Variables				Results				Energy Transformed	
Fixed Pump Disp in3	Load Flow gpm	Load Pressure psi	Accumulator or PC Pressure psi	Pump and Motor rpm	Pump and Motor Torque in/lb	Variable Motor Disp in3	Motor Flow gpm	Pump HP	Motor HP
8	18	1400	2000	520	1783	5.60	13	15	15
8	18	600	2000	520	764	2.40	5	6	6
8	18	1400	800	520	1783	14.00	32	15	15

Hydraulic Transformer Circuit



The fixed displacement pump needs to rotate at a specific RPM in order to produce the 20 gpm required.

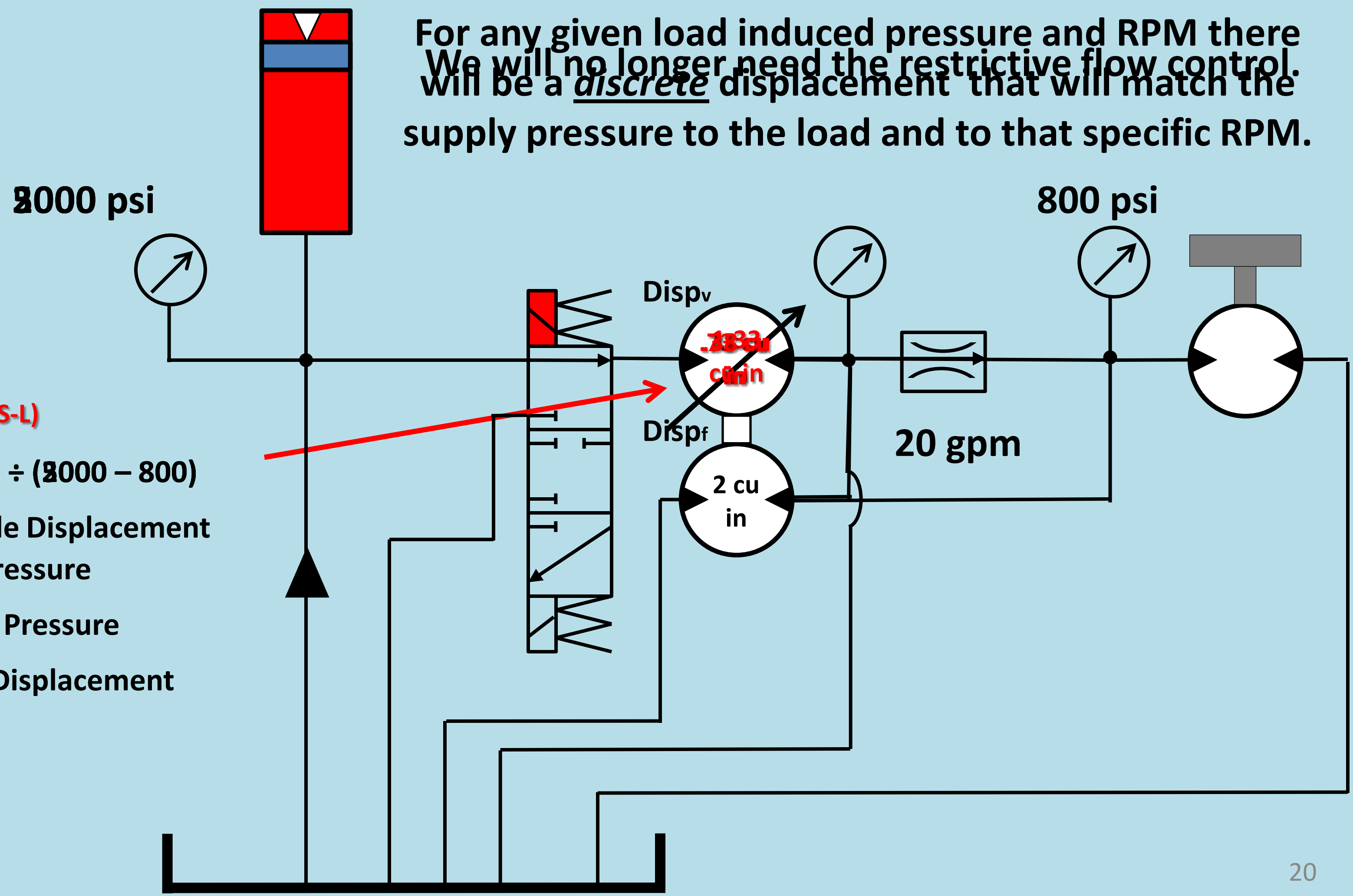
By making one side of the displacement flow divider variable, we add additional flexibility.

If we add a control to the variable motor that causes it to maintain a constant RPM, we will be able to use whatever pressure is available and adjust the motor displacement to match the need.

$$\text{Power} = \frac{\text{Torque x RPM}}{\text{Constant}} \qquad \text{Torque} = \frac{\text{Disp. x P}}{2\pi} \qquad \text{Power} = \frac{\frac{\text{Disp. x P x RPM}}{2\pi}}{\text{Constant}}$$

For any given load induced pressure and RPM there will be a *discrete* displacement that will match the supply pressure to the load and to that specific RPM.

We will no longer need the restrictive flow control.



Dispv = LDispf /(S-L)

Where:

Dispv = 800 x 2 ÷ (2000 – 800)

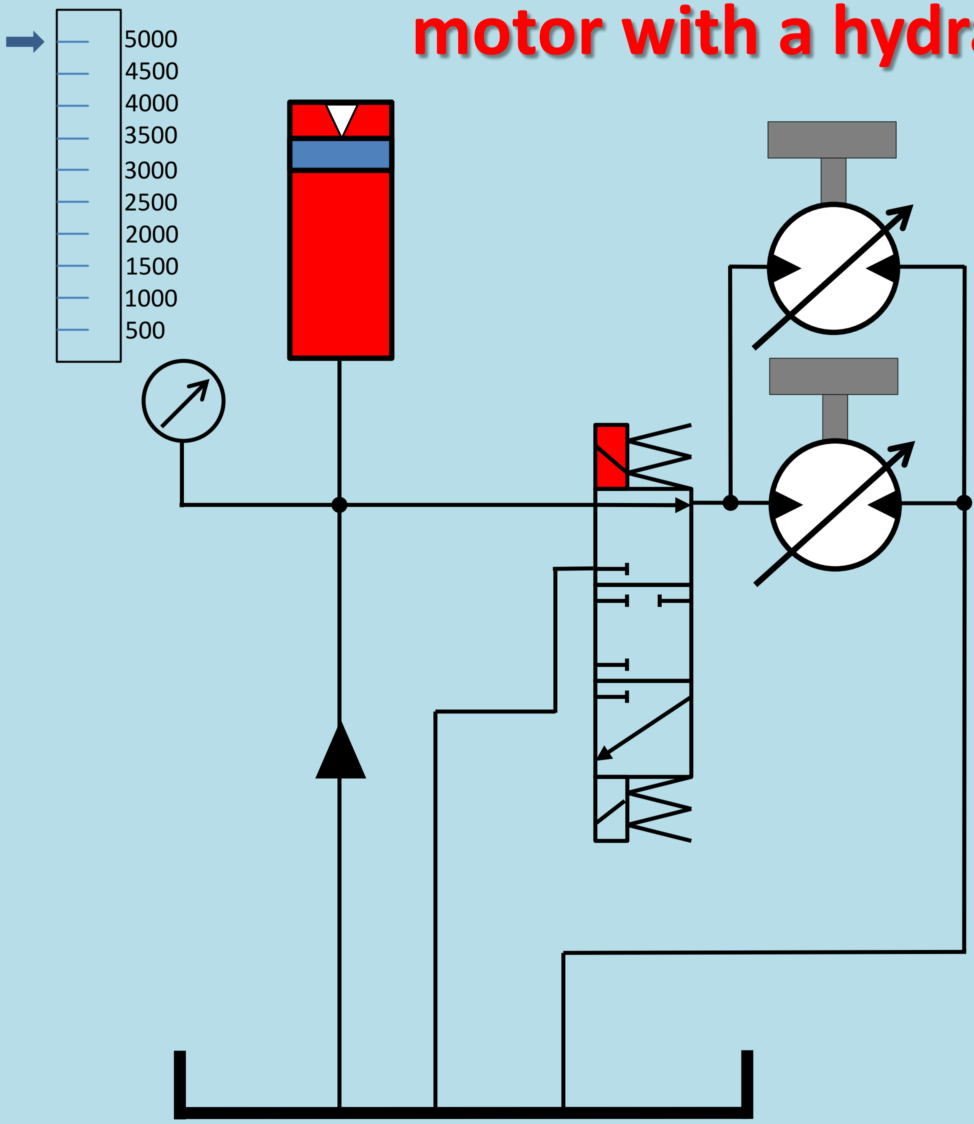
Dispv = Variable Displacement

L = Load Pressure

S = Supply Pressure

Dispf = Fixed Displacement

This will also hold true when we replace an electric motor with a hydraulic motor.



$$\text{Power} = \frac{\text{Torque x RPM}}{\text{Constant}}$$

$$\text{Torque} = \frac{\text{Disp. x P}}{2\pi}$$

$$\text{Power} = \frac{\frac{\text{Disp. x P x RPM}}{2\pi}}{\text{Constant}}$$

For any given combination of power and RPM, there will be a **discrete product** of displacement and pressure.

Using RPM as the controlling factor, the displacement will always reflect the available input pressure and the required output torque, even when there are multiple motors.

from

“Flow Control: If in doubt, think about … Energy.” Pages 10 - 12

When covering the material for taking the CFPS exams, I remind people about some of the laws of physics, namely the relationship between effort, work, and power. If I lean up against my file cabinet, I will be putting in some effort but I will not be doing any work. “Work” is defined as “effort over distance”, so, unless I actually *move* the file cabinet, all my effort will technically have done no work. If I am able to tilt the cabinet up and then realize I forgot to bring the hand truck and set it back down again, I will have done some work but then the work would be undone because the cabinet is in exactly the same spot as before I started. The net result is zero work with a lot of effort.

An illustration of this is what I am told about the DeLorean “Back to the Future” ride that used to be at a famous amusement park. The customers got into the car and closed the doors. A marvelous hydraulic system tossed them up and down, back and forth, this way and that while they watched a movie screen that depicted the virtual ride. When the ride was over, the doors opened and everybody got out… right where they started. It took 1000 hp to operate the ride but no useful work was done. Every motion was undone. So, where did the energy go? It all went into Btu’s through a huge heat exchanger. The ride was 100% inefficient. Despite all the movement, everyone landed right back where they had started. No work was accomplished. The thrill ride dumped about 42,000 Btu’s per minute into the atmosphere.

The point is this; when we lift a load we give it potential energy. When we set it back down again, we dissipate that energy, usually in the form of heat.

In the earlier article we had an upward acting press with a 32,000 pound platen that had to be lifted at a rate of 5” per second. We did the math and found that (32,000 / 550) * (5/12) = 24.24 or about 25 hp. (This will give you a chance to synchronize your calculators). Reflecting on the DeLorean illustration, it should occur to us that when the press operators turn off the machine and go home for the evening, the 32,000 platen is right where it was when they started up in the morning. A lot of energy had been put in but it had all been undone.

Once the platen is lifted, we could just let it drop and we would have a dramatic illustration of the fact that the potential energy has become kinetic when the platen hit the bottom and suddenly dissipated all its energy into the floor of the building. To avoid this show, I had added a pressure compensated flow control to limit the speed of descent.

We know that when hydraulic fluid goes from high pressure to a lower pressure without doing work the energy is converted into heat. So, here are the questions;

1. Given a 6” bore cylinder controlling a 32,000 pound load and lowering it at 5” per second, what would the pressure be upstream from the flow control? **1132 psi**
2. What would be the flow rate across the flow control? **37 gpm**
3. What would be the hp loss across the flow control? **24.4**
4. What would be the total Btu load added to the fluid if the load dropped 72”? **248 Btu**

From

A Failed Experiment: pages 41 -43

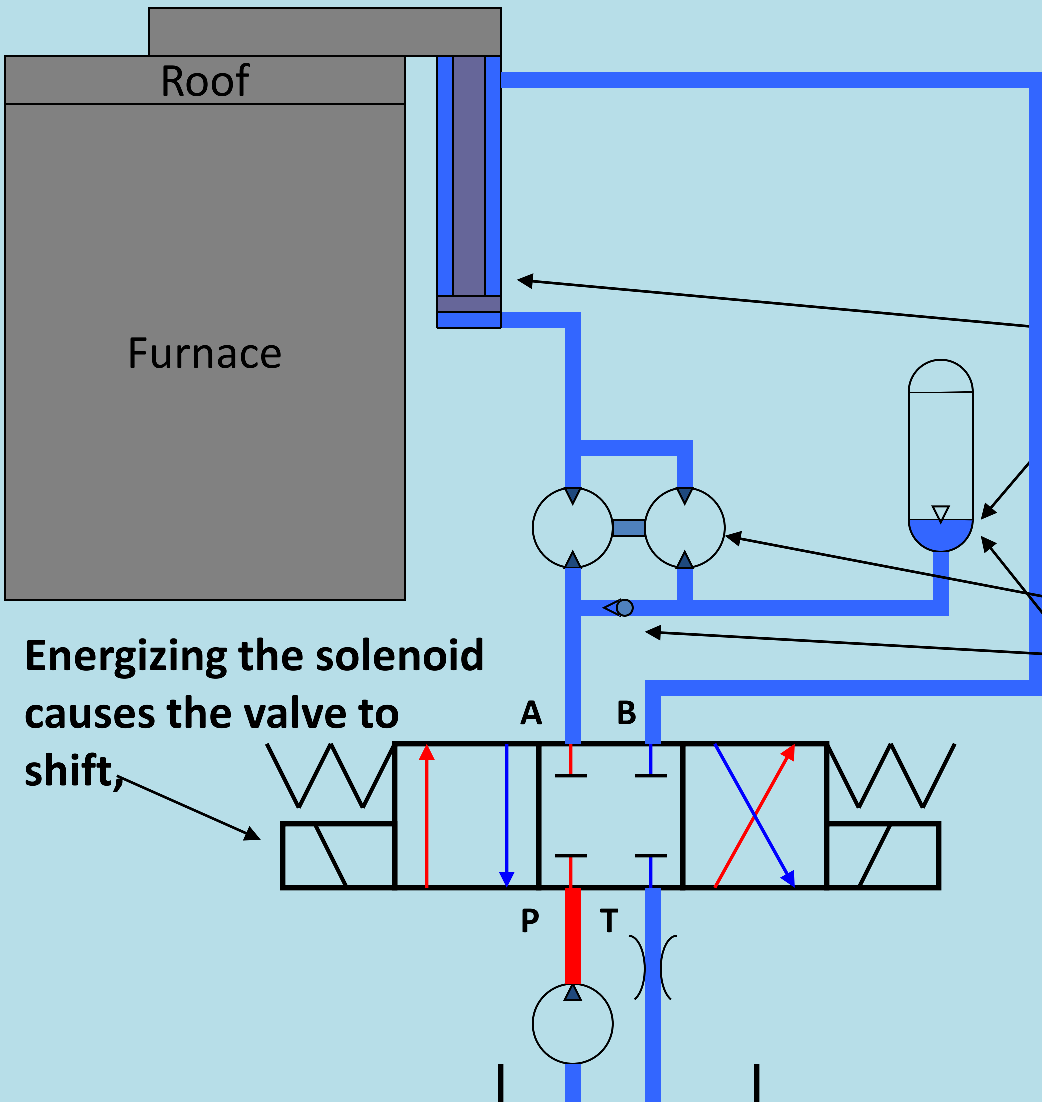
Probably the one barrier that is worse then the “we’ve never done that before” resistance is the “we tried that once but it didn’t work” objection.

I find myself having just created the “we tried that once but it didn’t work” objection.

I am reminded of a quote from Thomas Edison; “I have not failed. I’ve just found 10,000 ways that won’t work.” I am certain that there were times during the 10,000 that he felt the sting of having failed but he pressed on and we are grateful.

Let me explain.

Energy Recovery System



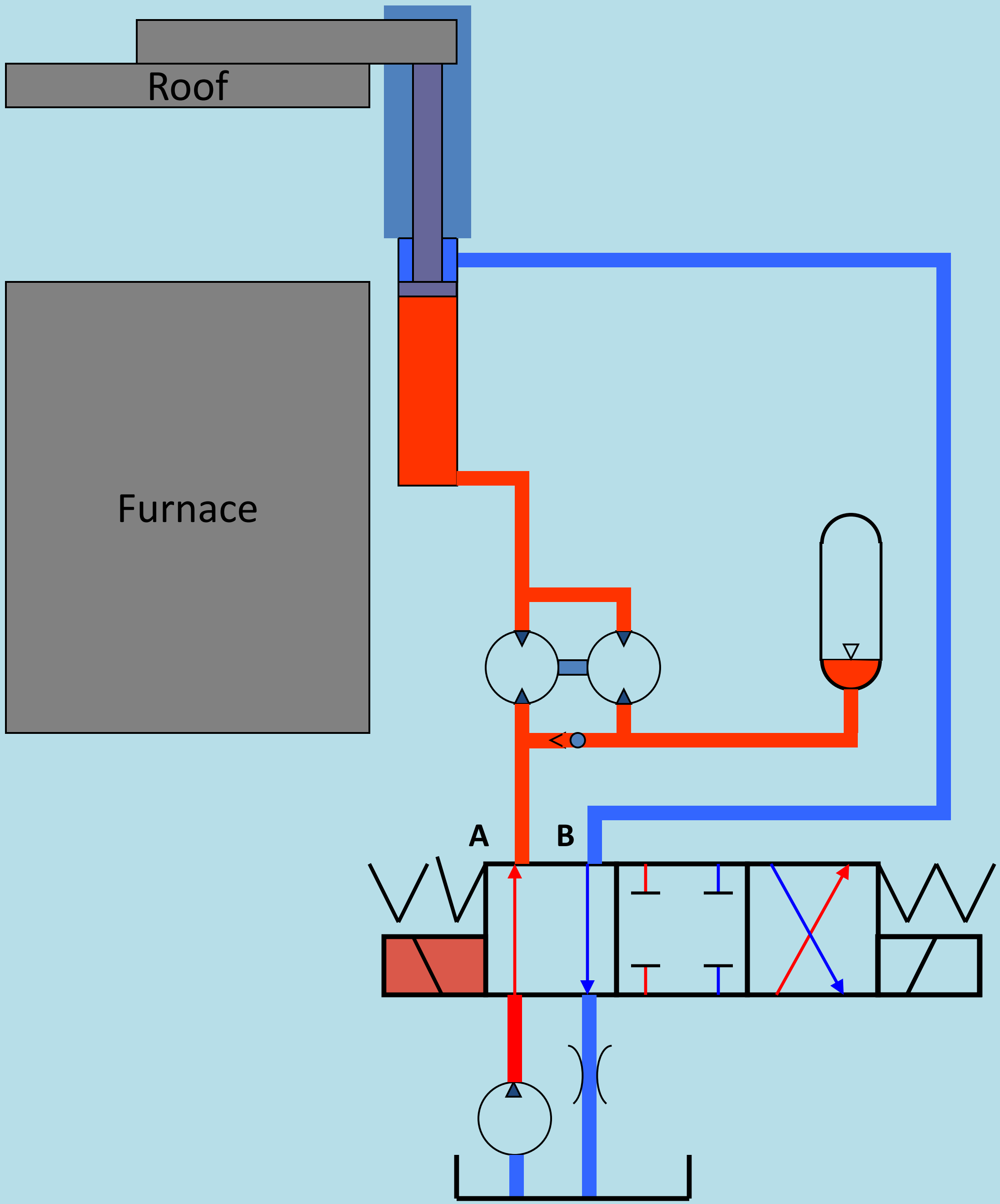
When the pressure in the accumulator rises to where it can begin to lift the load, all pump flow is directed across the displacement device and to the cylinder, lifting the load at pump flow speed.

which directs fluid to the displacement flow divider and across a check valve to the accumulator.

Energizing the solenoid causes the valve to shift,

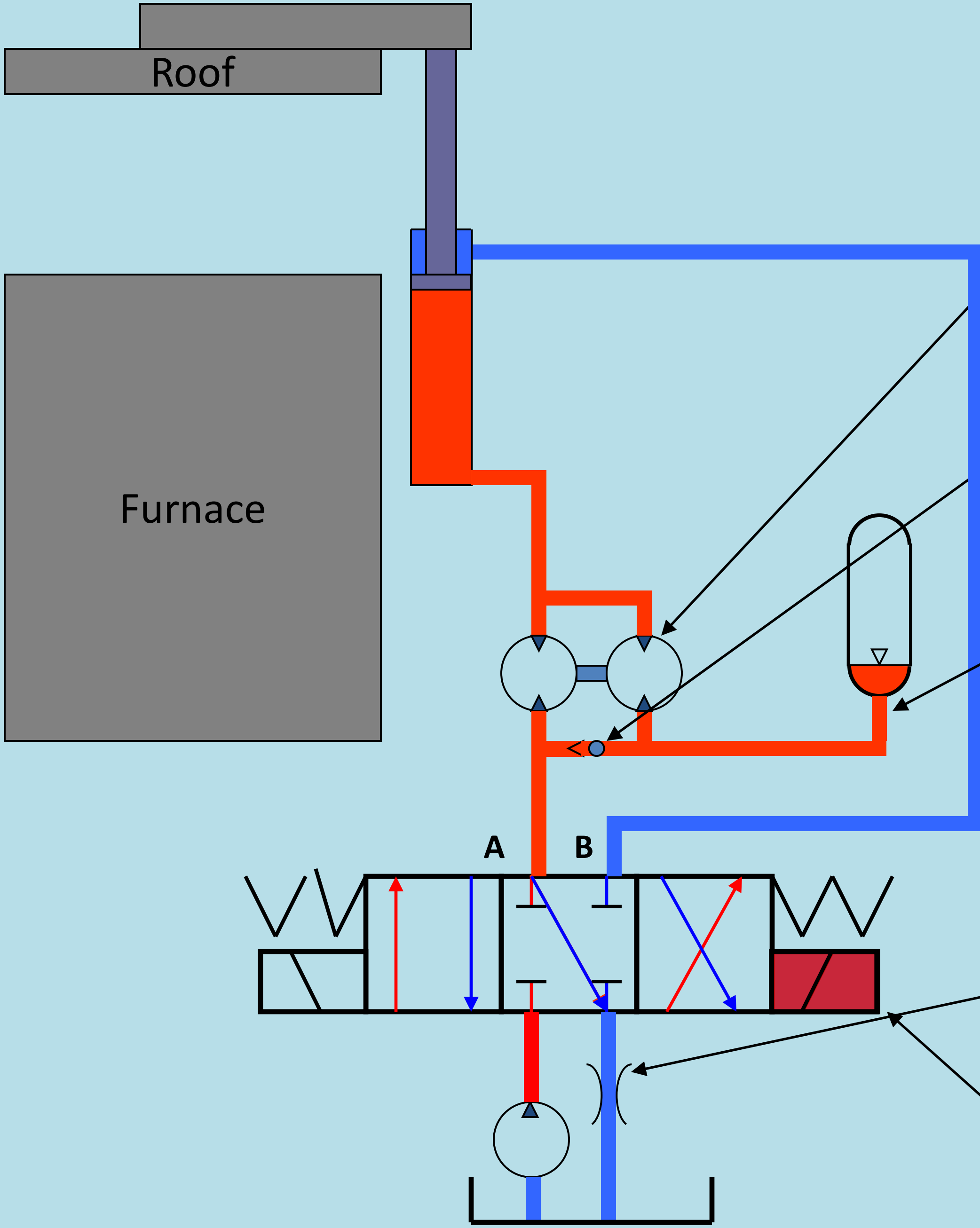
The accumulator is pre-charged to about 90% of the pressure required to lift the load so the initial pump flow is directed to the accumulator.

Energy Recovery System



De-energizing the solenoid returns the valve to the center position and holds the load.

Energy Recovery System



The returning flow passes through the displacement device.

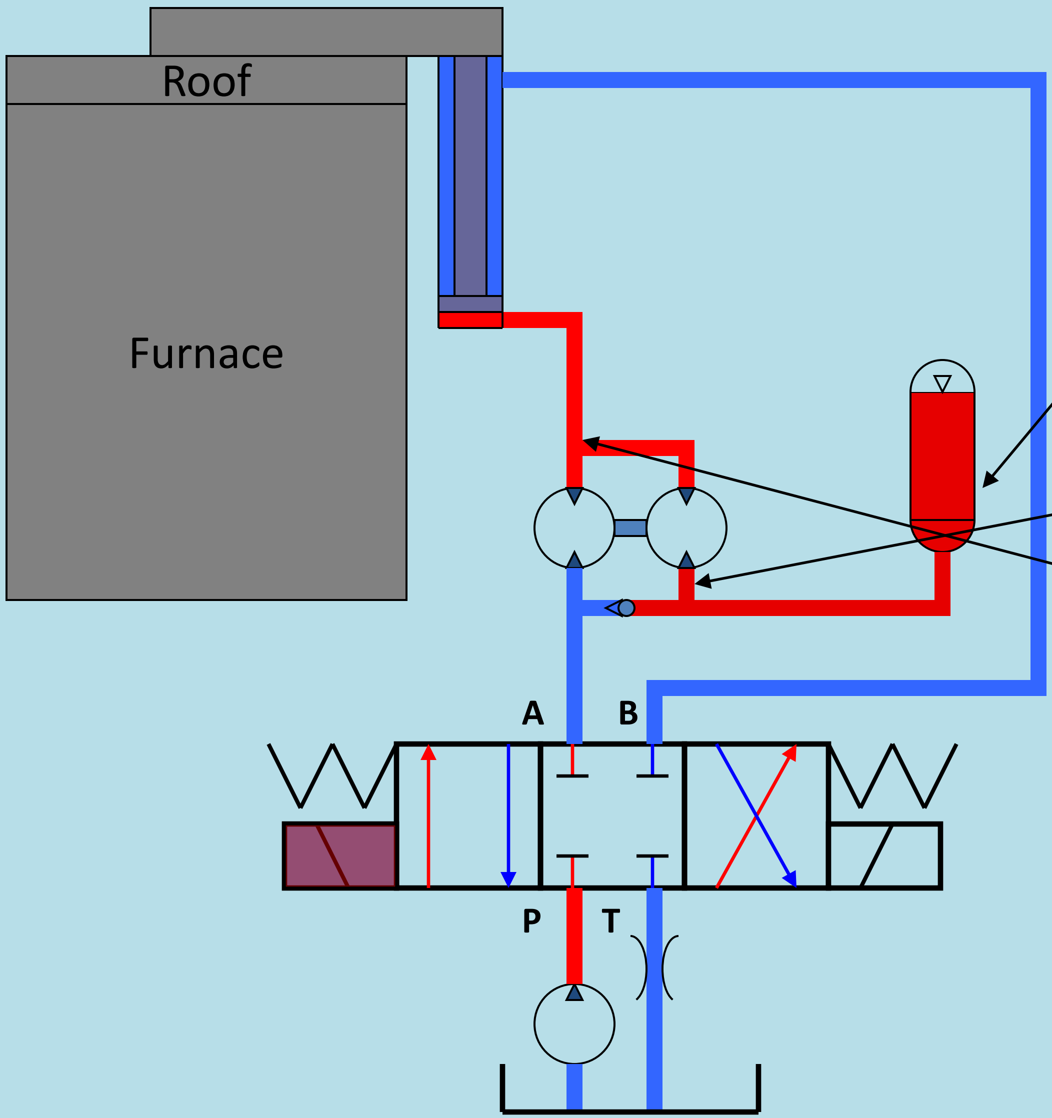
The exhaust from one side of the device is blocked by the check valve and is directed to the accumulator.

The accumulator is already at load pressure and so the pressure rises to a higher pressure based on the ratio of the displacement device.

The cylinder retracts at a speed controlled by the pressure compensated flow control valve.

Energizing this solenoid causes the valve to shift to the lowering position.

Energy Recovery System



When we return the valve to the center condition,

we find that the pressure in the accumulator is almost what is needed to lift the load.

The next time the valve is shifted

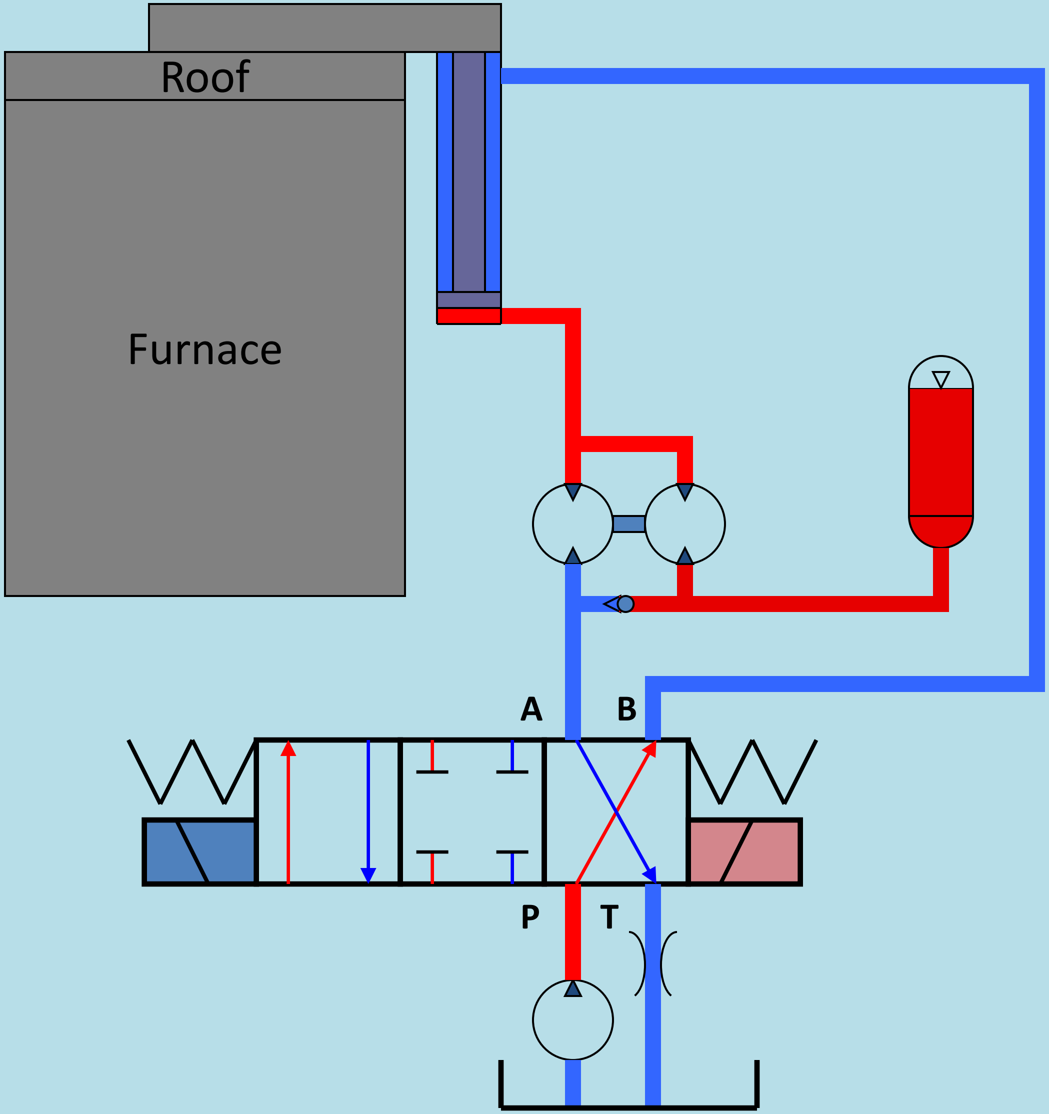
pump flow is directed to the displacement flow divider as before.

But now the accumulator is a power source and directs its flow to the other side of the flow divider.

The pump flow and accumulator flow are combined as they leave the flow divider, driving the load at twice the speed as before,

and with the pump pressure beginning at near zero and gradually increasing to load induced pressure.

Energy Recovery System



After the first cycle, the system will continue to work in the high speed energy recovering mode.

from

“Efficient hydraulic Systems Pages 10 – 12

I think I may have a surprise for you.

We will look at a system and try three different hydraulic systems and see which is best from an energy perspective. The requirements are these:

- a hydraulic pump needs to supply either 17 or 20 gpm at either 1750 or 2100 psi to do some work.
- 20% of the time the system operates at maximum flow and maximum pressure.
- 20% of the time it is at maximum flow and minimum pressure.
- Another 20 % of the time it sees minimum flow at maximum pressure.
- 5% of the time it is at minimum flow and minimum pressure.
- That leaves 35% of the time during which the system is idle (dwells).

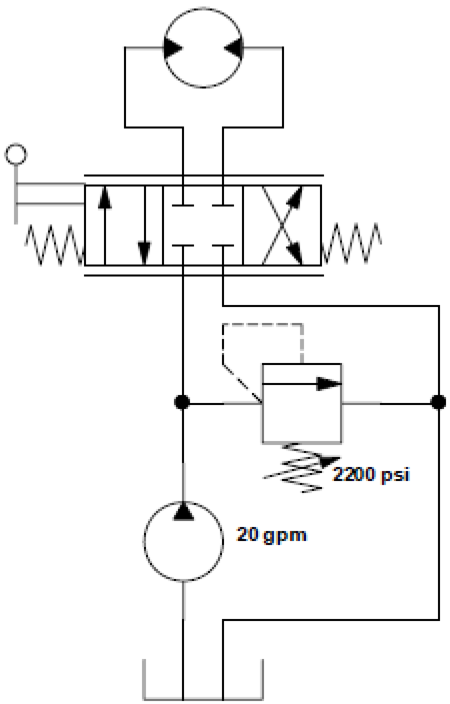
We will first use a fixed displacement pump, a relief valve, and a metering directional control valve that has a center condition with all ports blocked.

We will then try a fixed displacement pump, a relief valve, and a metering directional control valve with a center condition where all pump flow goes to tank (a bleed off circuit).

Finally, we will try a pressure compensated pump and a metering directional control valve with a center condition having all ports blocked.

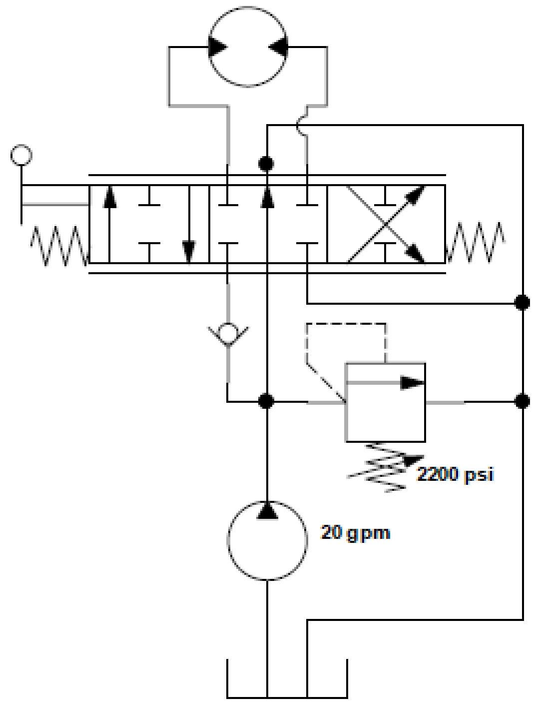
Option 1

Fixed pump / Relief valve



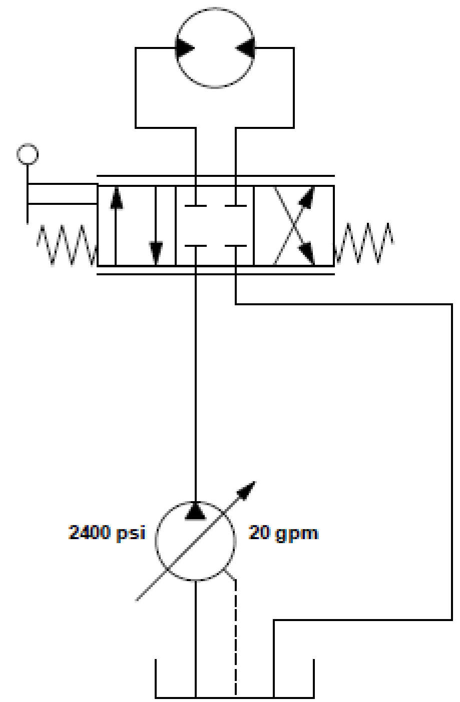
Option 2

Fixed pump / Bleed off

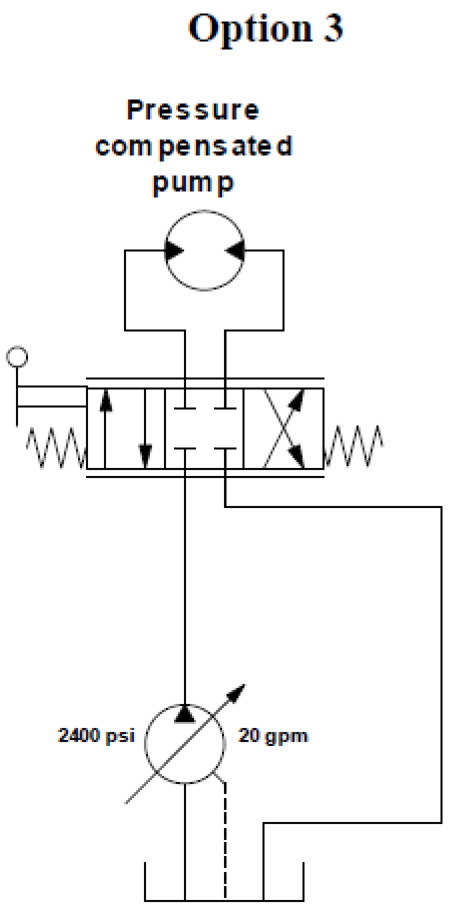


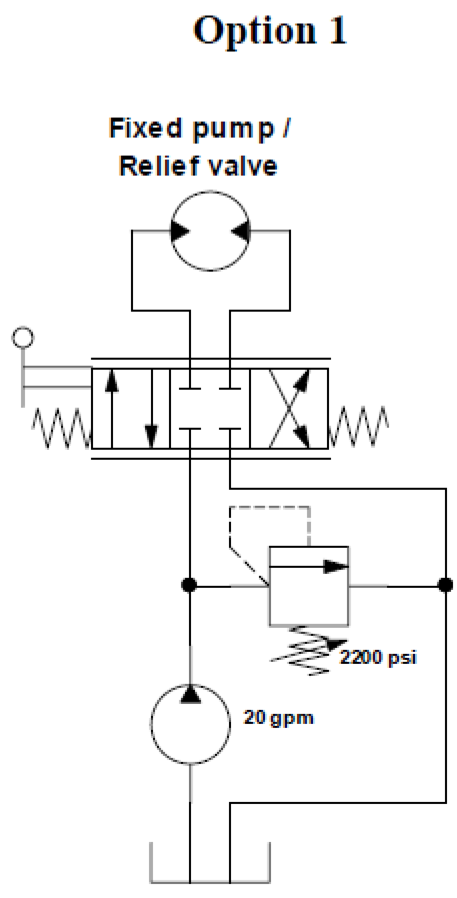
Option 3

Pressure compensated pump



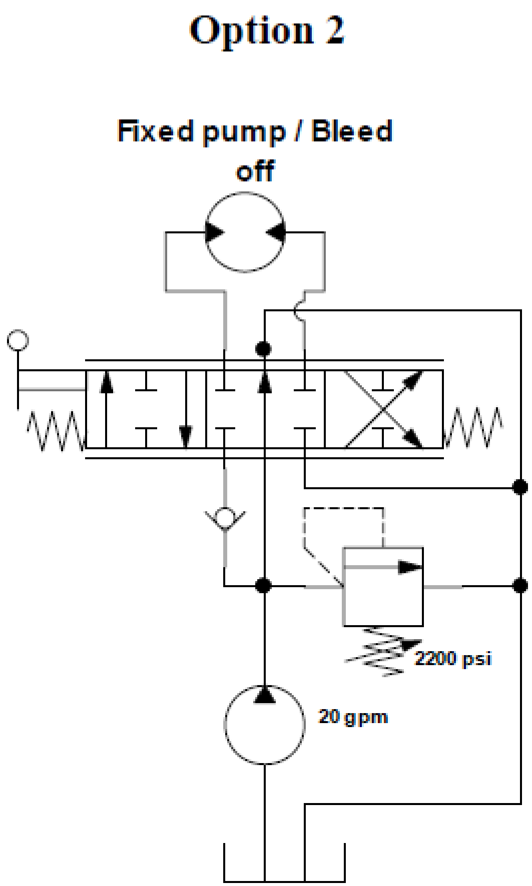
System Information			Fixed Displacement Closed Center	Fixed Displacement Bleed Off Center	Pressure Compensated
Max Flow to Motor	20	GPM	20	20	20.25
Min Flow to Motor	17	GPM	20	20	17.25
Max Pressure (ΔP)	2100	PSI	2200	2100	2400
Min Pressure	1750	PSI	2200	1750	2400
Circulating Pressure	100	PSI	100	100	2400
Dwell Flow	20	GPM	20	20	0.25
Relief Pressure	2200	PSI	2200	2200	
Compensator Pressure	2400	PSI			2400
Max Flow/Max Pressure	20	%	20%	20%	20%
Max Flow/Min Pressure	20	%	20%	20%	20%
Min Flow/Max Pressure	20	%	20%	20%	20%
Min Flow/Min Pressure	5	%	5%	5%	5%
Dwell Time	35	%	35%	35%	35%
Max HP	**25.67**	**HP**	**26.84**	**25.67**	**28.35**
Max Flow Low PSI HP	21.59	HP	26.84	21.59	28.35
Min Flow High PSI HP	21.82	HP	26.84	25.67	24.15
Min Flow/Low PSI HP	18.35	HP	26.84	21.59	24.15
Dwell HP	1	HP	26.84	1.17	0.35
Average HP	**15.14**		**26.84**	**16.07**	**17.50**

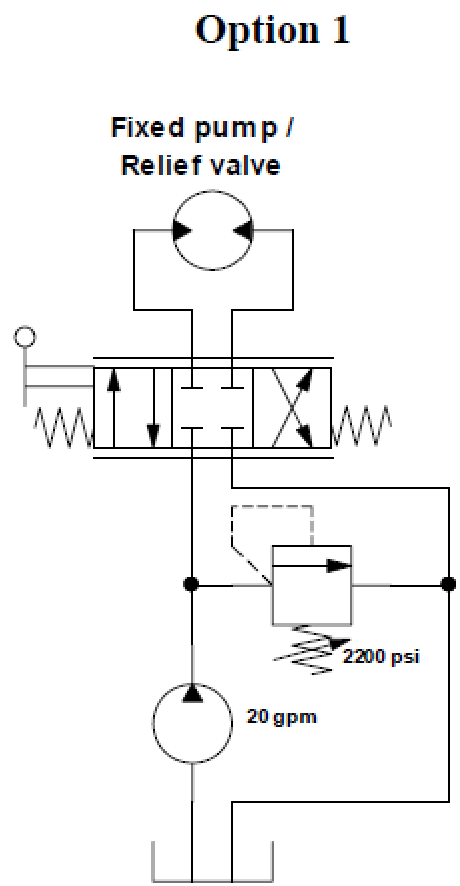




The pressure compensated pump and the fixed closed center system have something in common. They are always at maximum pressure at the pump. The difference is the flow. The fixed pump produces 20 gpm continually. Any flow that is not needed for the job is sent across the relief valve at full pressure. So this system always operates at maximum hp no matter what.

The pressure compensated pump always operates at its set pressure but it will vary the flow based on demand. But when the required pressure is less than the compensator setting, there is a pressure drop across the metering directional control valve. The excess energy goes into heat. In addition, there is a constant case drain flow of about .25 gpm which is also generated at compensator pressure. So, even when in dwell mode, the system remains at compensated pressure.





The bleed-off system and the fixed closed center system also share a characteristic. They both produce all the flow all the time. The big difference, listen up now, the big difference is that the fixed closed center system is always at **relief pressure**. The bleed-off system is always at **load pressure**. Any excess flow from the bleed-off circuit is diverted to tank at load pressure, not at relief pressure. In a dwell mode, all flow is directed to tank at a low pressure.

I am not saying that the bleed-off system is *always* the best. I am trying to point out that we need to do our homework and look at all the options when offering the best in Fluid Power.

Forget the fudge factor, reject the rule of thumb, shun the shortcut, do the math.

From

A Failed Experiment: pages 41 -43

Probably the one barrier that is worse then the “we’ve never done that before” resistance is the “we tried that once but it didn’t work” objection.

I find myself having just created the “we tried that once but it didn’t work” objection.

I am reminded of a quote from Thomas Edison; “I have not failed. I’ve just found 10,000 ways that won’t work.” I am certain that there were times during the 10,000 that he felt the sting of having failed but he pressed on and we are grateful.

Let me explain.

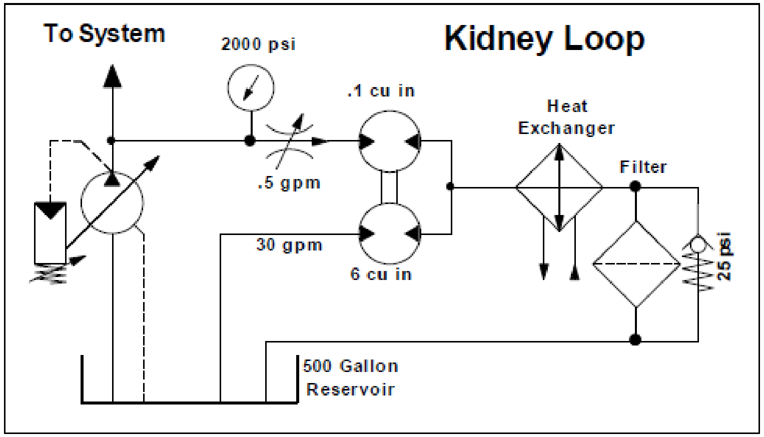
From

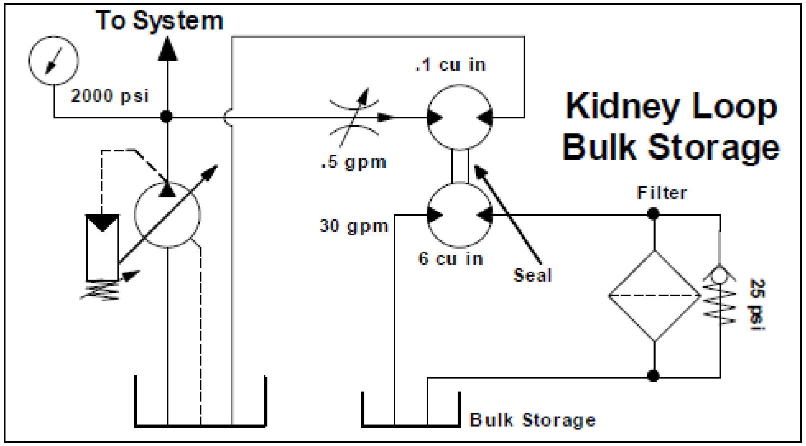
You Made the Mess;

Now You Clean It Up! Pages 53 - 55

Now, don't laugh, but I once designed a hydraulic system for automatically cleaning horse stalls using the energy from the movement of the waiting horse. I won't get into the details but I was going to market it with the slogan, "You made the mess, now you clean it up!"

When I think about the way we usually do off-line filtering and cooling, I was reminded of this. Our systems generate the particles and the heat that needs to be removed. So, why do we ask electric motors to drive our off-line filtering and temperature control systems?





The “Perfect” Hydraulic System