Energy Efficient Hydraulics and Pneumatics Conference

Methods and Tools to Identify, Analyze, Compare and Reduce Energy Losses in Industrial Hydraulic Systems

November 27-29, 2012

Chicago Marriott O'Hare Hotel

Chicago, IL

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…Energy Losses in Industrial Hydraulic Systems

- What is Energy?
- Energy Losses & Inefficiencies
- Hydraulic Circuit Approaches
- Energy Calculators

FLUID POWER SOCIETY INTERNATIONAL · THE FPDA MOTION & CONTROL NETWORK · NATIONAL FLUID POWER ASSOCIATION NFPA

Energy via Coal Burning Plant

Nuclear Energy

Wind Energy

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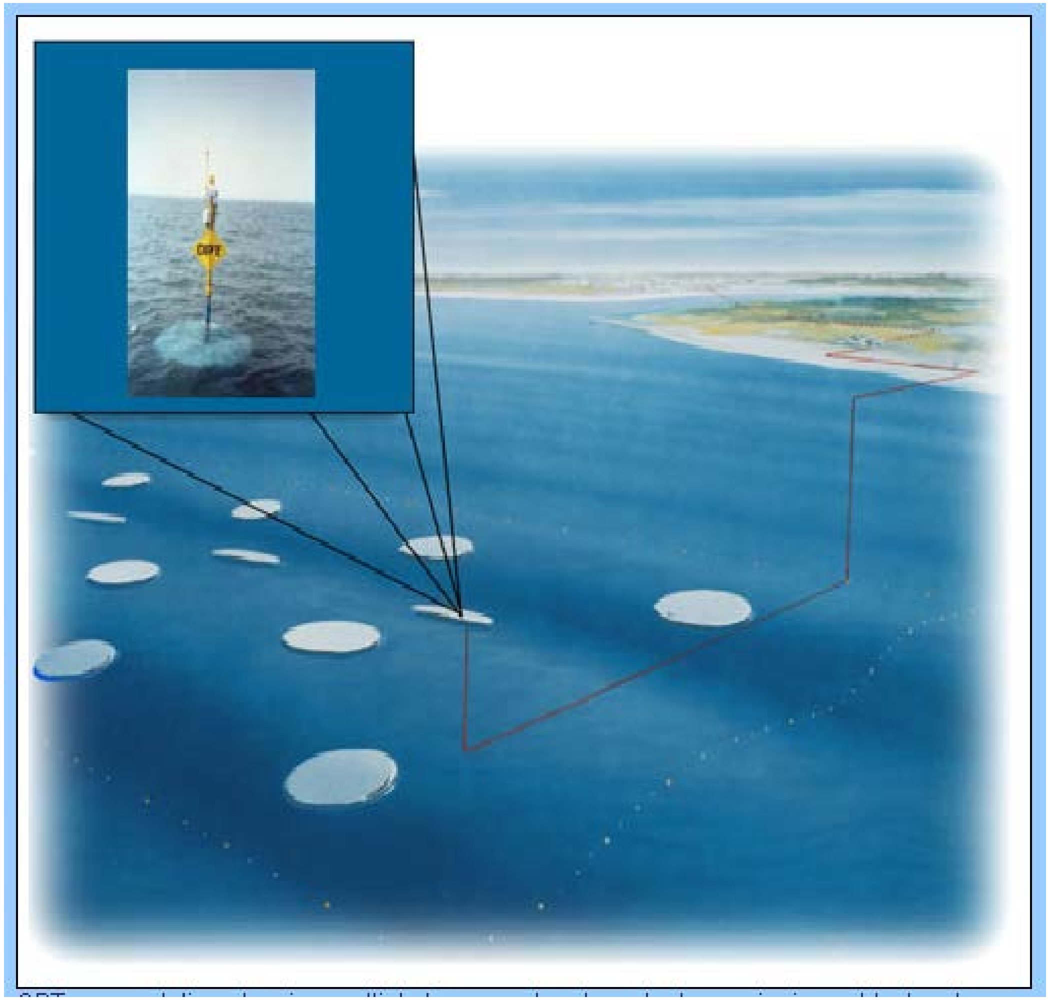
Wave Energy



Riding the Waves

The ocean offers hope for green energy, and a New Jersey company is among those developing technology to harness that power.

By Sandy Bauers

Inquirer Staff Writer

Five miles off the southern tip of Long Beach Island, an oversize yellow buoy floats alone,

purposefully mounting the waves and occasionally phoning home.

After two years it has proven itself, at least to its inventors,

as a workable design for what may well be the biggest technological

quest of the 21st century: renewable energy.

With every significant bob of the buoy, pistons slide up

and down inside a cylinder, generating electricity.

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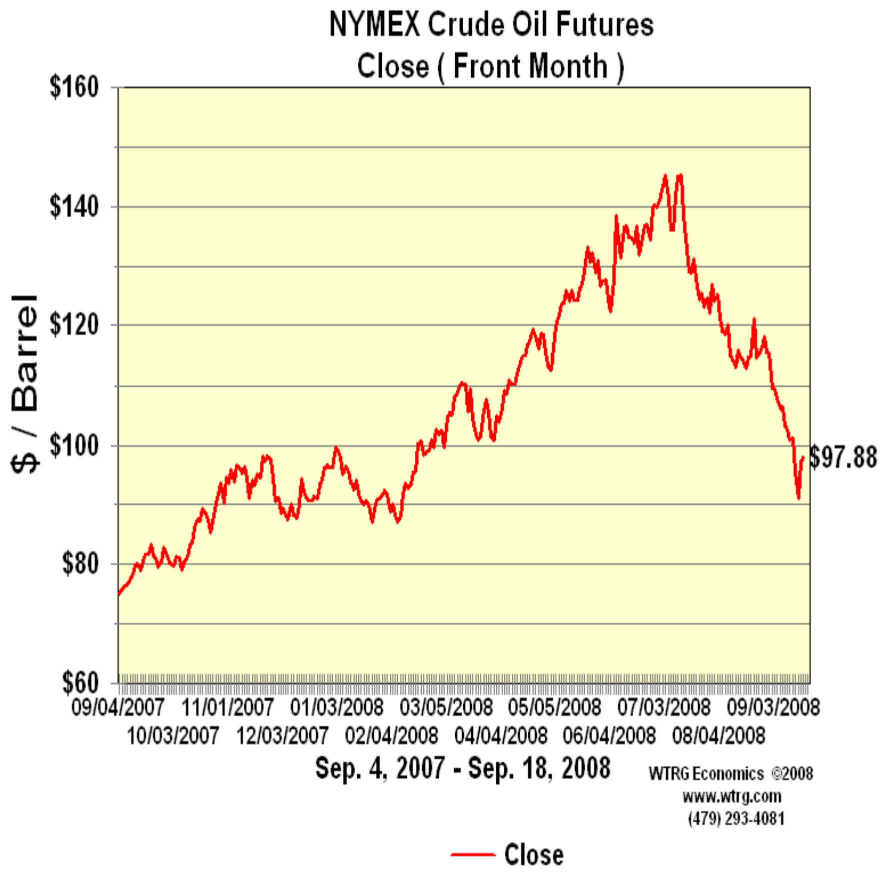
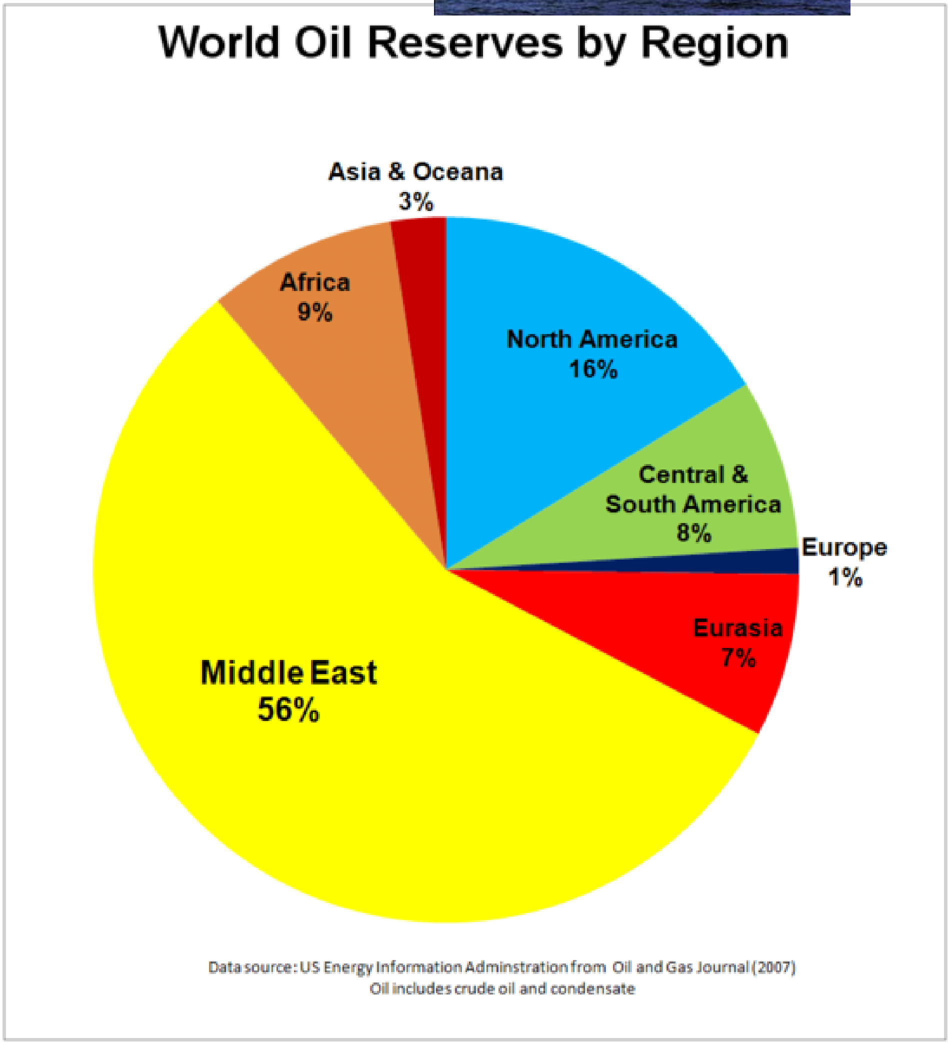
Energy & Power

Energy & Power





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Energy & Power

Europe Worries About a 1970s-Style Oil Shock

Juan Medina/Reuters

Truck drivers blocked a highway in Madrid this week in a protest against rising fuel costs.

Eric Conrad, manager of the Ideal gasoline station in Madisonville, Ky., changes the price for unleaded fuel Friday, from $3.62 to $3.99 a gallon. Hurricane Ike has pushed prices higher.

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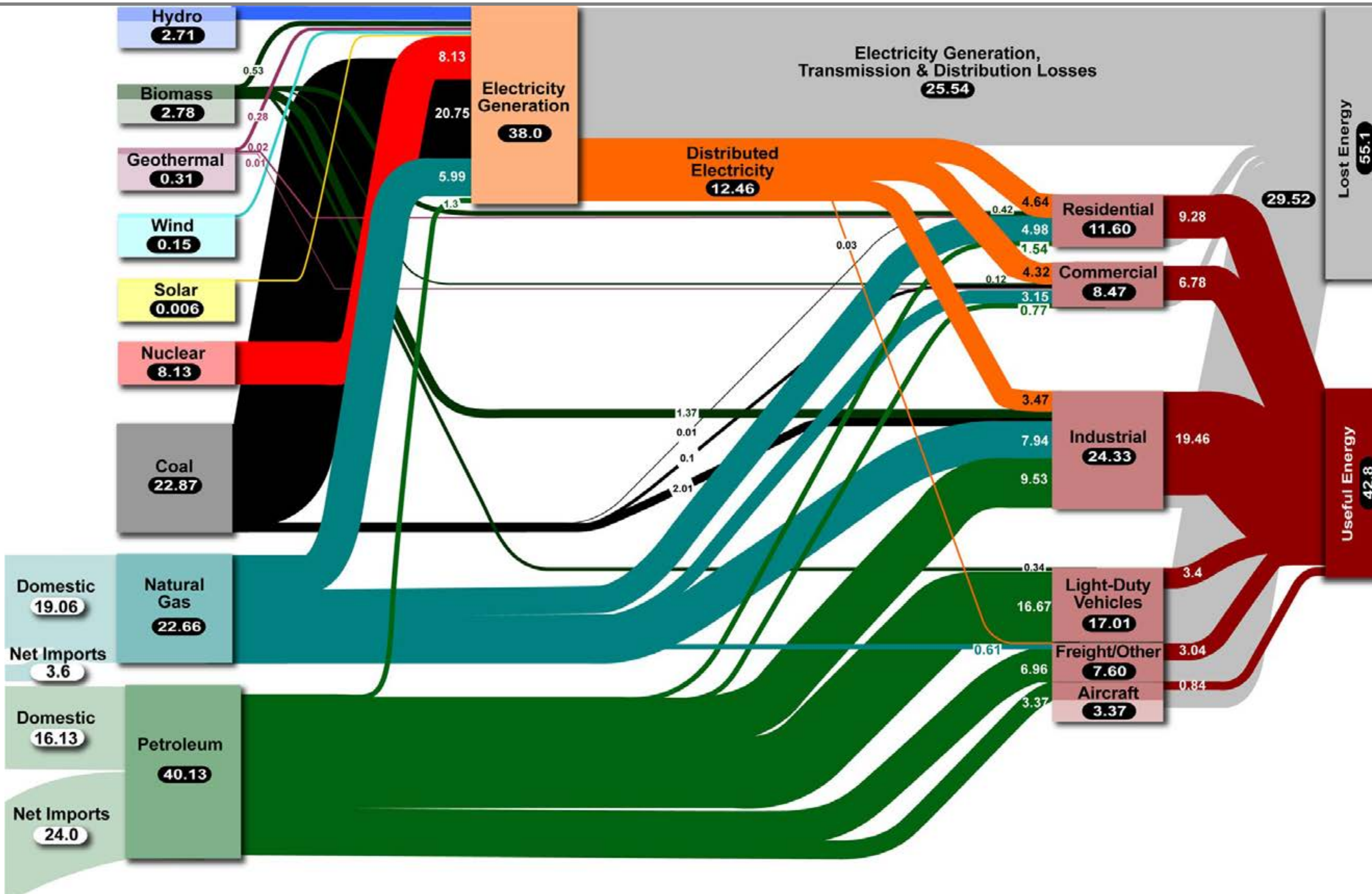
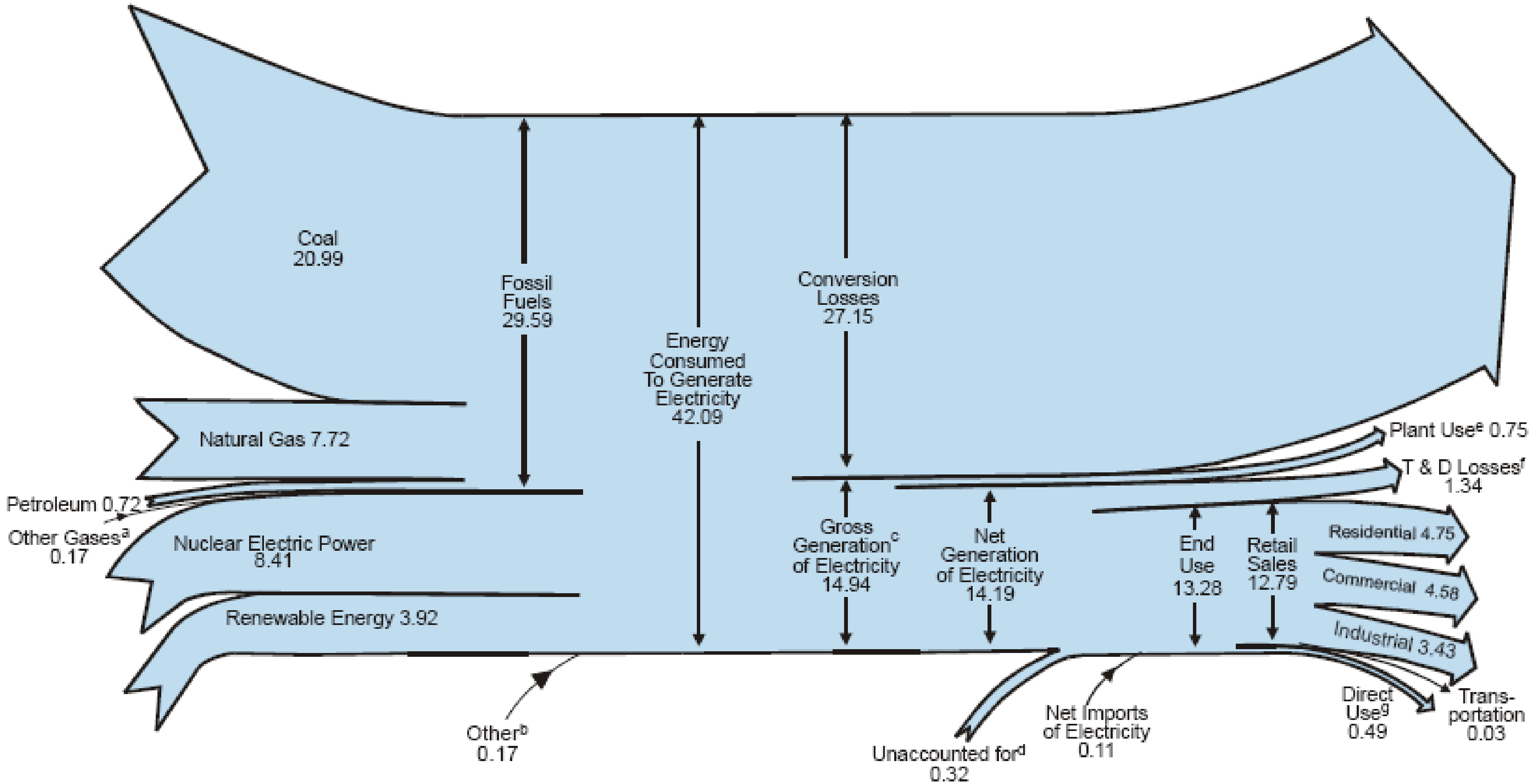
Energy Summary - US



Source:-https://eed.llnl.gov/flow/

US Electricity Flow, 2007



Source: http://www.eia.doe.gov/

Plant Energy Overview

- Motor-driven equipment accounts for 64% of the electricity used in the U.S. industrial sector, according to the U.S. Department of Energy (DOE). That’s approximately 290 billion kilowatt hours (kWh) of power per year.

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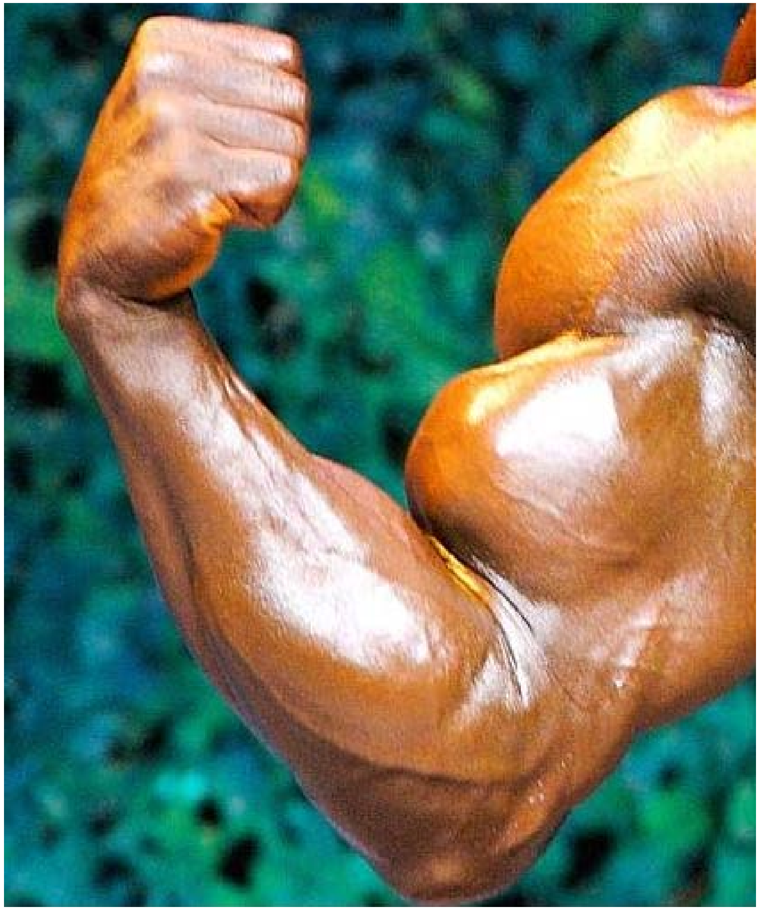
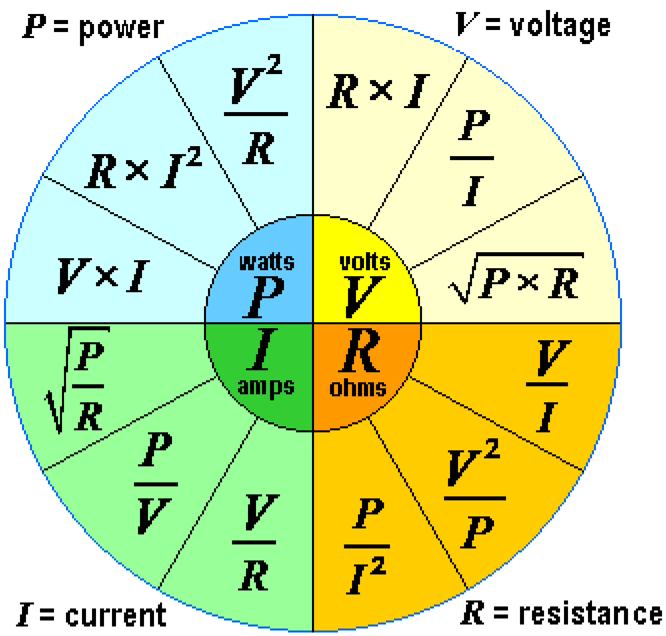
What is Energy?

ENERGY : ABILITY to perform **WORK (KWH)**

Power: Energy transferred per unit of time (KW, HP)



Electrical Power



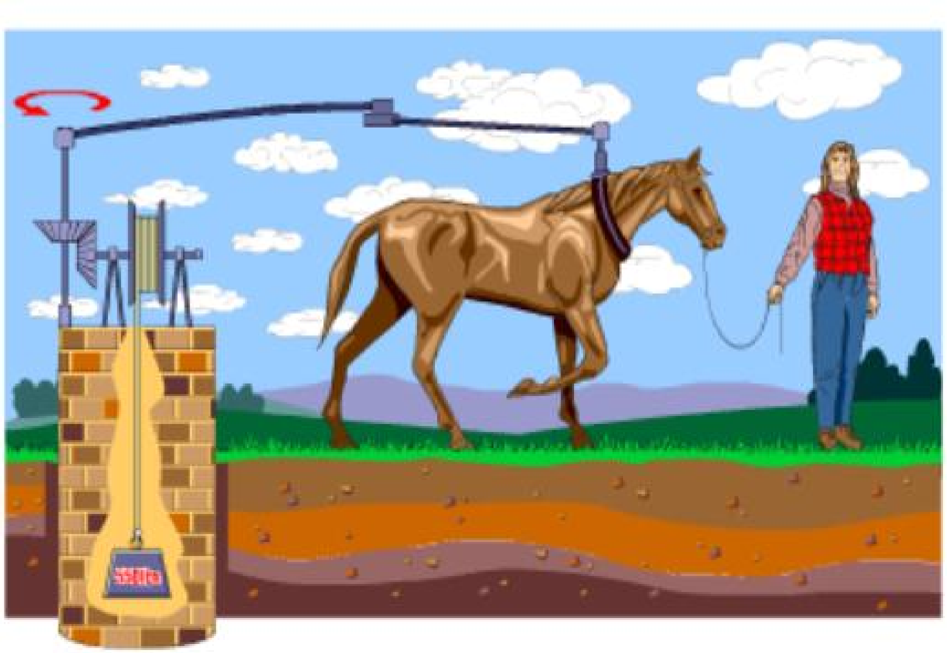
P - POWER in WATTS

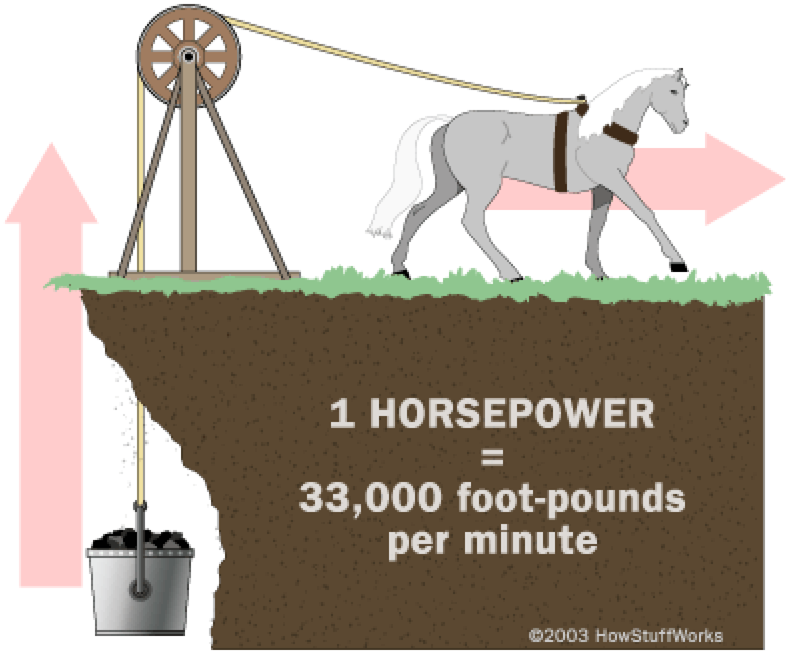
V - VOLTAGE in Volts

I – CURRENT in AMPHERE

R – RESISTANCE in OHM

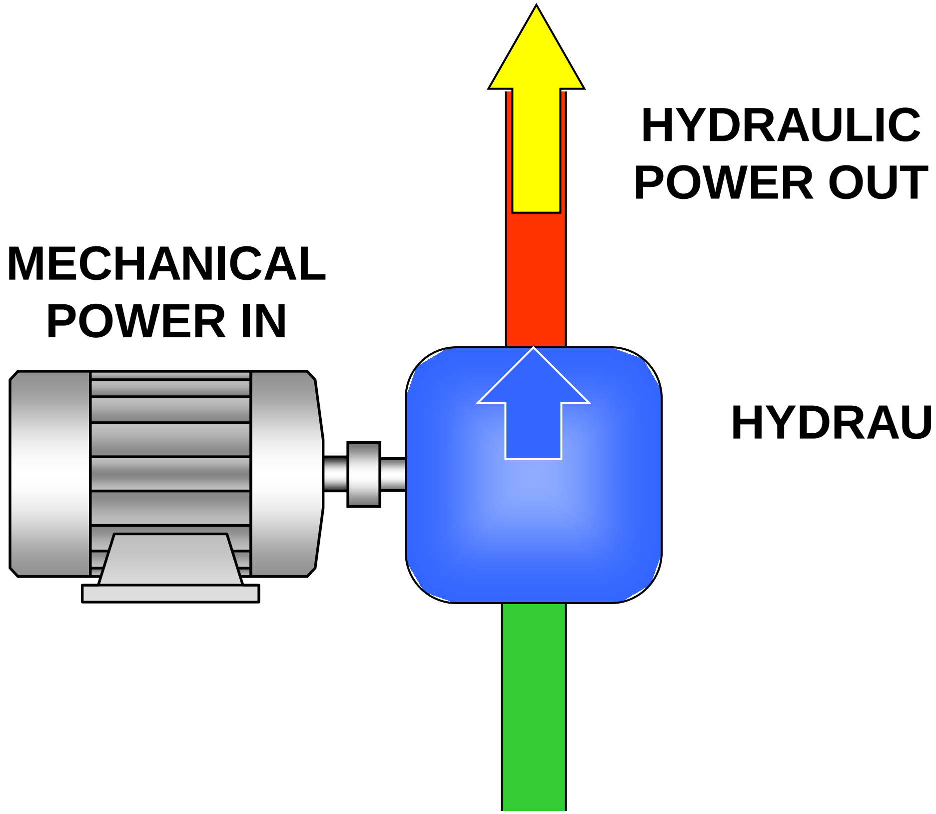
Mechanical Power





$$\text{POWER (HP)} = \frac{\text{TORQUE in lb-ft} \times \text{SPEED in rpm}}{5252}$$

Hydraulic Power



HYDRAULIC POWER = FLOW x PRESSURE

$$\text{POWER (HP)} = \frac{\text{PRESSURE (psi)} \times \text{FLOW (gpm)}}{1714}$$

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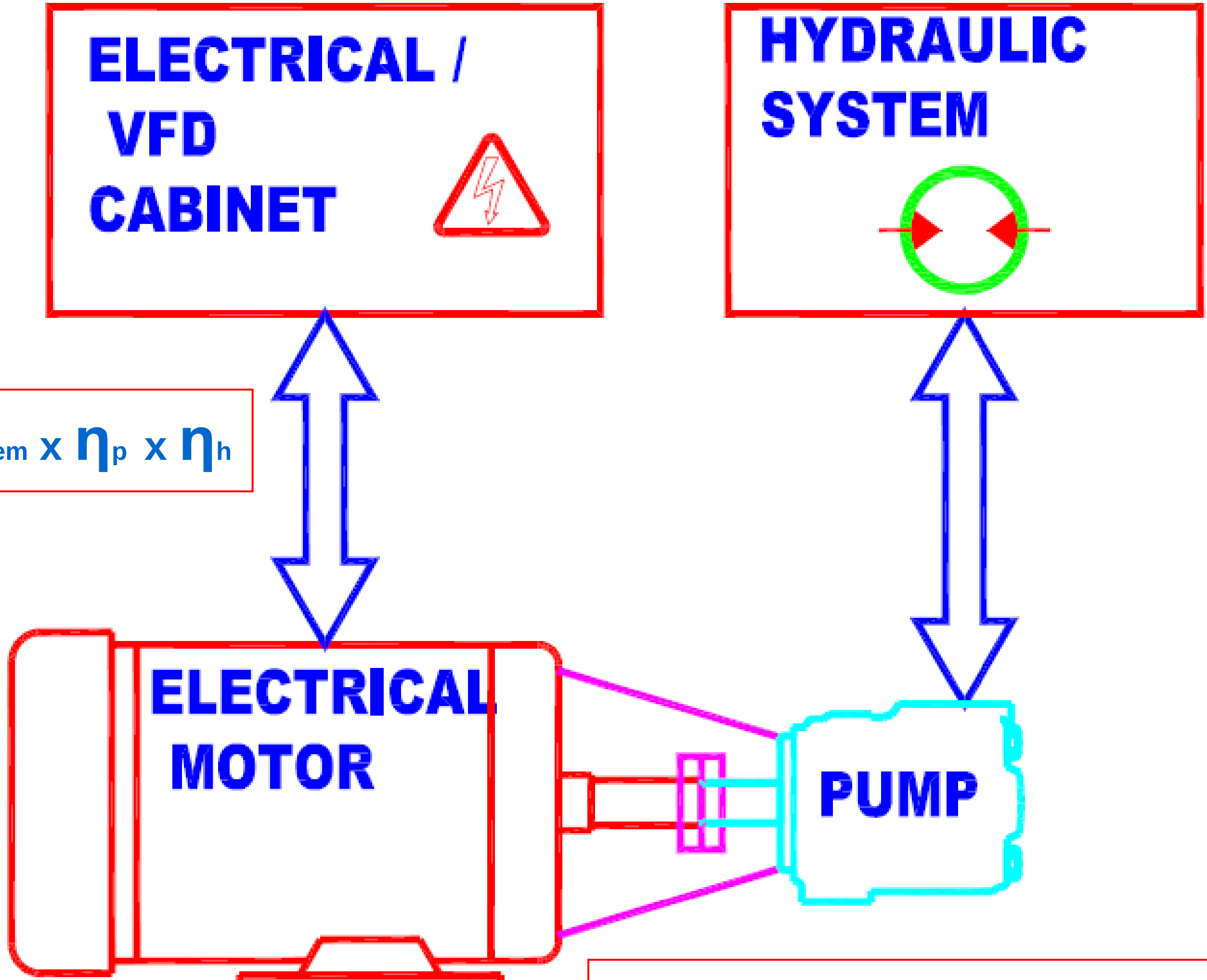
TYPICAL ENERGY FLOW



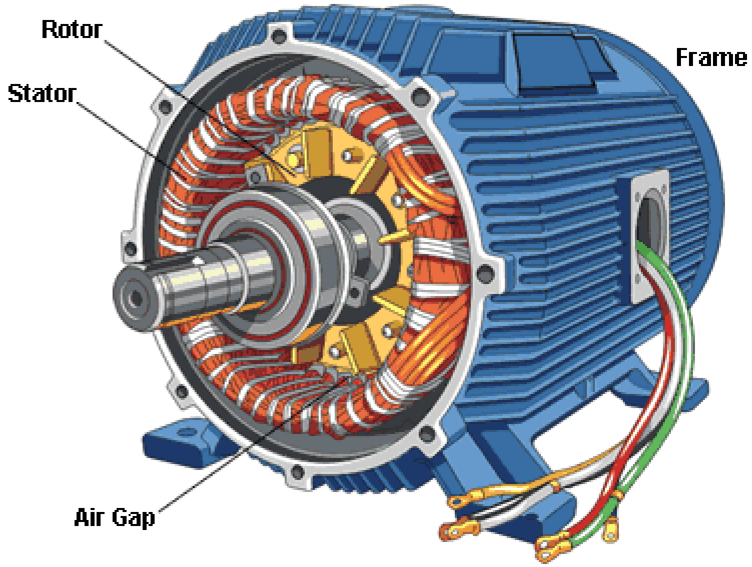
$$\eta_o = \eta_{dr} \times \eta_{em} \times \eta_p \times \eta_h$$

$$L_o = L_{dr} + L_{em} + L_p + L_{h1} + (L_{h2})$$

LOSSES - Electrical

CONTROL CABINET / VFD LOSSES

- VFD LOSES - 2% TO 5%



MOTOR LOSSES

- STATOR Cu LOSSES
- ROTOR Cu LOSSES
- IRON LOSSES
- MECHANICAL FRICTION & WINDAGE LOSSES
- STRAY LOAD LOSSES

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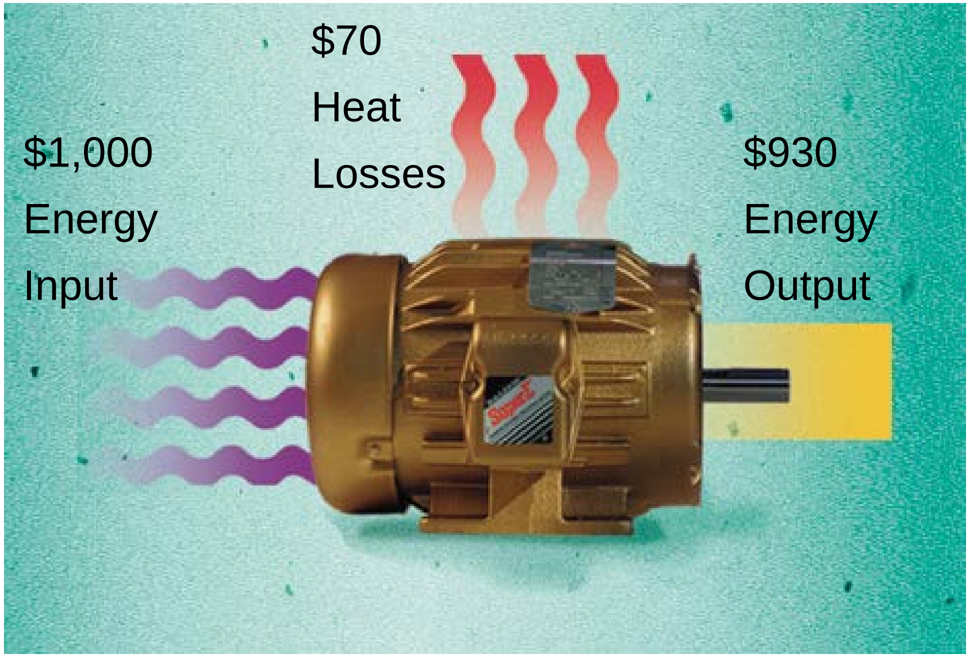
Electric Motor Efficiency

The efficiency of any machine, including an electric motor, is determined by the amount of useful power it produces compared to the amount of electricity required to operate it. This graphic illustrates how an Electric Motor effectively turns in $1000 electrical power into $930 worth of mechanical power. Since motor efficiencies are commonly expressed as a percentage, you can see that this rating equals 93 percent.



LOSSES – HYDRAULIC SYSTEM

HYDRAULIC PUMP LOSSES	SYSTEM LOSSES

• INTERNAL LEAKAGE
  • Rotating group
  • Controls
• MECHANICAL LOSSES
  • Friction
  • Bearings
  • Windage
• $\eta_o = \eta_v \times \eta_t$
	• Passages/Line ΔPs
	• Valve Leakage
	• Circuit design
	  • Excess Flow
	  • Excess Pressure
	• Cooler HP

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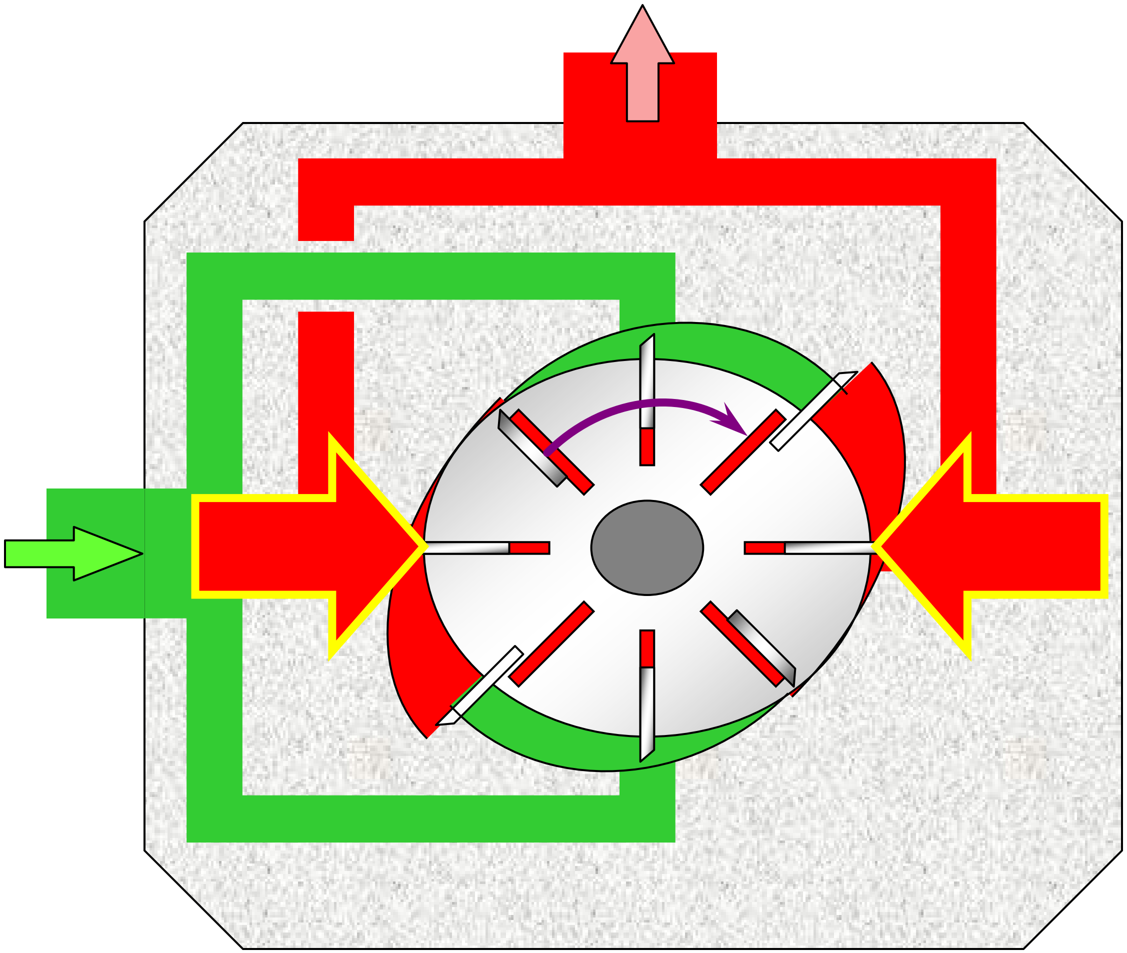
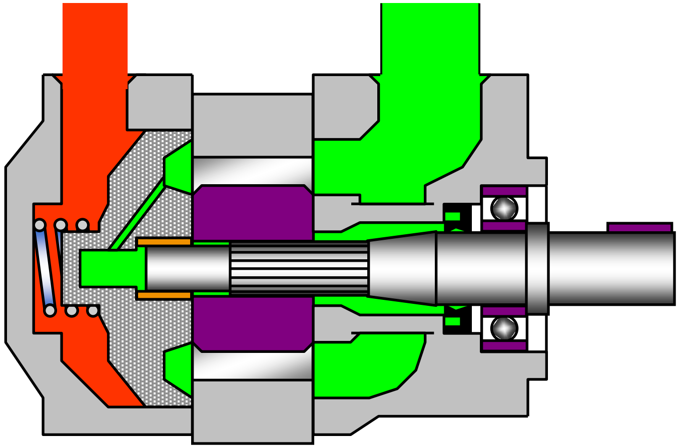
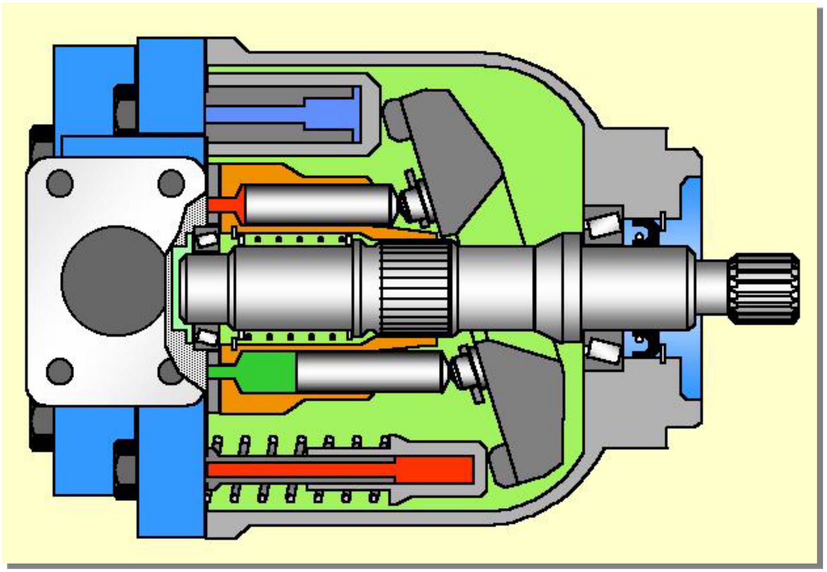
Design Basics:

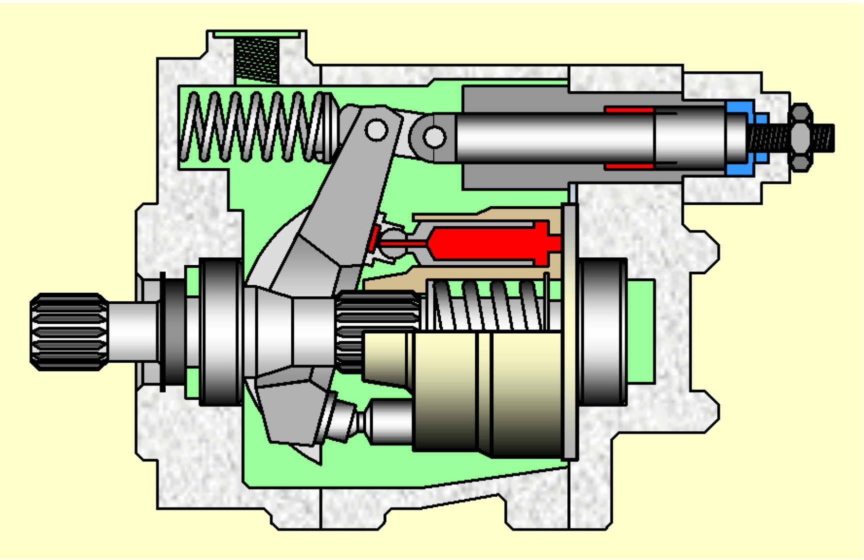
Fixed Displacement Pump

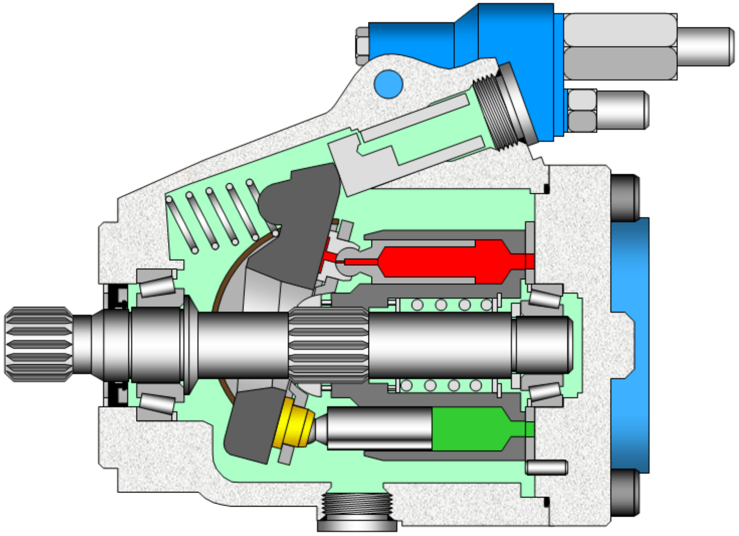




Piston Pump Cross-sections







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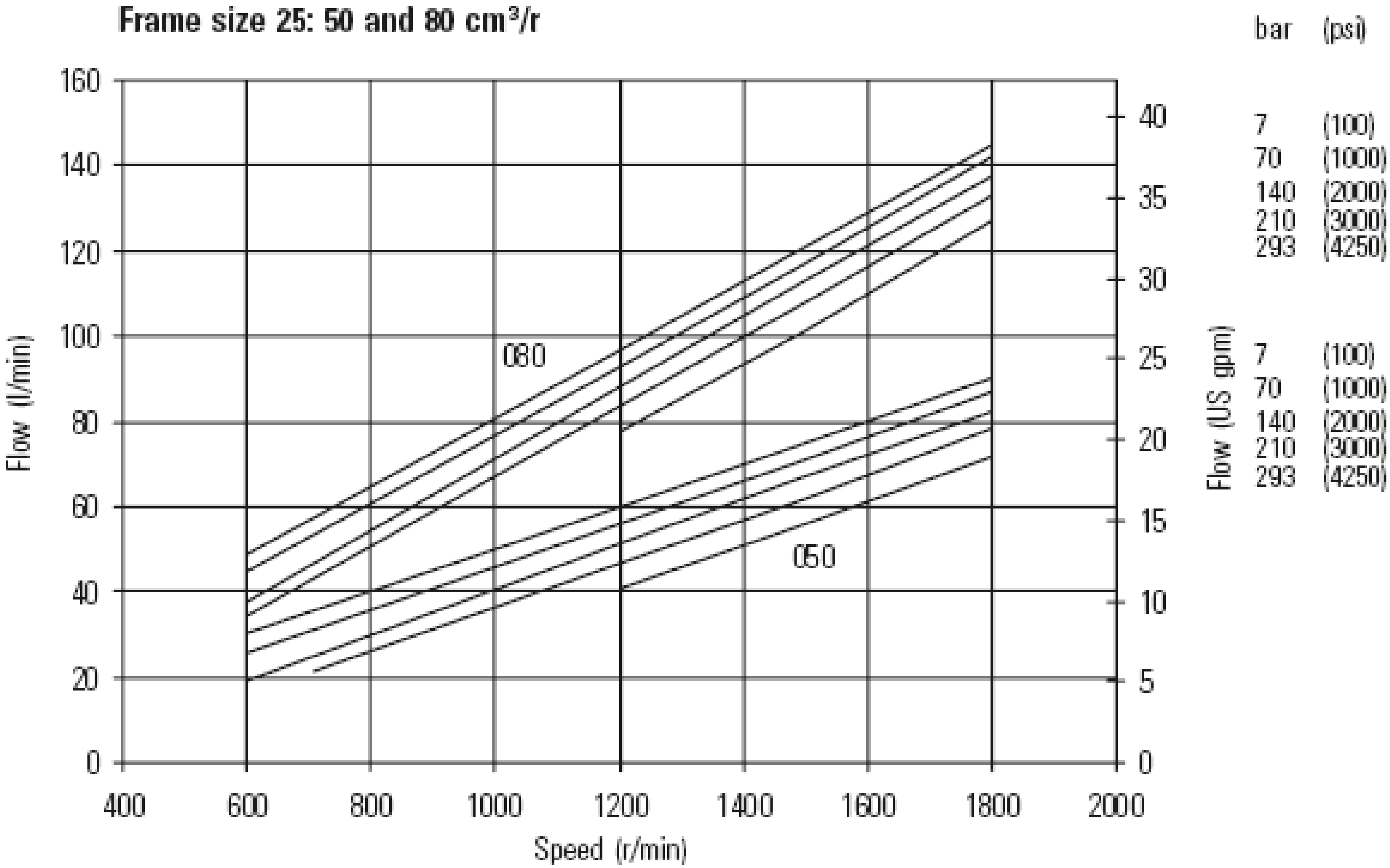
Fixed Pump Performance curves



PUMP PERFORMANCE CURVE

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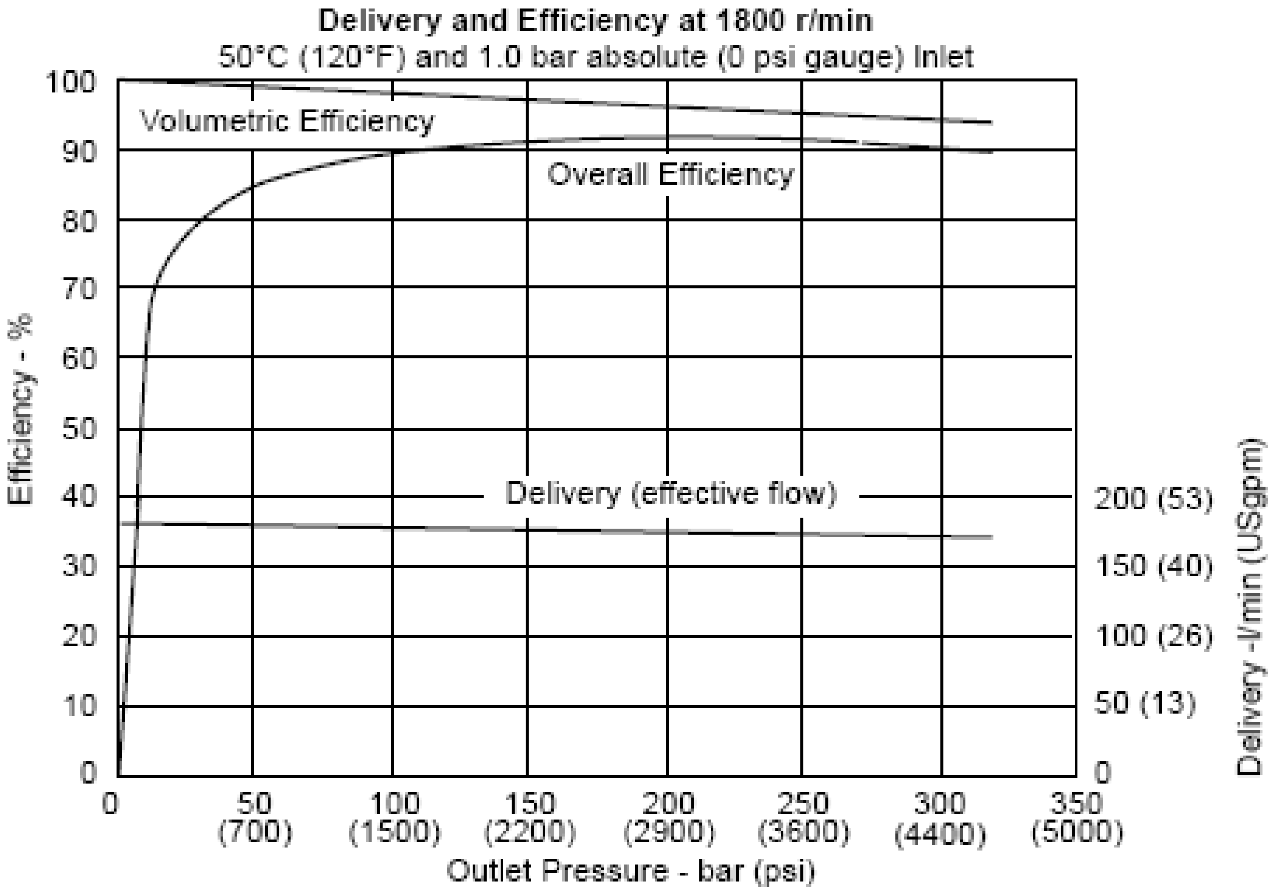
Variable Pump Performance curves



PUMP PERFORMANCE CURVE

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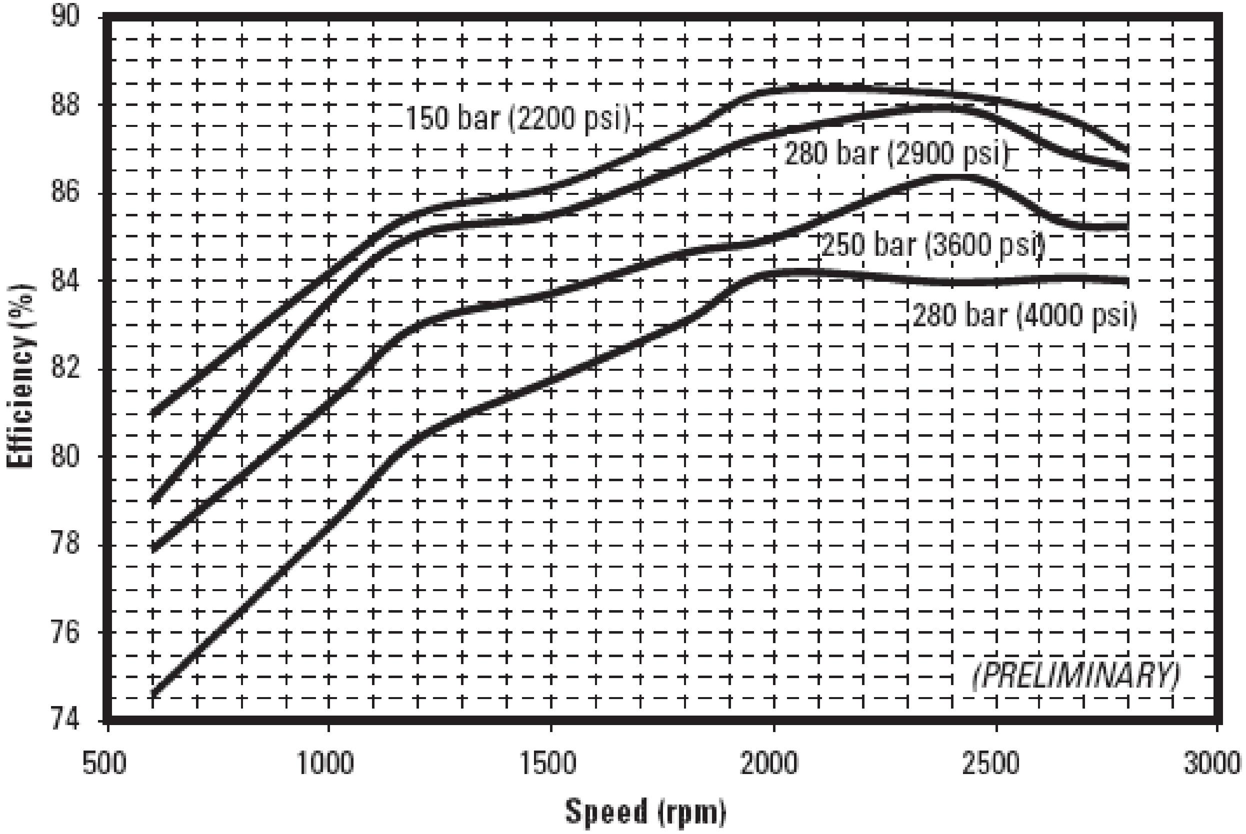
Variable Pump Performance curves



PUMP SPEED Vs EFFICIENCY

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Fluid Power Society International
THE FPDA MOTION & CONTROL NETWORK
National Fluid Power Association • NFPA •

Hydraulic System LOSSES

- Simple Circuit w/ minimal valves -25% Loss
- Simple Circuit w/ cylinders - 28% Loss
- Simple Circuit w/ Fluid motors - 31% Loss
- Hydrostatic transmissions - 35%-40% Loss
- Servo Based system -55% Loss
- Low Pressure Fluid Transfer Systems – 15% loss

Source: Lightning Reference Handbook

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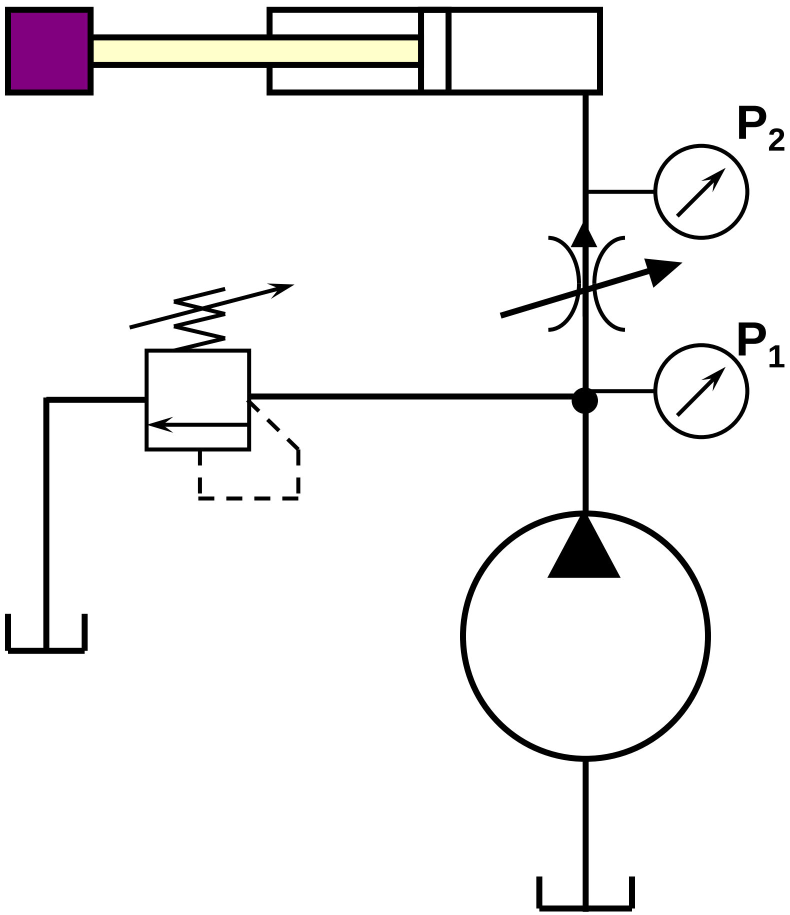
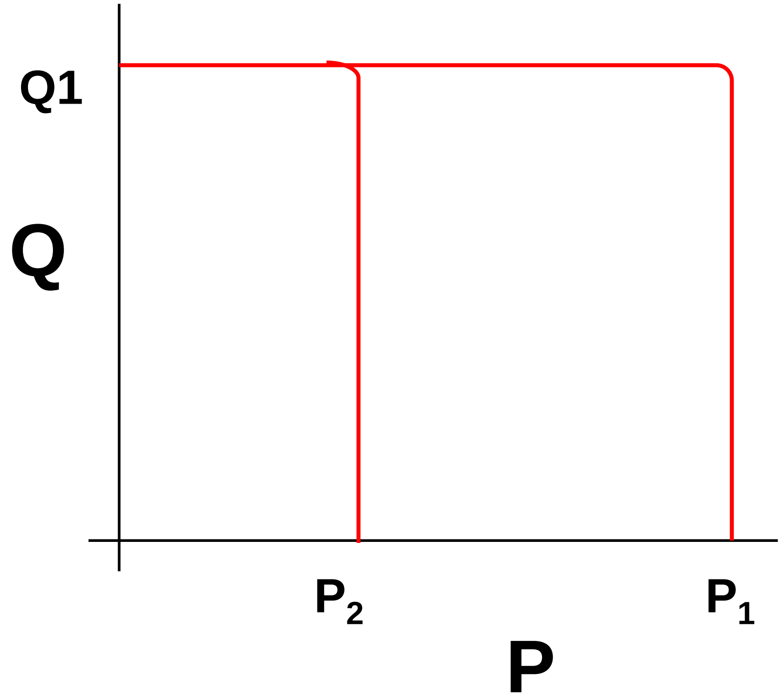
Hydraulic Circuit Approaches

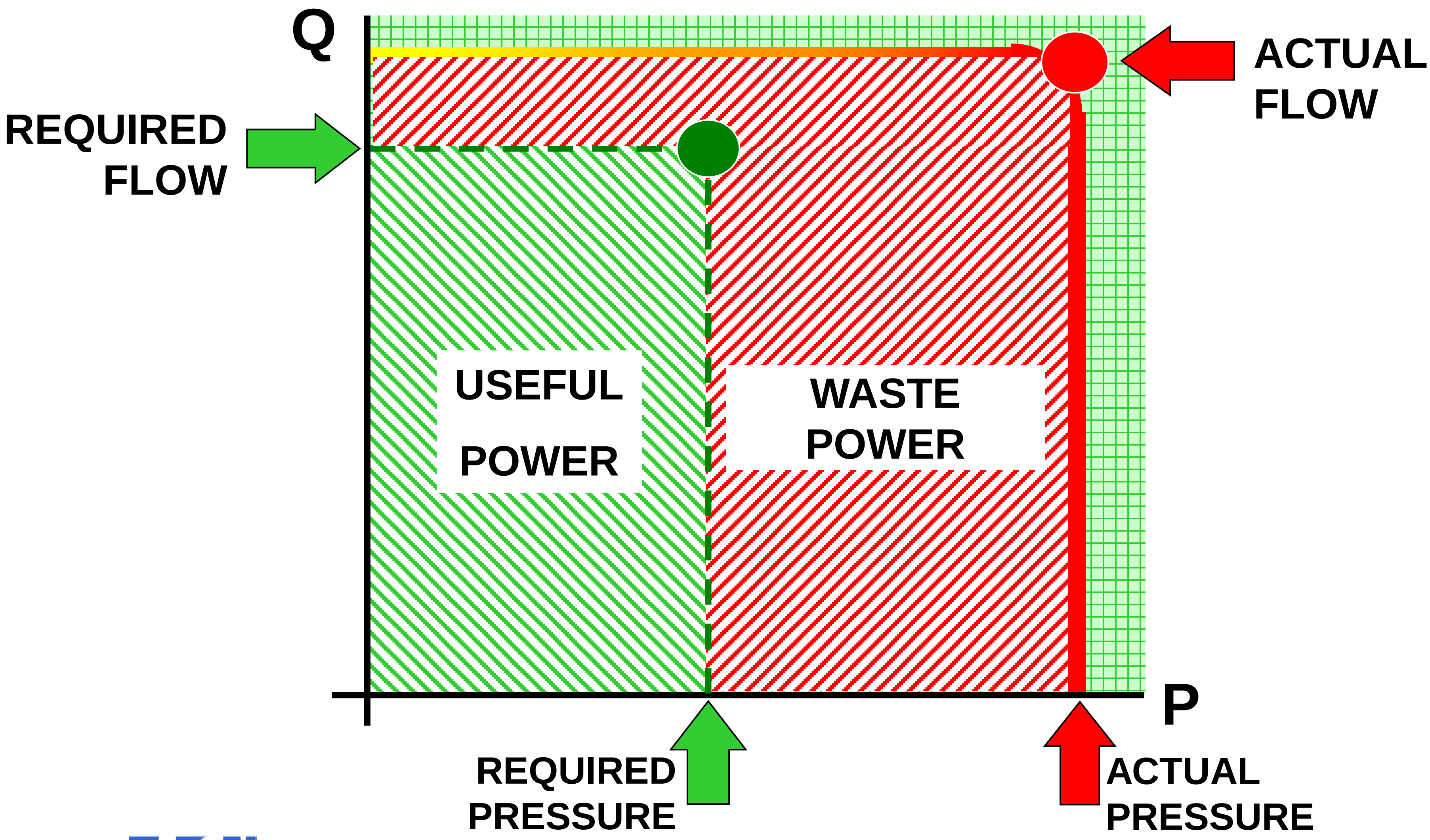
- FIXED DISPLACEMENT PUMP
- FIXED DISPLACEMENT PUMP W/ LOAD SENSE(LS)
- VARIABLE DISPLACEMENT PUMP W/ PRESSURE COMPENSATOR
- VARIABLE DISPLACEMENT PUMP W/ LOAD SENSE(LS)
- VARIABLE PUMP PQ
- FIXED DISPLACEMENT PUMP W/ VFD

FIXED DISPLACEMENT PUMP

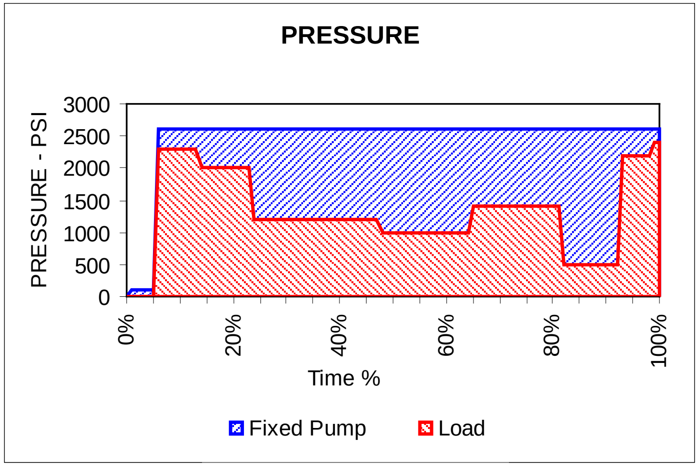


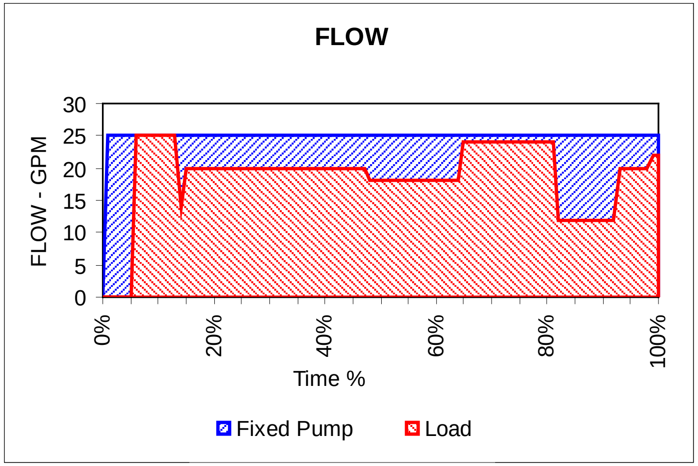


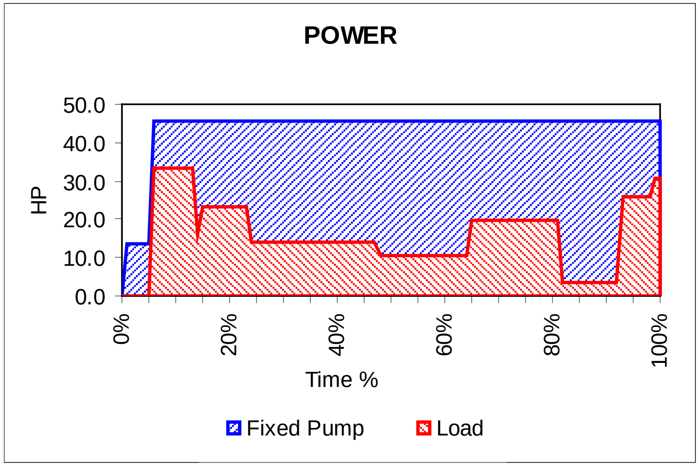
FIXED DISPLACEMENT PUMP

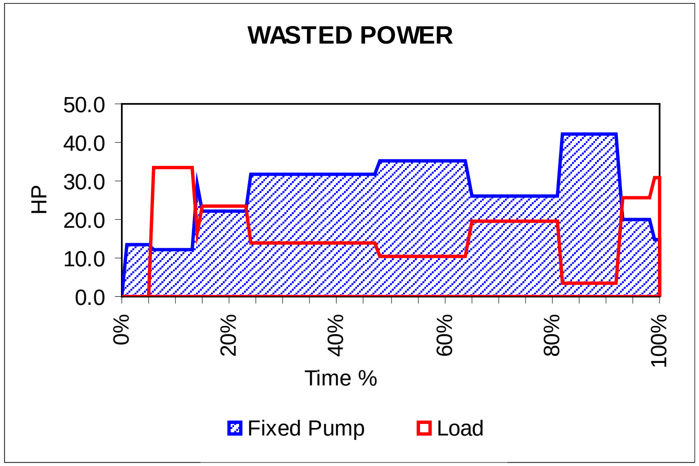


PQ – CURVE- FIXED PUMP









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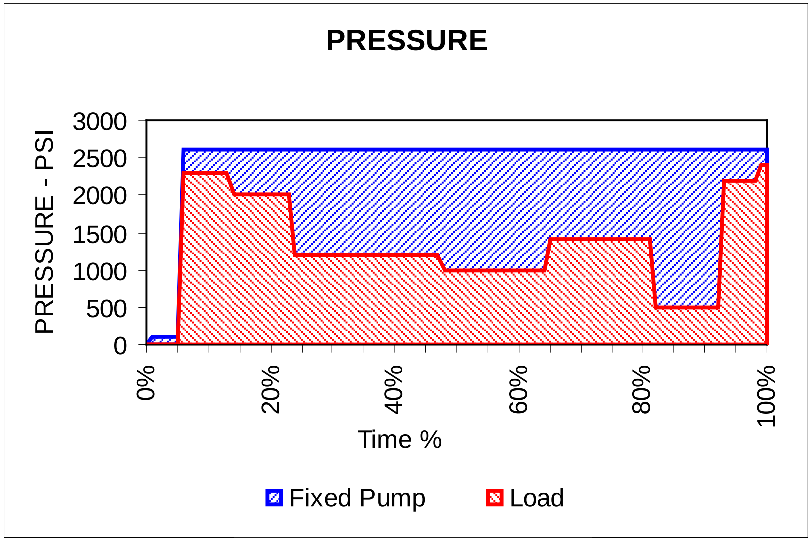
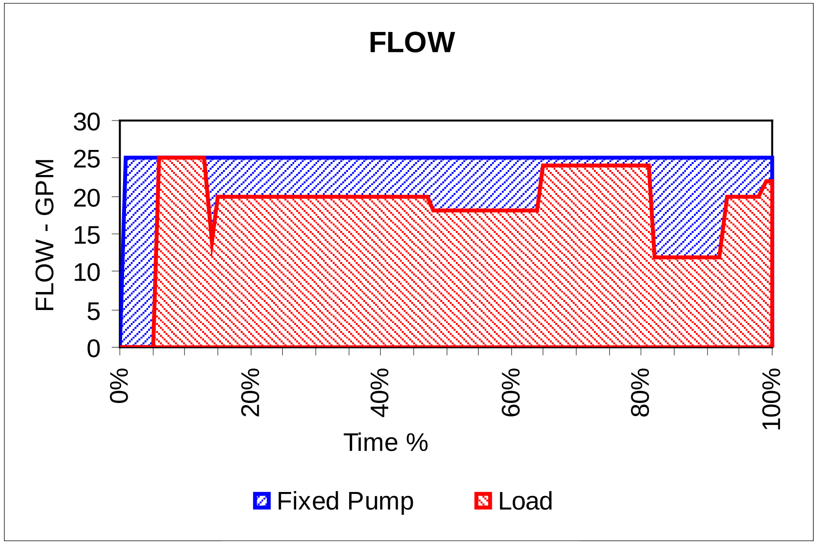
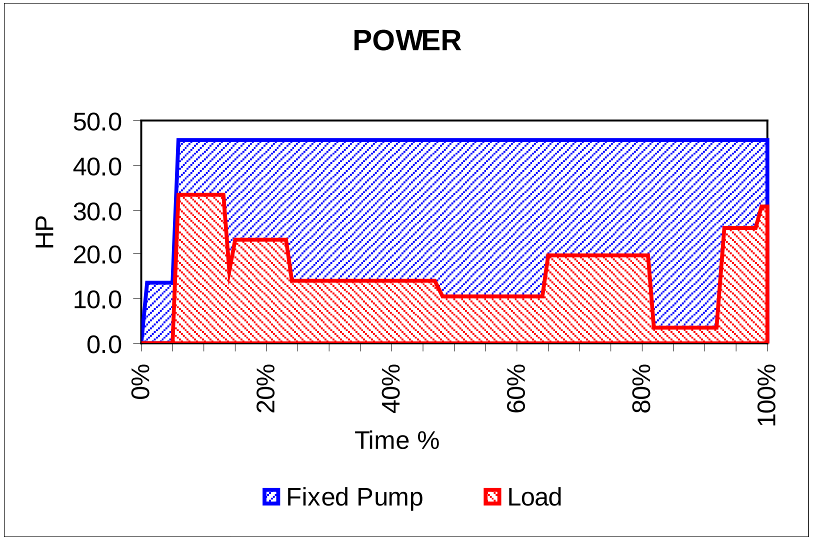
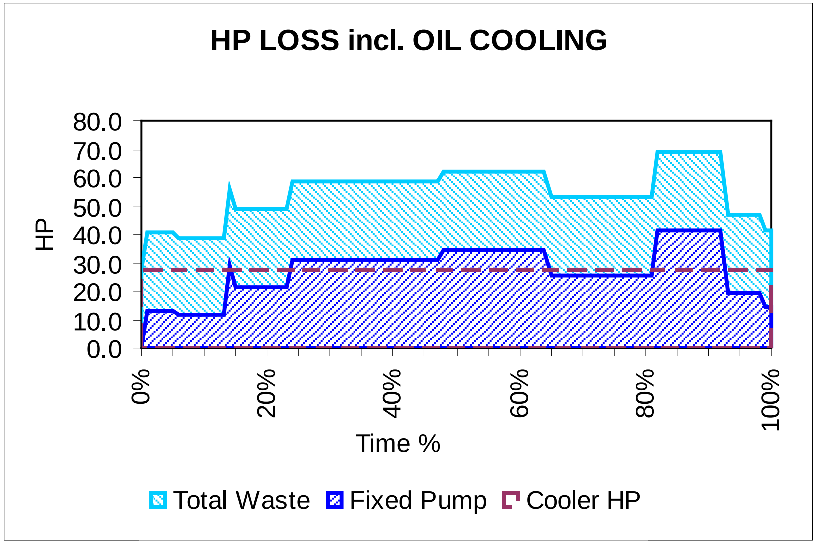
PQ – Curve - Fixed Displacement Pump









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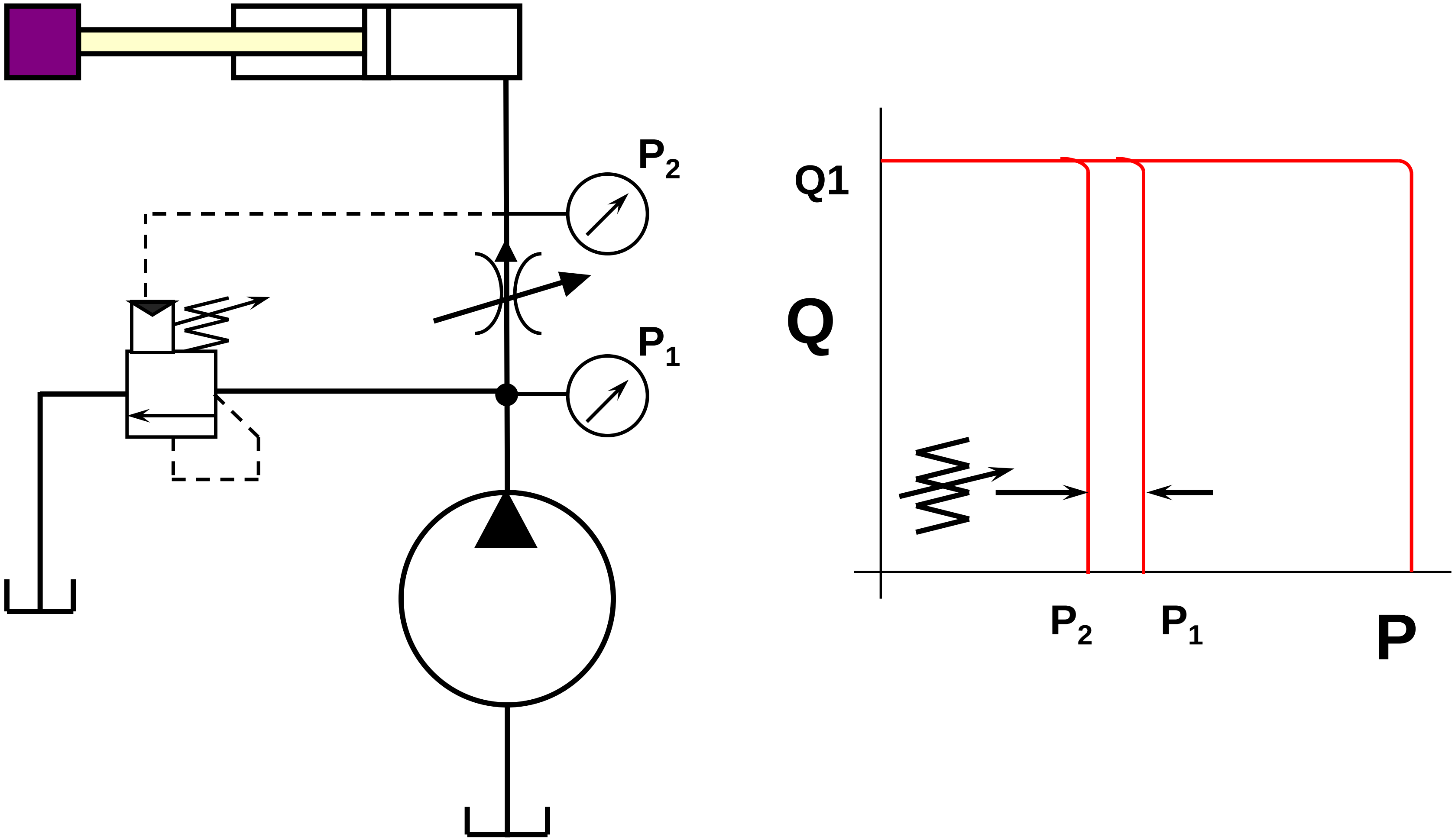
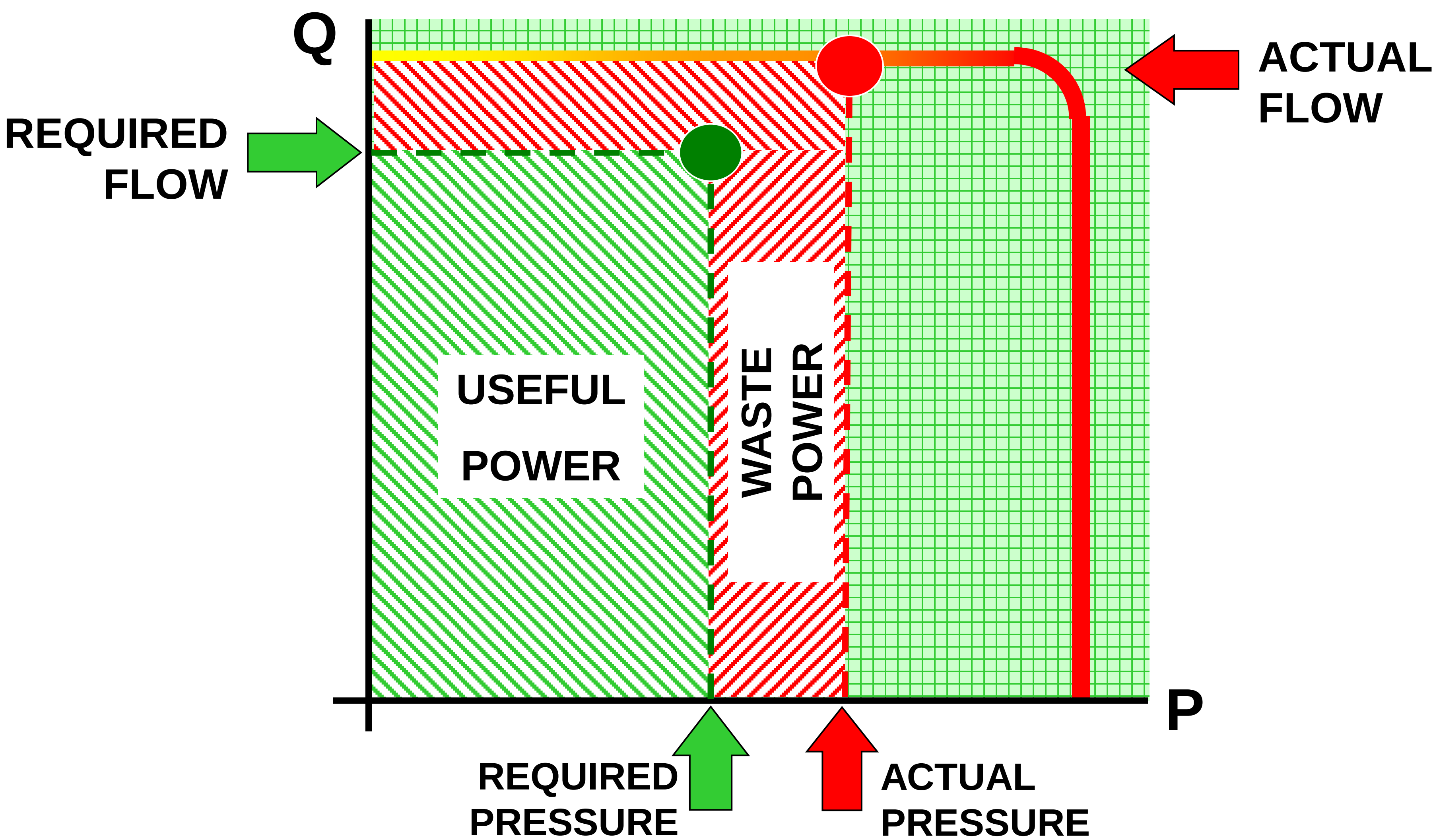
FIXED DISPLACEMENT PUMP w/ LS



FIXED DISPLACEMENT PUMP w/ LS



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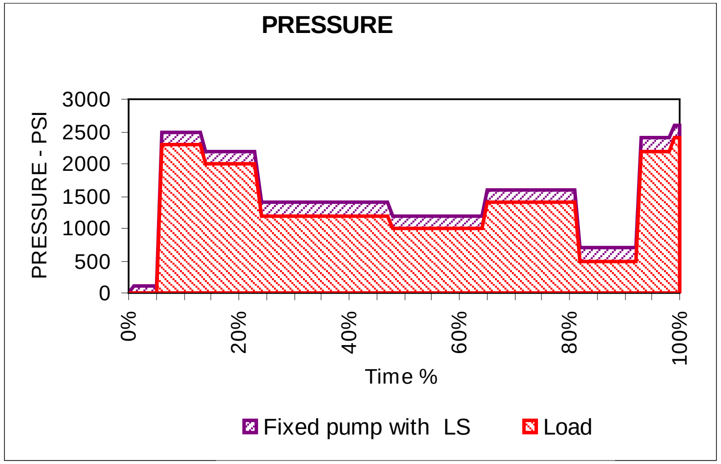
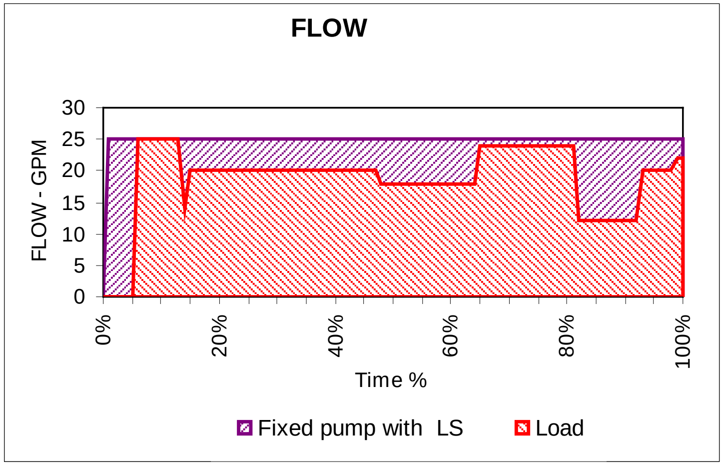
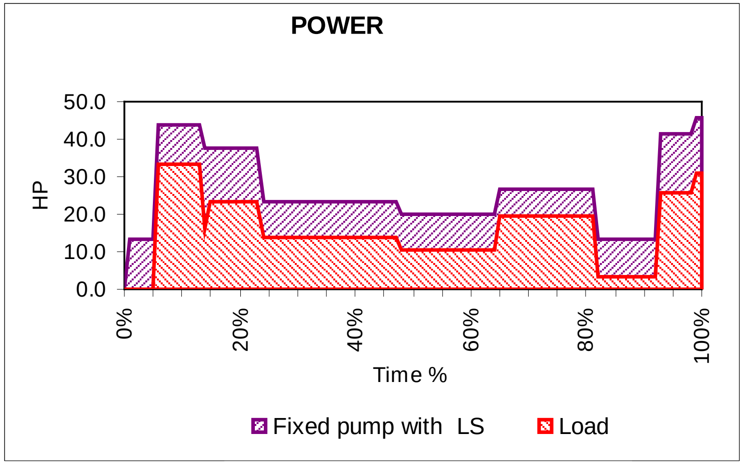
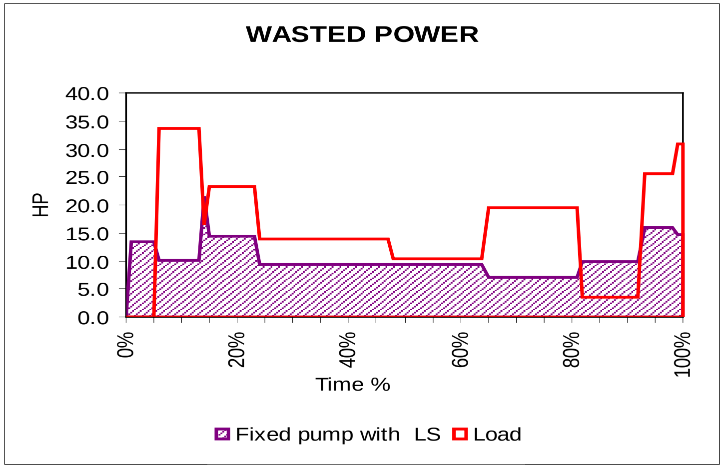
PQ – CURVE- FIXED PUMP W/ LS









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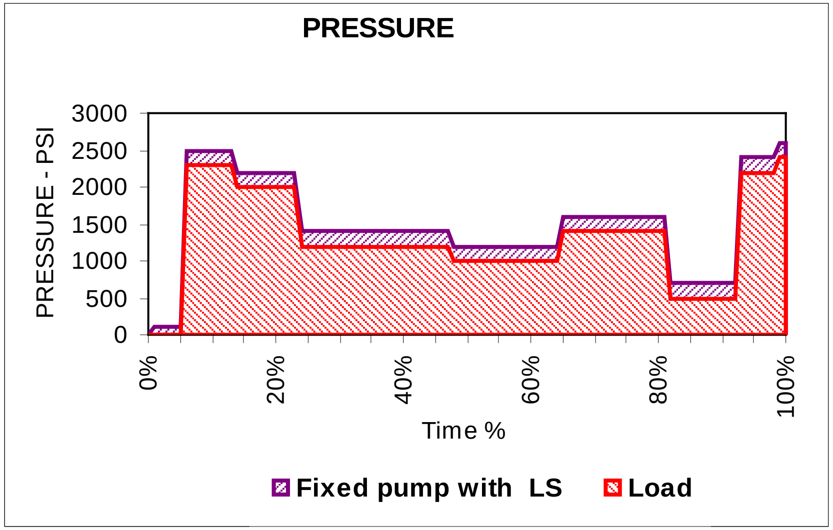
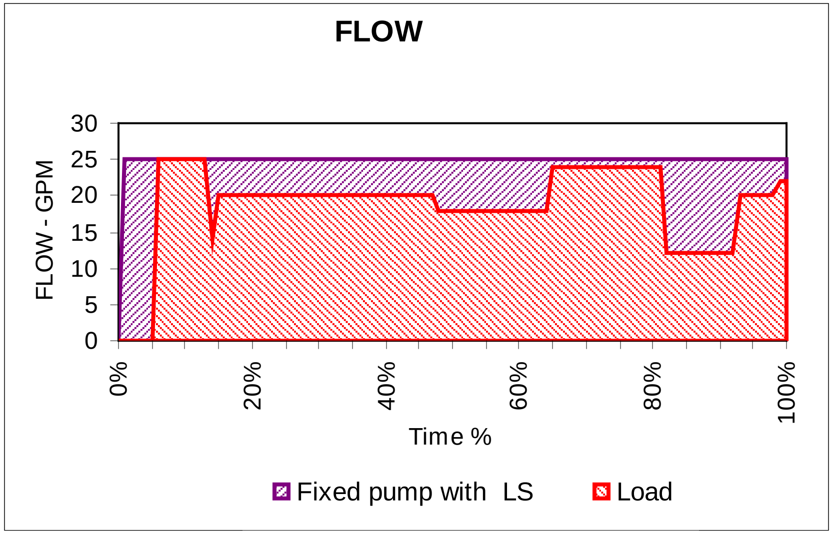
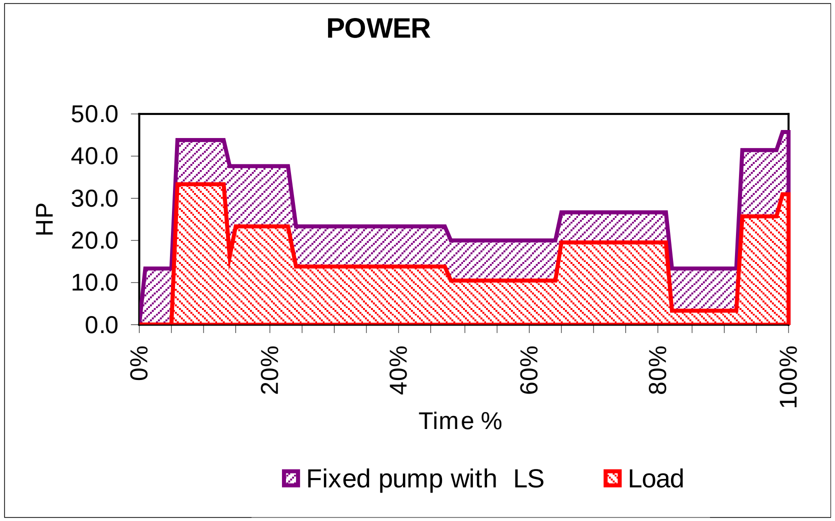
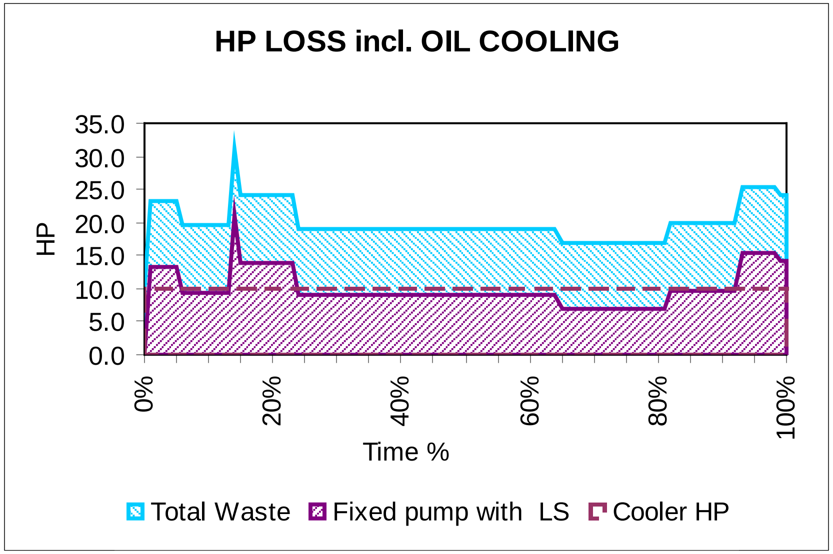
PQ -Curve -Fixed Displacement Pump w/ LS









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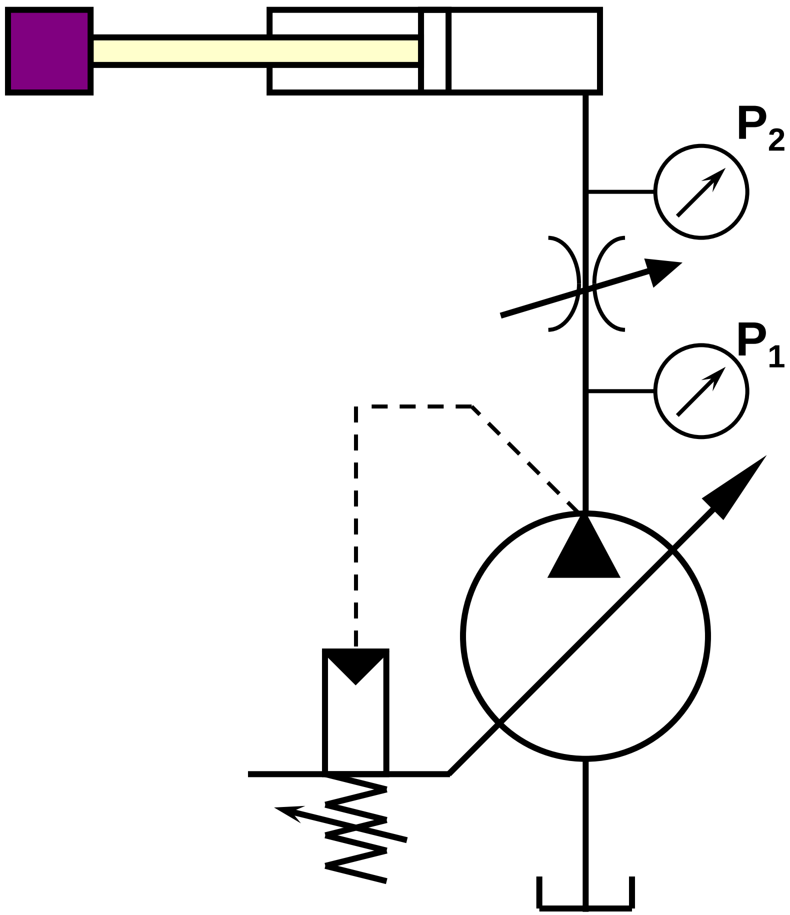
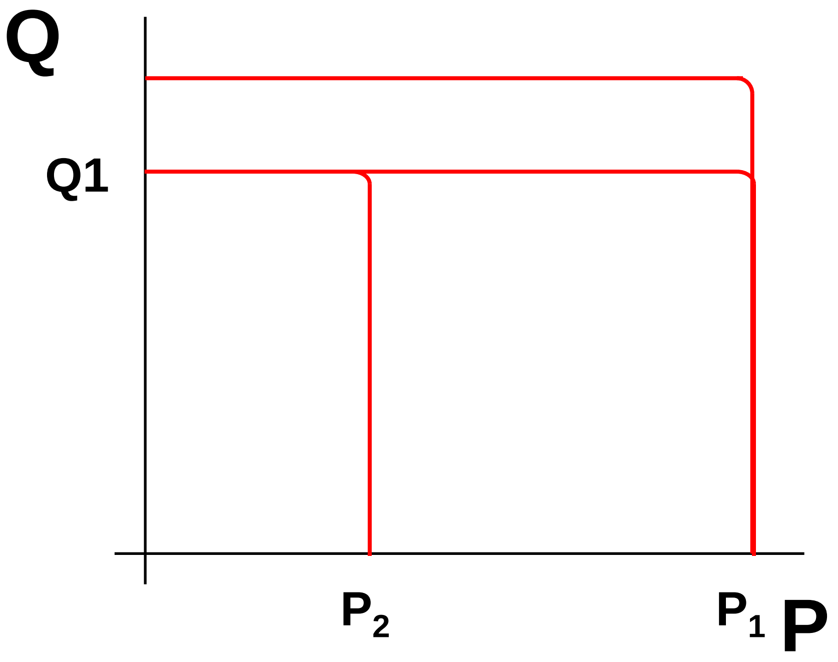
VARIABLE PUMP W/ PRESSURE COMP.





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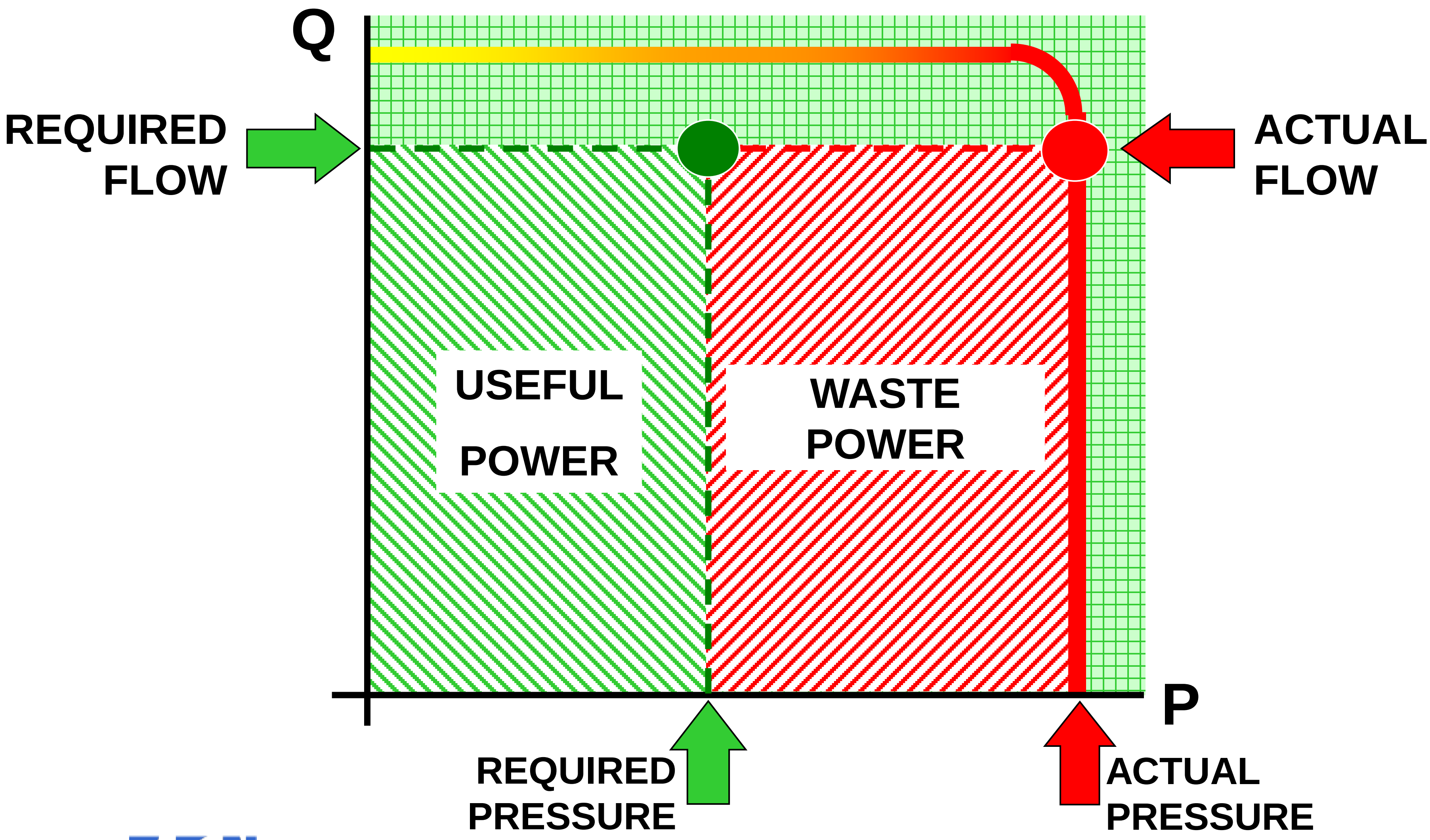
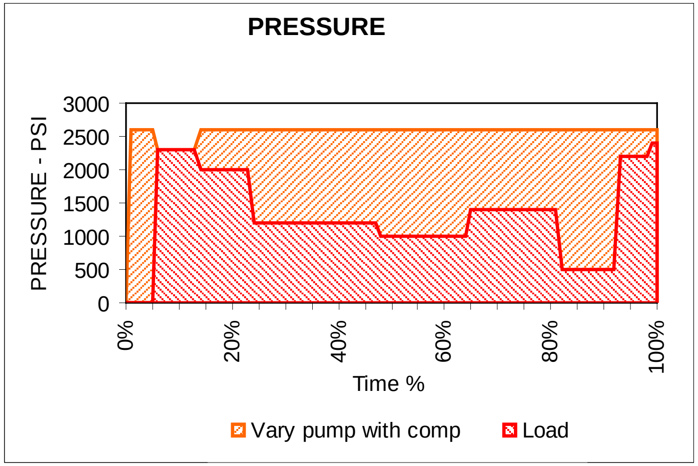
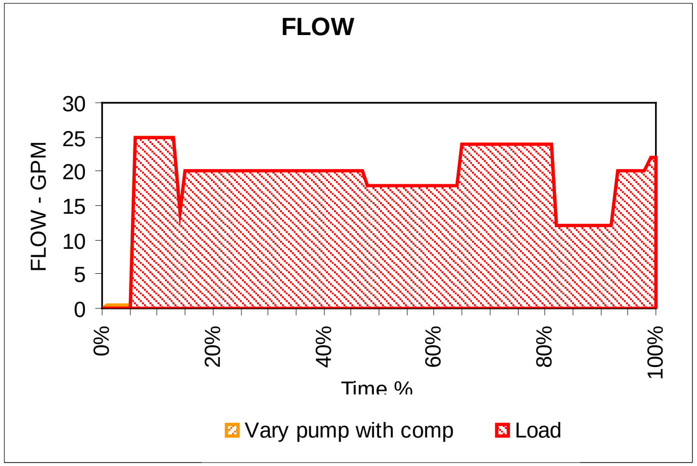
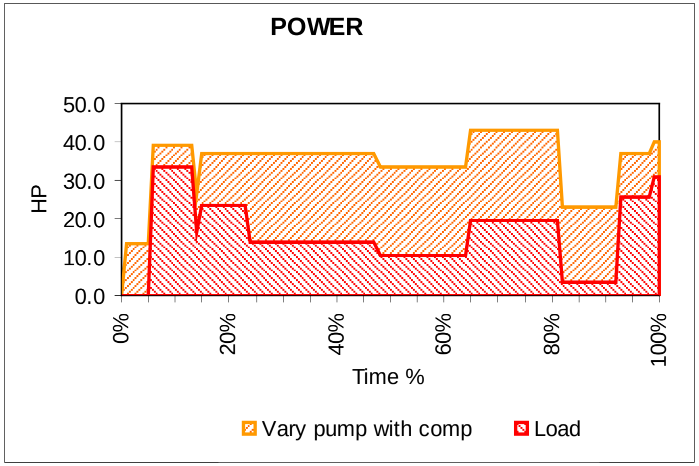
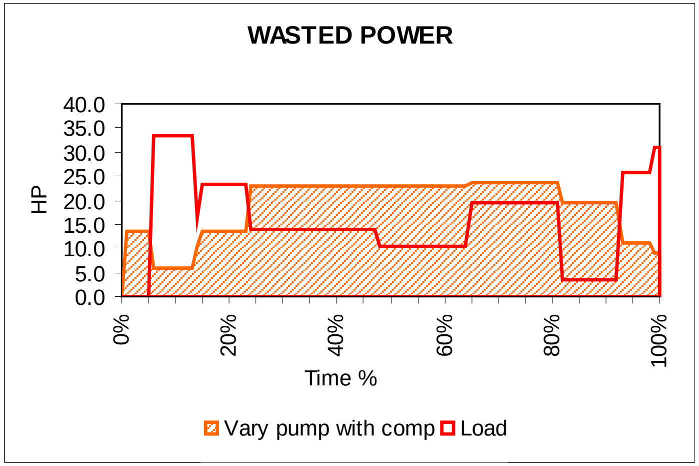


PQ – CURVE- VARIABLE PUMP W/ PC









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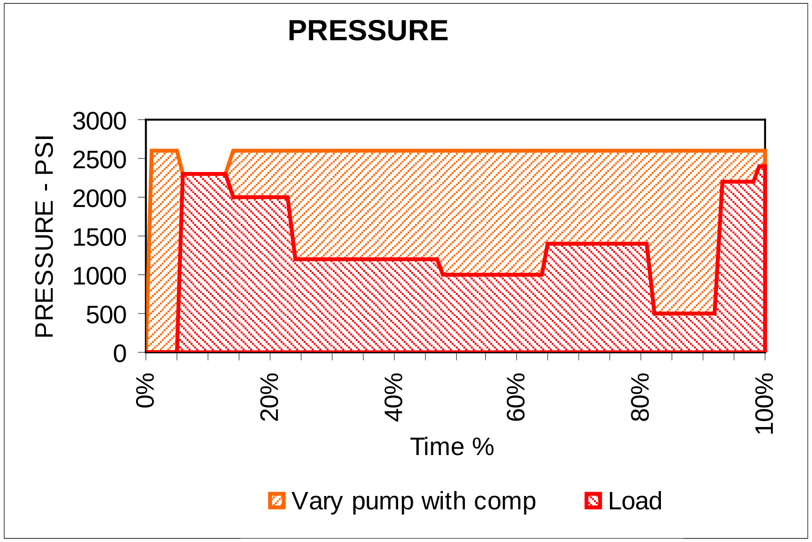
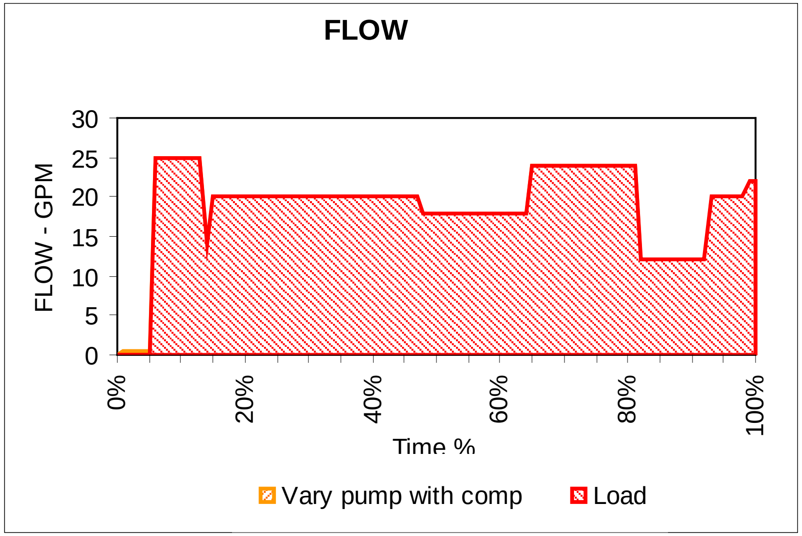
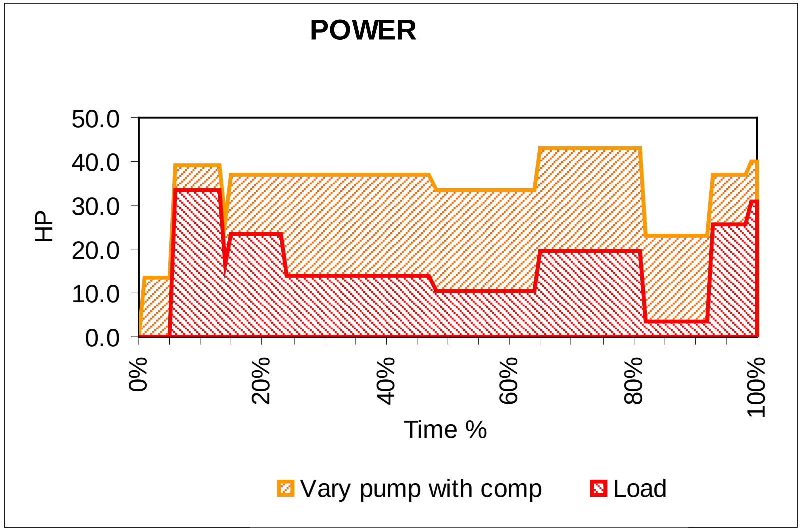
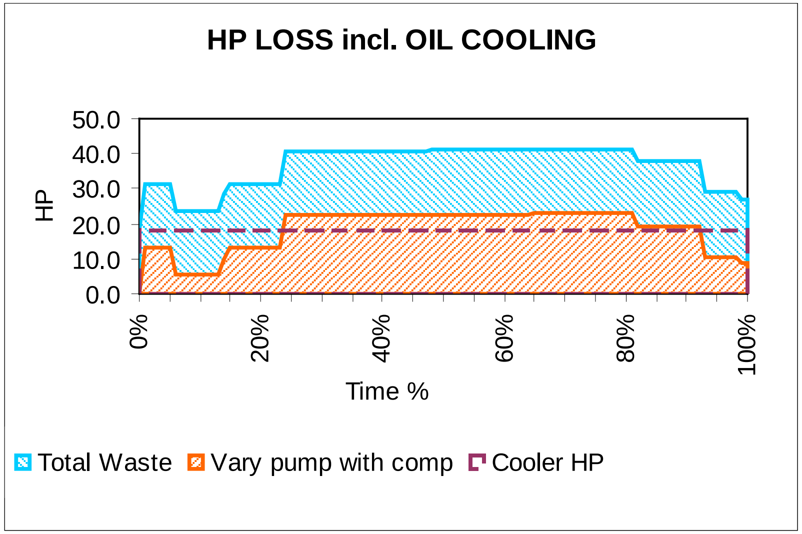
PQ – Curve - Variable Pump W/ PC









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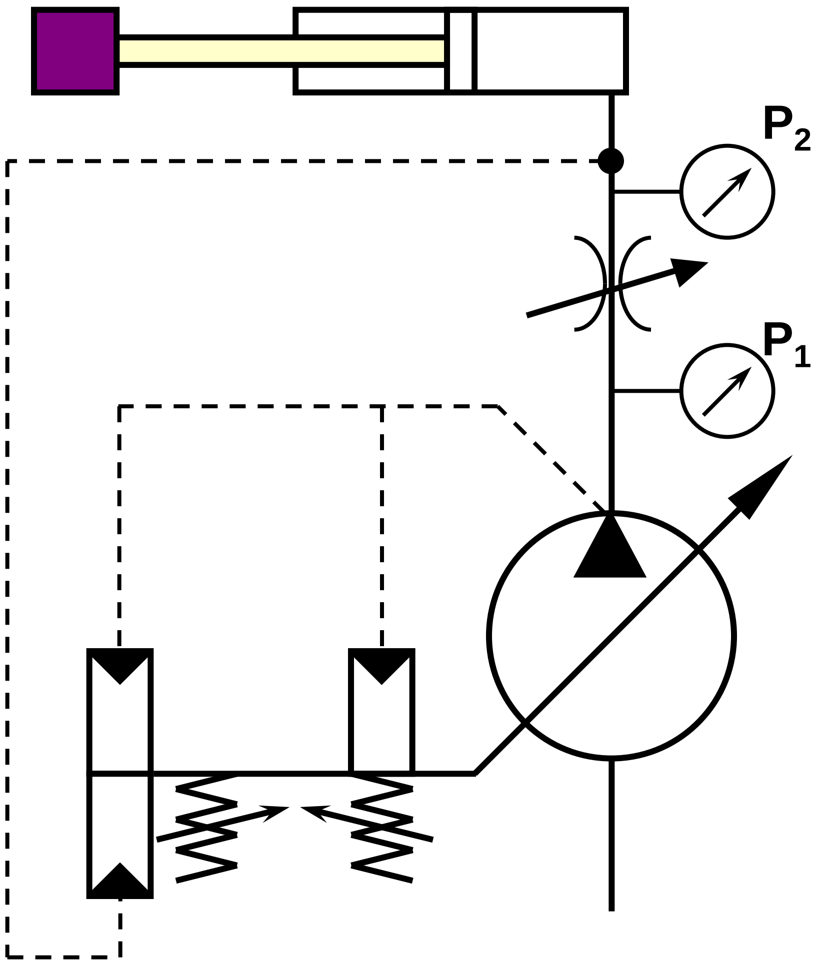
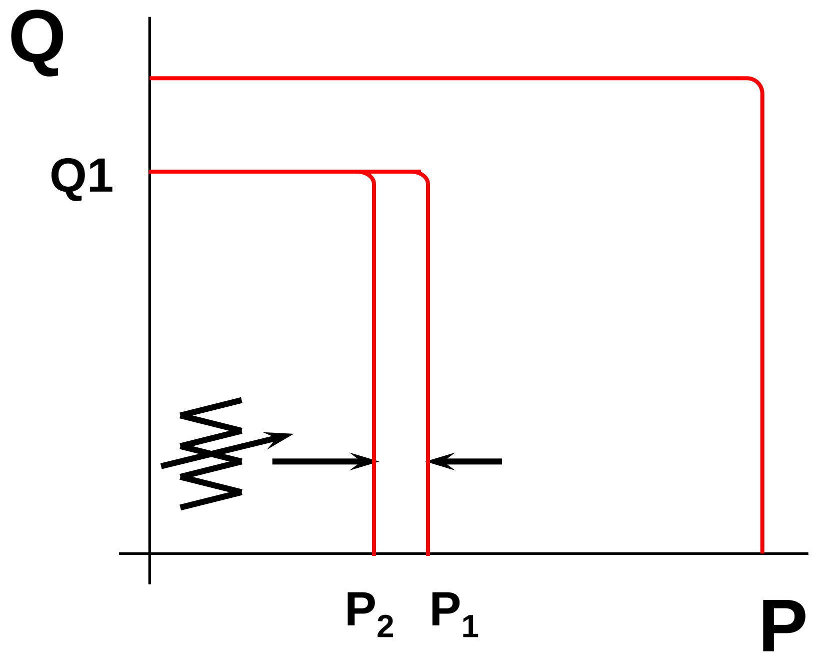
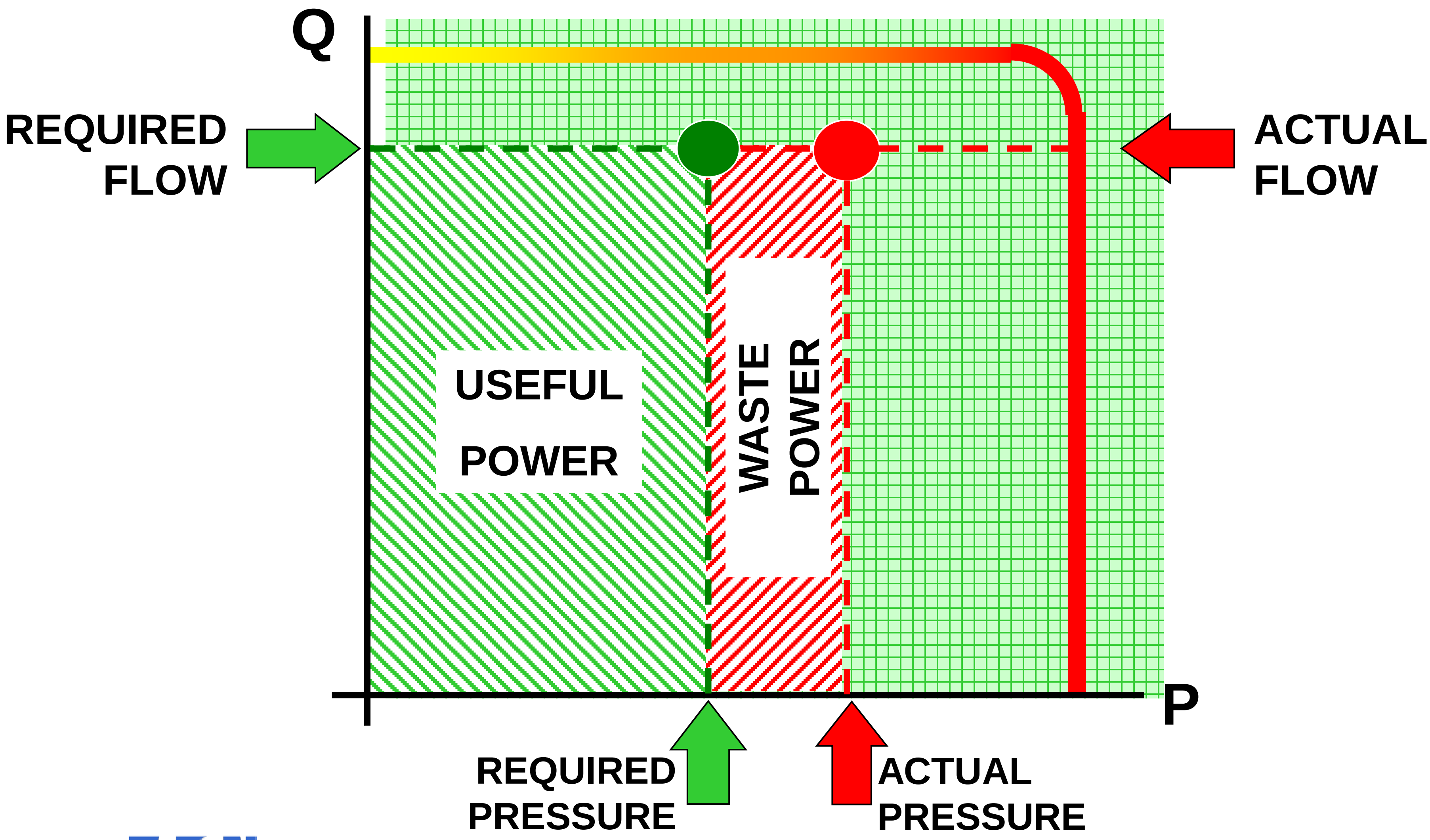
VARIABLE PUMP W/ LOAD SENSE





VARIABLE PUMP W/ LOAD SENSE



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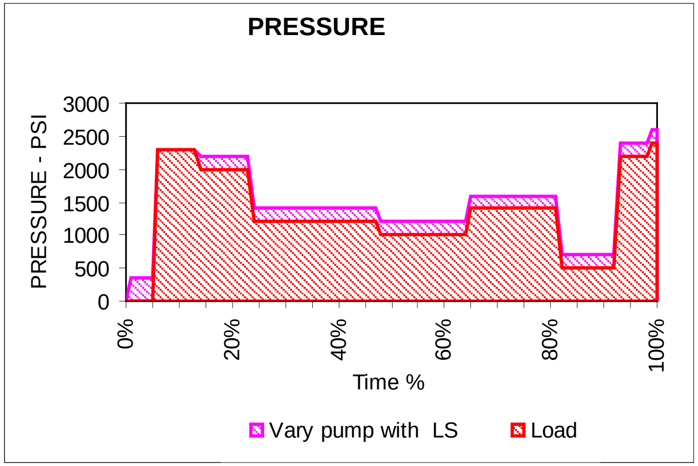
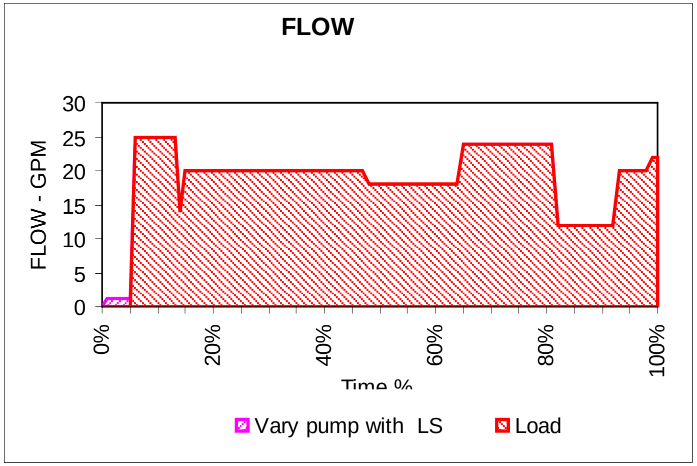
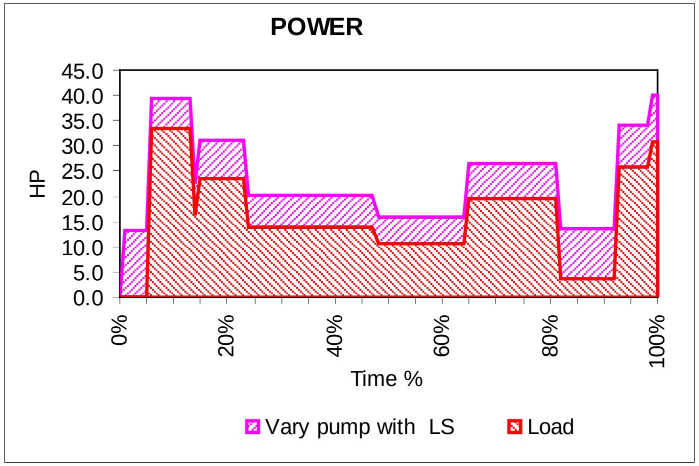
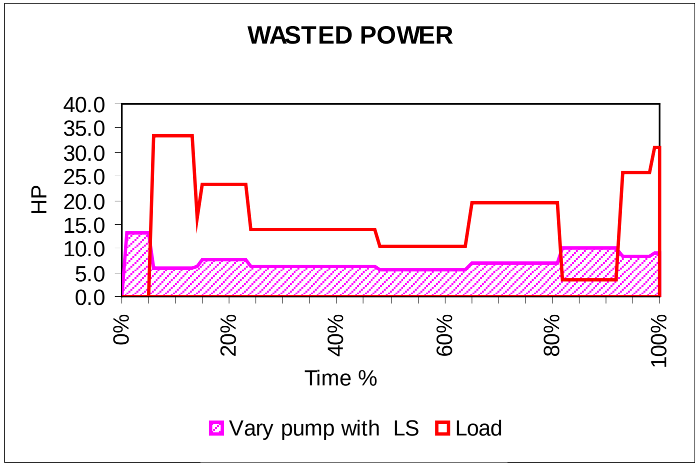
PQ – CURVE- VARIABLE PUMP W/ LS









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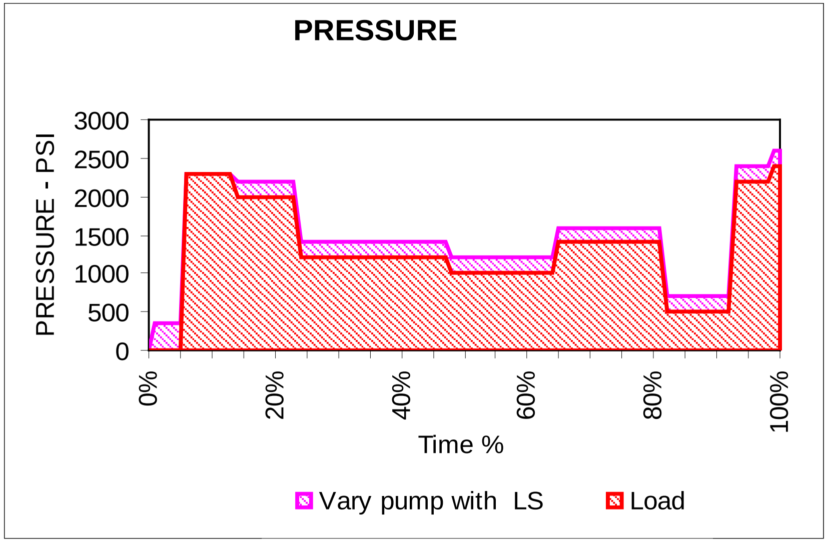
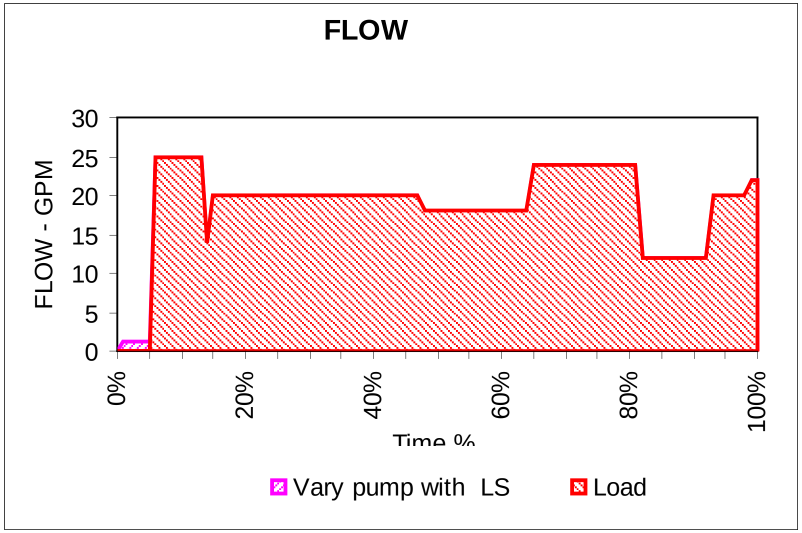
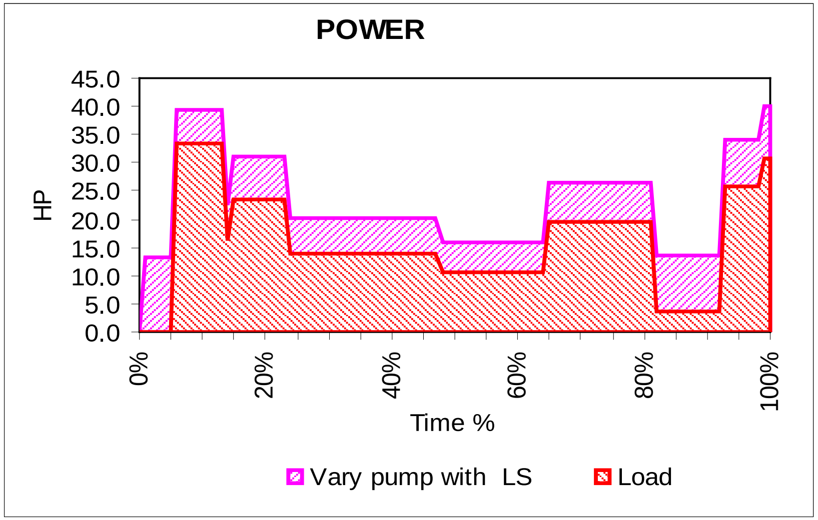
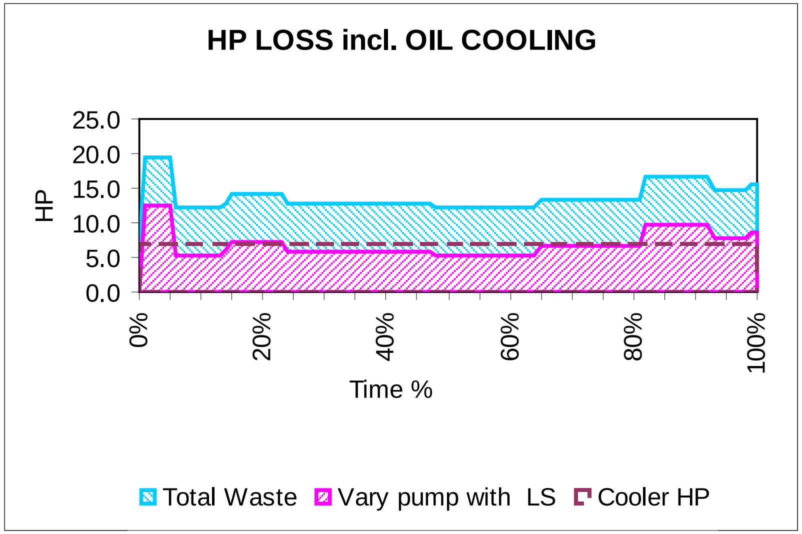
PQ – Curve - Variable Pump W/ LS

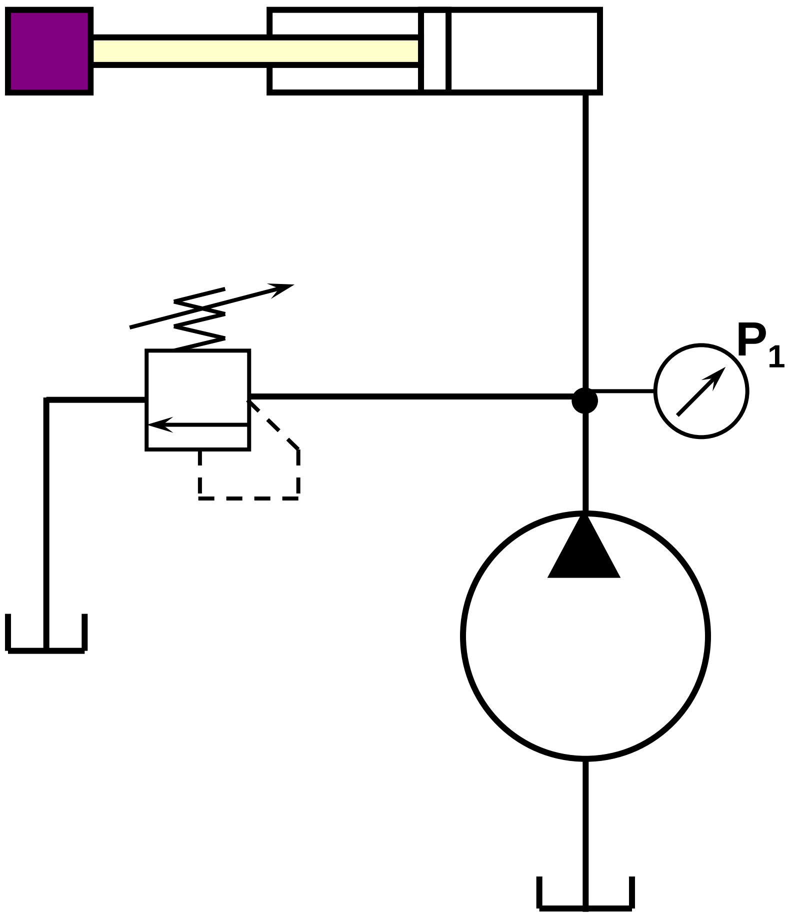


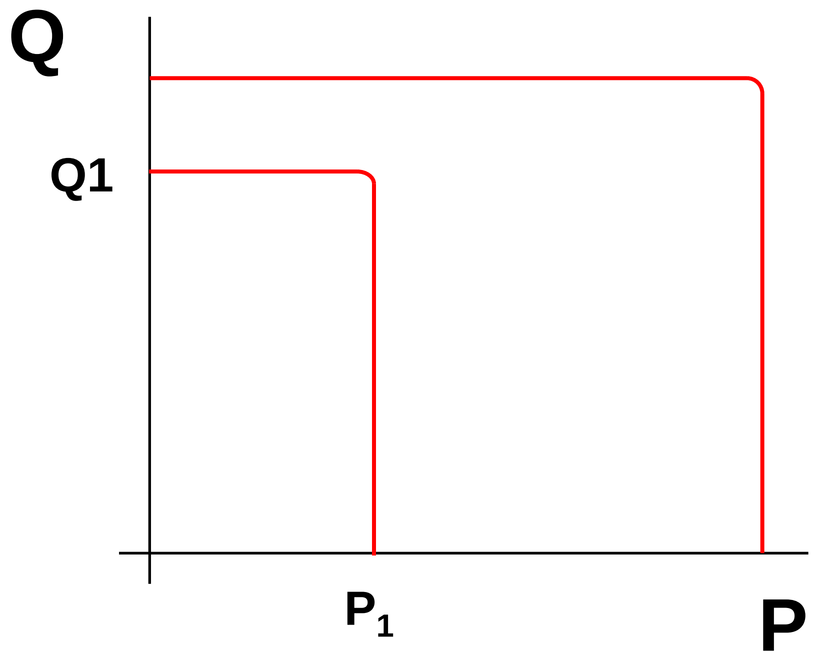






FIXED PUMP W/ VFD





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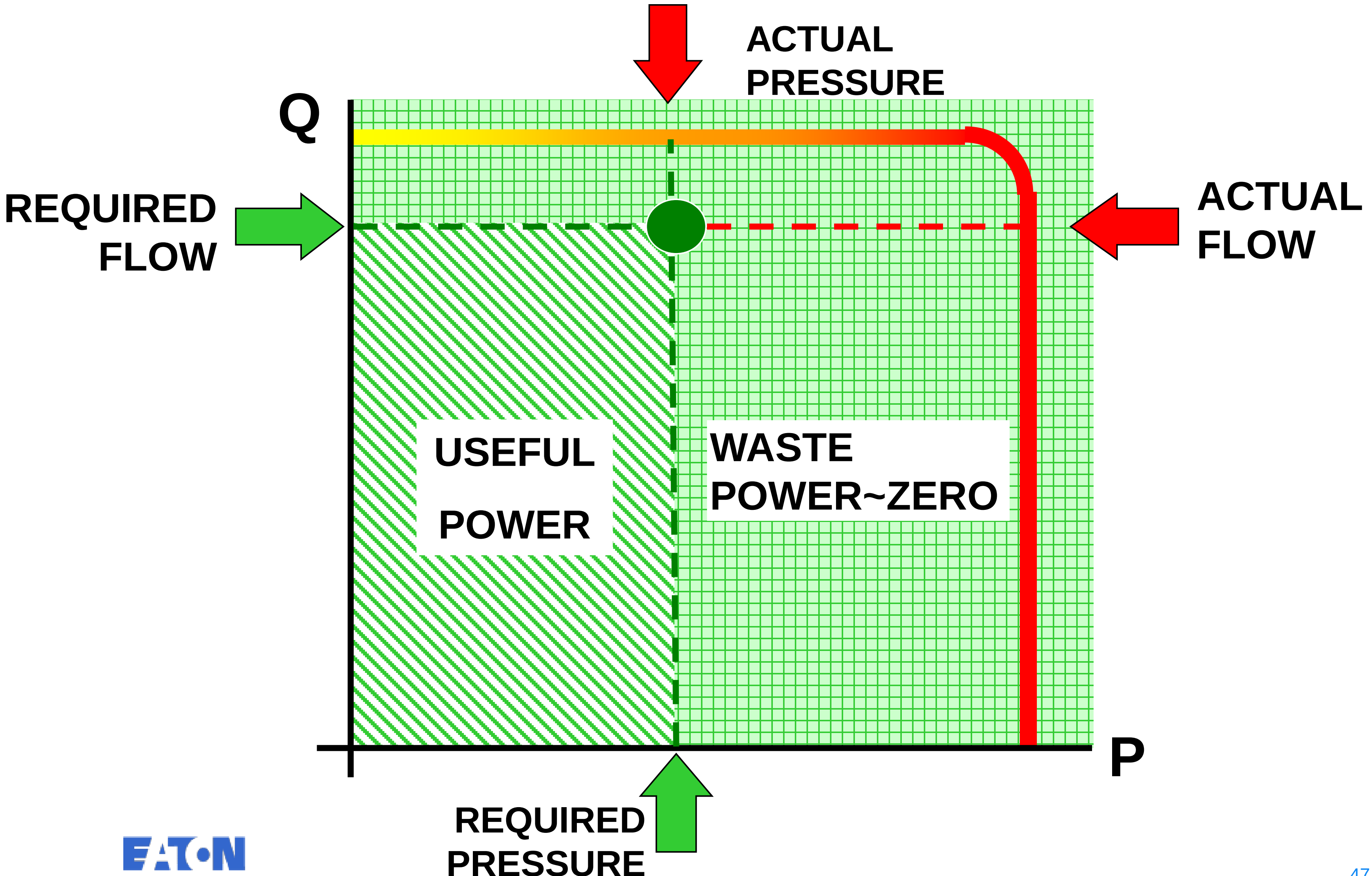
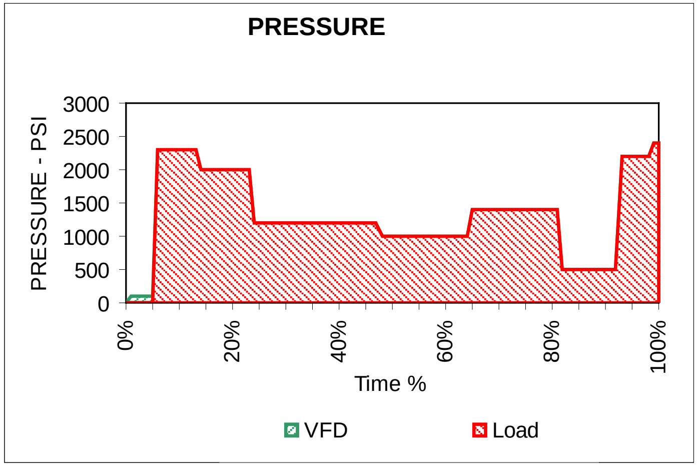
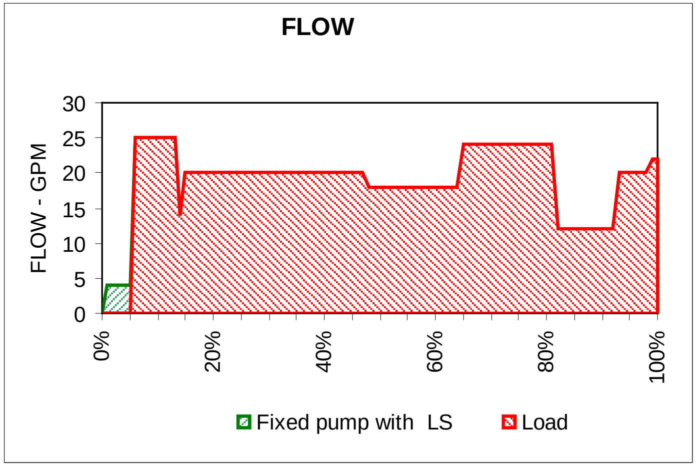
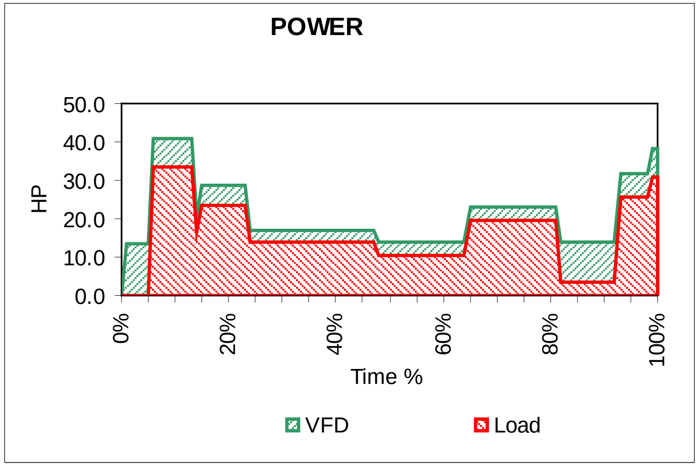
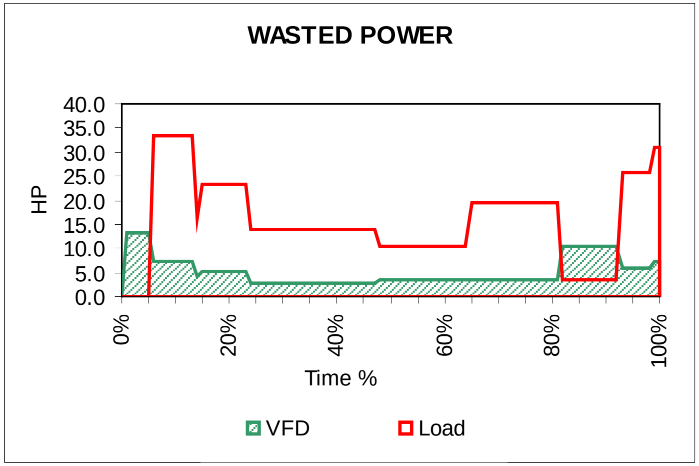


FIXED PUMP W/ VFD









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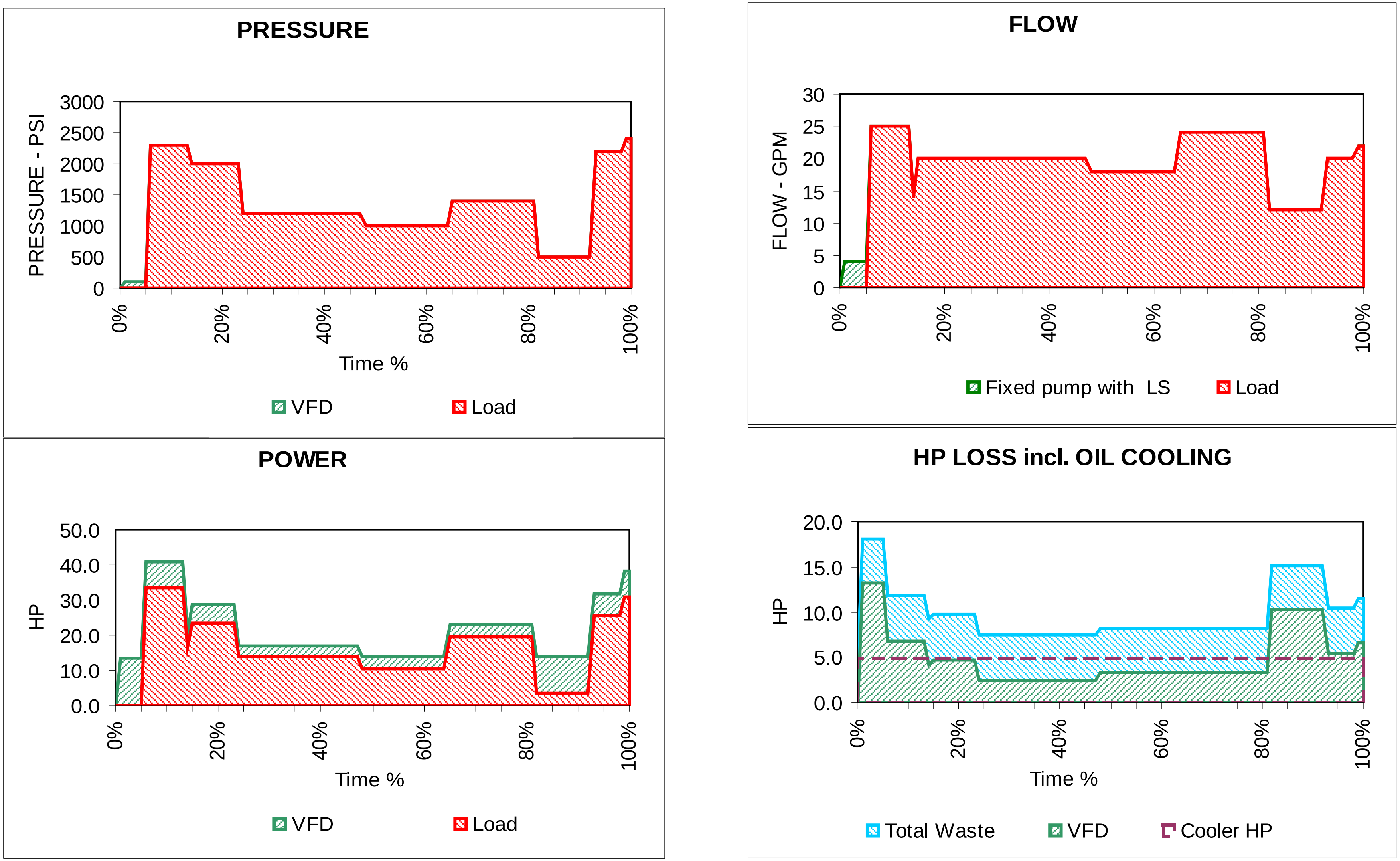
PQ – Curve - Fixed Pump W/ VFD



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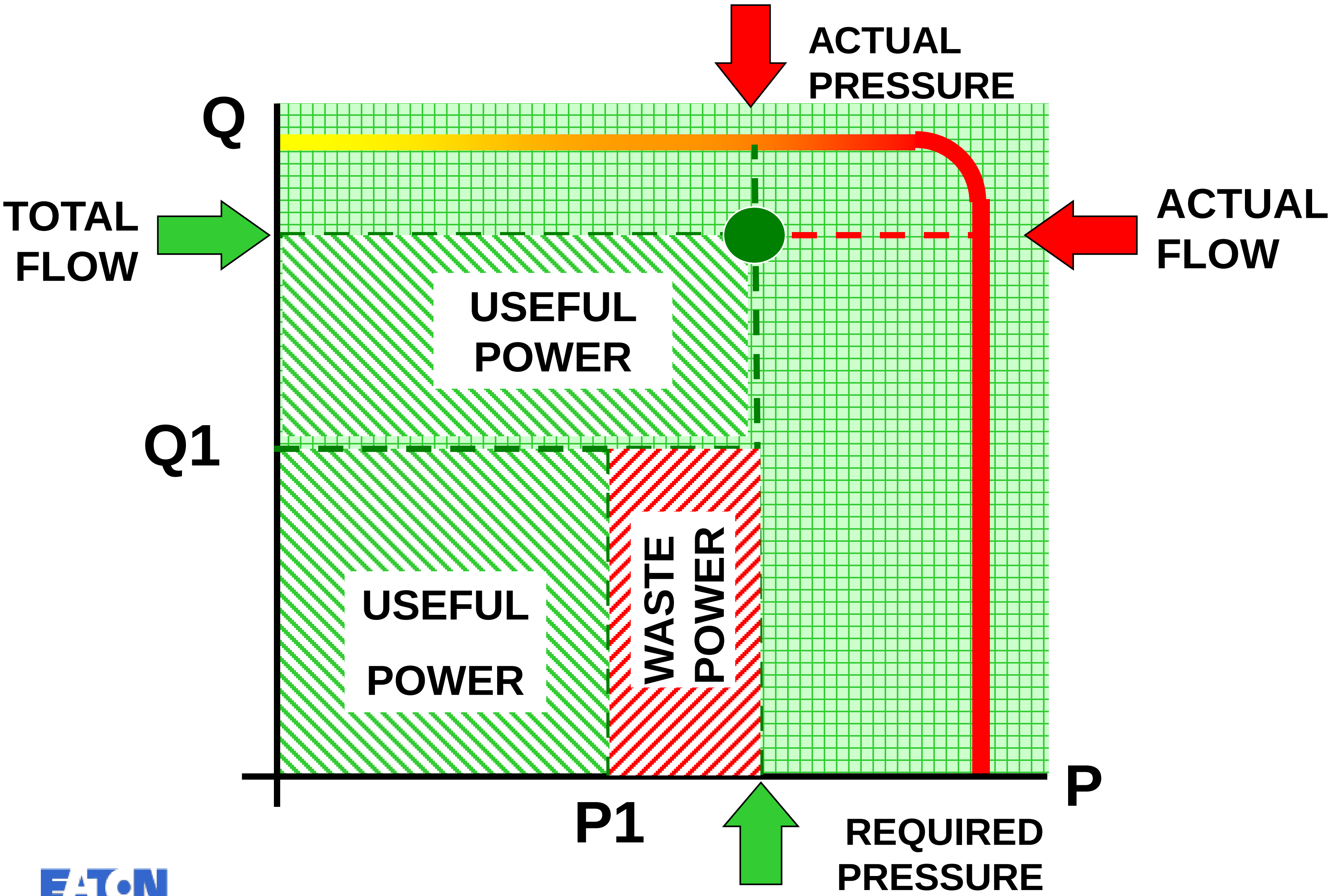
Load Interference



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Energy Efficiency & Circuit Approach

- Inefficiencies are duty-cycle dependent
- Circuit approaches have a major effect on inefficiencies
- Energy Calculators can be helpful in determining payback of various approaches
- Load Interference losses, line losses, M-O losses, don't change results

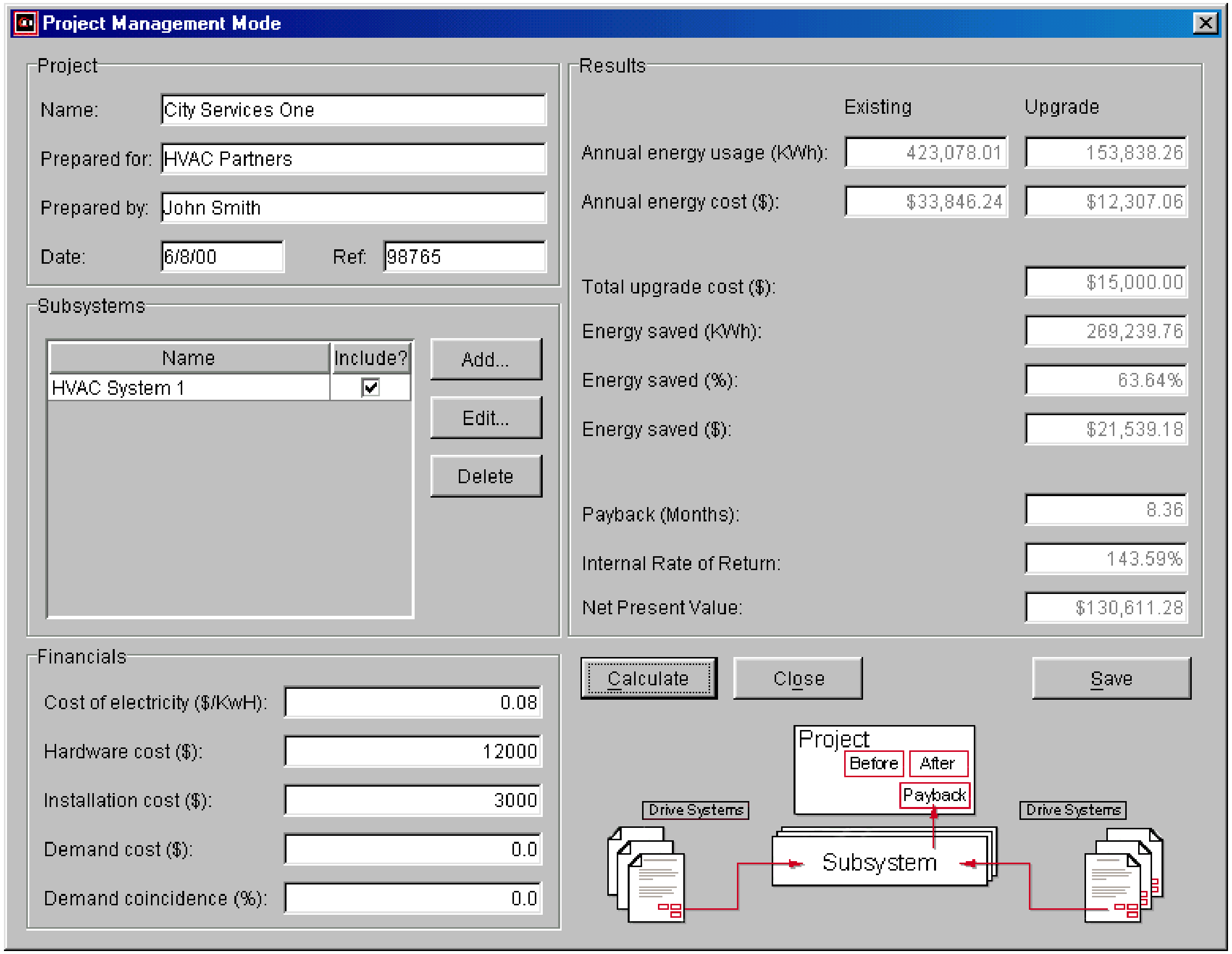
…Energy Losses in Industrial Hydraulic Systems

- What is Energy?
- Energy Losses & Inefficiencies
- Hydraulic Circuit Approaches
- Energy Calculators

Energy Calculators

- HVAC Energy Calculator
- Hydraulic Energy Calculator
  - Excel-based
  - Expressed in comparative usage (KWH, $)
  - Screen shot of each worksheet

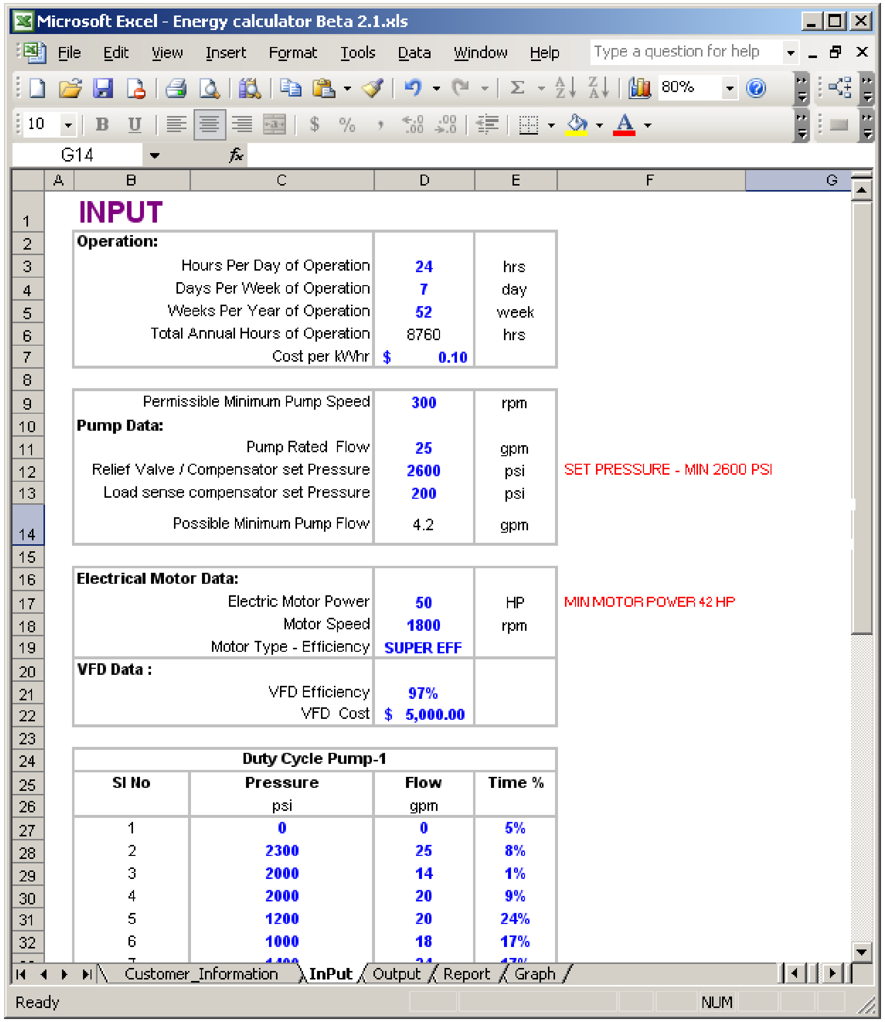
HVAC Energy Calculator



Energy Calculator: Methods to Quantify Inefficiencies

- How and where to get data
  - Catalogs!
  - Engineering/Lab databases
- Approximations employed
  - η=.97 (VFD unit)
  - Fixed pump data from Vane products
  - Variable pump data from Piston products
  - Correction factors approximated for pressure, speed, displacement
  - Standby losses approximated
  - Temperature of 120 degF.
  - Electric Motors are not turned off during cycle
  - No accumulators (typ converts flow losses to pressure losses)

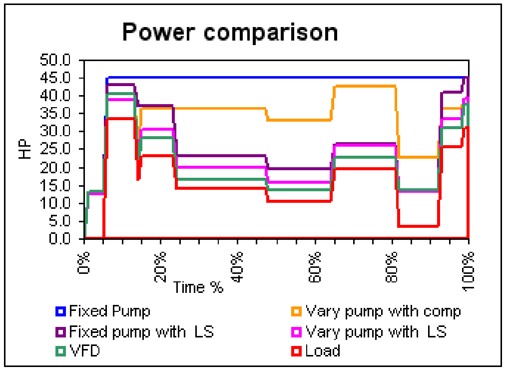
Energy Calculator

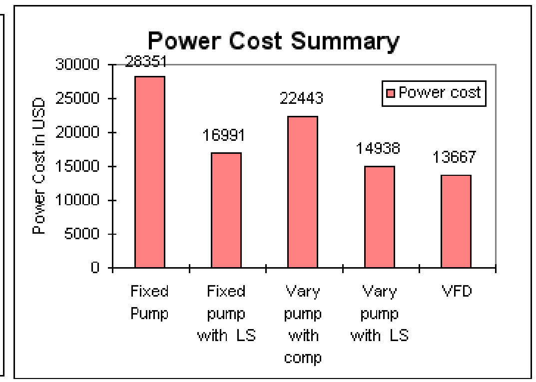


Energy Calculator

Microsoft Excel - Energy calculator Beta 2.1.xls

OUTPUT



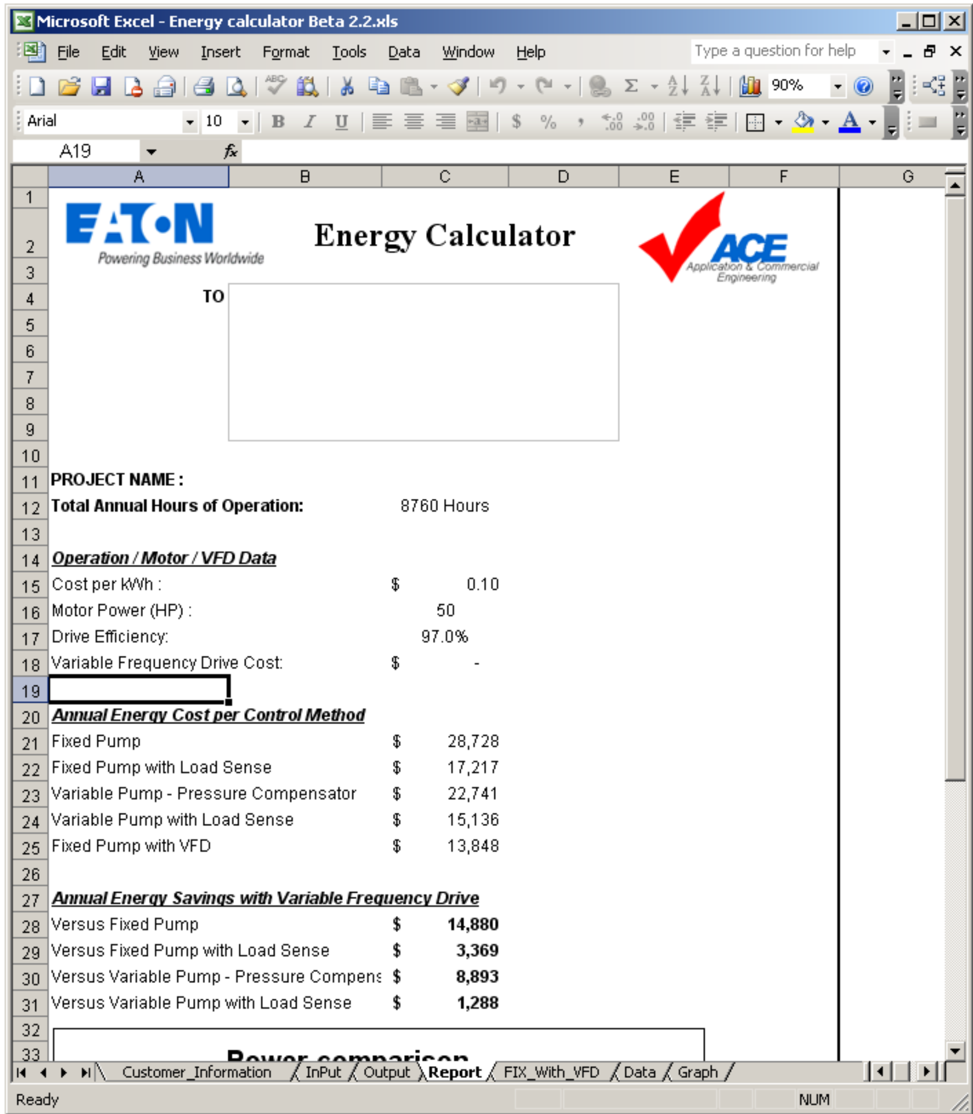


	Motor Power					Time	Power cost				
Time %	Fixed Pump	Fixed pump with LS	Vary pump with comp	Vary pump with LS	VFD	Hours	Fixed Pump	Fixed pump with LS	Vary pump with comp	Vary pump with LS	VFD
	HP	HP	HP	HP	HP		USD	USD	USD	USD	USD
0%	0.0	0.0	0.0	0.0	0.0	0	0	0	0	0	0
1%	13.2	13.2	13.1	12.5	13.1	88	86	86	86	81	86
2%	13.2	13.2	13.1	12.5	13.1	88	86	86	86	81	86
3%	13.2	13.2	13.1	12.5	13.1	88	86	86	86	81	86
4%	13.2	13.2	13.1	12.5	13.1	88	86	86	86	81	86
5%	13.2	13.2	13.1	12.5	13.1	88	86	86	86	81	86
6%	45.0	43.0	38.8	38.8	40.4	88	294	281	254	254	264
7%	45.0	43.0	38.8	38.8	40.4	88	294	281	254	254	264
8%	45.0	43.0	38.8	38.8	40.4	88	294	281	254	254	264
9%	45.0	43.0	38.8	38.8	40.4	88	294	281	254	254	264

Customer_Information / InPut / **Output** / Report / Graph

Ready NUM

Energy Calculator



Microsoft Excel - Energy calculator Beta 2.2.xls

Energy Calculator

TO

PROJECT NAME :		
Total Annual Hours of Operation:		8760 Hours
Operation / Motor / VFD Data		
Cost per kWh :	$	0.10
Motor Power (HP) :		50
Drive Efficiency:		97.0%
Variable Frequency Drive Cost:	$	-
Annual Energy Cost per Control Method		
Fixed Pump	$	28,728
Fixed Pump with Load Sense	$	17,217
Variable Pump - Pressure Compensator	$	22,741
Variable Pump with Load Sense	$	15,136
Fixed Pump with VFD	$	13,848
Annual Energy Savings with Variable Frequency Drive		
Versus Fixed Pump	$	**14,880**
Versus Fixed Pump with Load Sense	$	**3,369**
Versus Variable Pump - Pressure Compens	$	**8,893**
Versus Variable Pump with Load Sense	$	**1,288**

Power comparison

Customer_Information / InPut / Output / Report / FIX_With_VFD / Data / Graph

Energy Calculation Examples

- Injection Molding Machine (IMM)
- Baler
- Down-acting Press
- VMC

EXAMPLE - IMM

	Function	Pressure	Flow	Time	Time
		psi	GPM	sec	%
1	Clamp close	900	18	1.8	11.3%
2	Clamp Tonnage	2300	20	0.4	2.5%
3	Injection	2000	16	3	18.8%
4	Refill	2200	18	5	31.3%
5	Cooling time	0	0	3	18.8%
6	Clamp Decomp	1000	2	0.4	2.5%
7	Clamp Open	800	12	1.1	6.9%
8	Ejector Forward	650	10	0.8	5.0%
9	Ejector Retract	500	6	0.5	3.1%

Relief set	2500	psi
Pump Flow	20	GPM
Motor HP	40	HP
Efficiency Type	Super E	

Shift	2
Week	6 days
Working week annually	48

EXAMPLE - IMM

Microsoft Excel - IMM 2.2.xls

File Edit View Insert Format Tools Data Window Help

H37

INPUT

Operation:			
Hours Per Day of Operation	16	hrs	**INPUTS**
Days Per Week of Operation	6	day	
Weeks Per Year of Operation	48	week	
Total Annual Hours of Operation	4608	hrs	
Cost per kWhr	$ 0.10		

Permissible Minimum Pump Speed	300	rpm	
Pump Data:			
Pump Rated Flow	25	gpm	
Relief Valve / Compensator set Pressure	2500	psi	*SET PRESSURE - MIN 2500 PSI*
Load sense compensator set Pressure	200	psi	
Possible Minimum Pump Flow	4.2	gpm	

Electrical Motor Data:		
Electric Motor Power	40	HP
Motor Speed	1800	rpm
Motor Type - Efficiency	SUPER EFF	
VFD Data :		
VFD Efficiency	97%	
VFD Cost		

Duty Cycle Pump-1

Sl No	Pressure psi	Flow gpm	Time %
1	900	18	11%
2	2300	20	3%
3	2000	16	19%
4	2200	18	31%
5	0	0	19%
6	1000	2	3%
7	800	12	7%
8	650	10	5%
9	500	6	3%
10			
			100%

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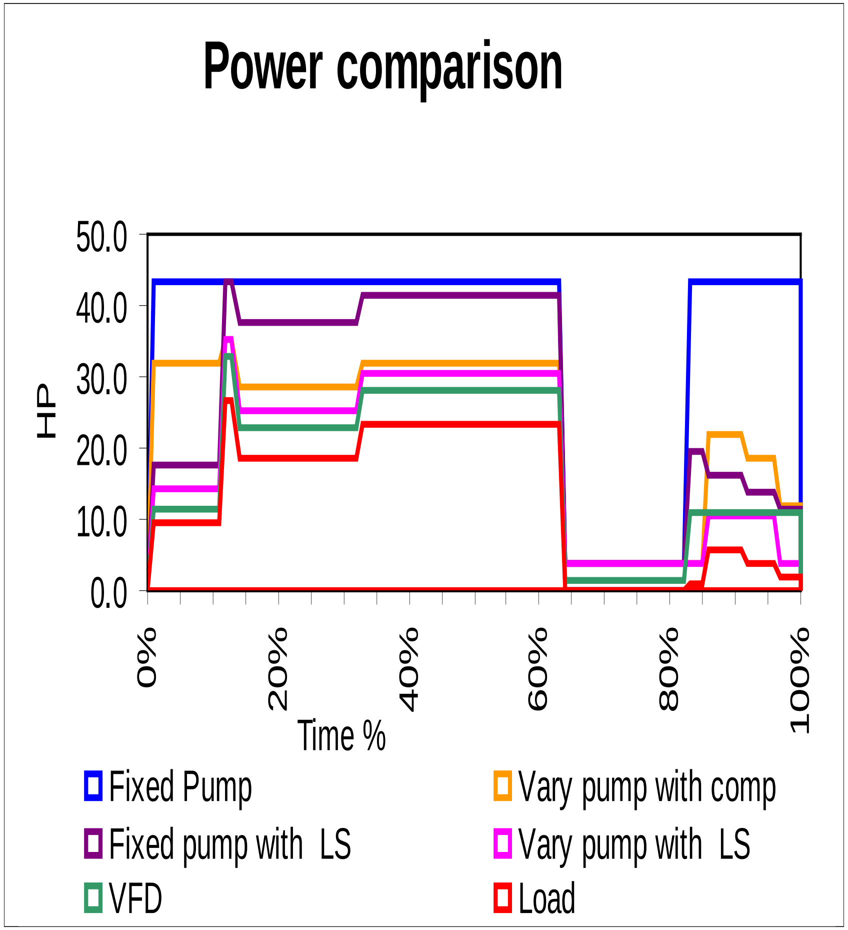
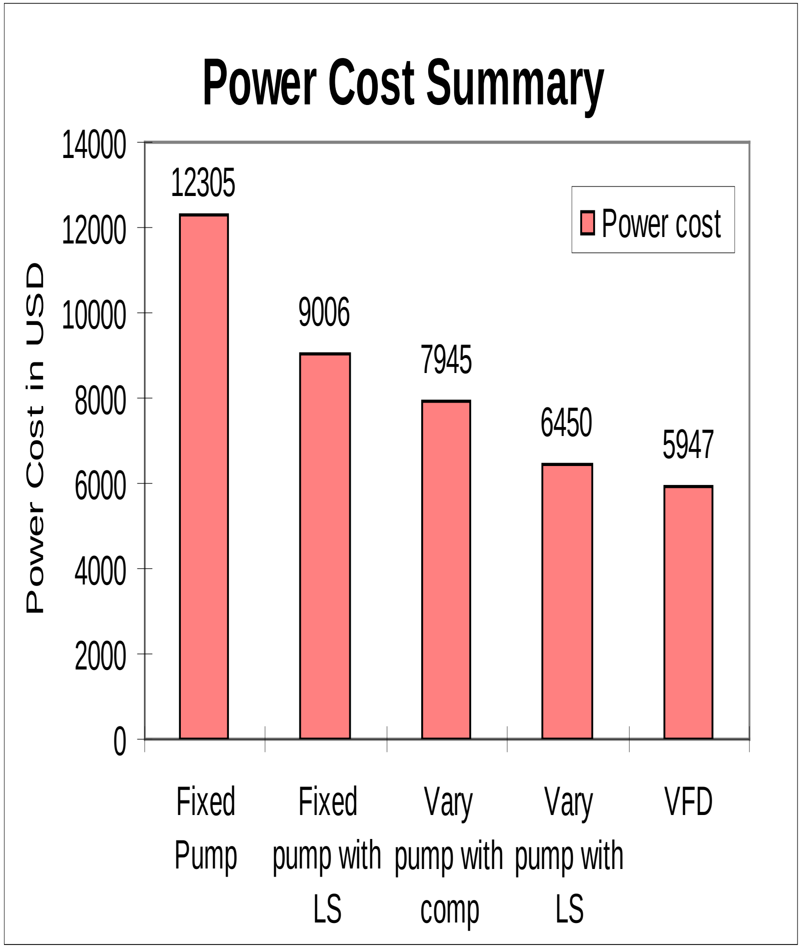
EXAMPLE - IMM





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EXAMPLE - IMM

Microsoft Excel - IMM 2.2.xls

Energy Calculator

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Application & Commercial Engineering

TO ABC INC
STEVEN

PROJECT NAME : Small Bucket

Total Annual Hours of Operation: 4608 Hours

Operation / Motor / VFD Data

Cost per kWh :	$	0.10
Motor Power (HP) :		40
Drive Efficiency:		97.0%
Variable Frequency Drive Cost:	$	5,000.00

Annual Energy Cost per Control Method

Fixed Pump	$	12,305
Fixed Pump with Load Sense	$	9,006
Variable Pump - Pressure Compensator	$	7,945
Variable Pump with Load Sense	$	6,450
Fixed Pump with VFD	$	5,947

Annual Energy Savings with Variable Frequency Drive

Versus Fixed Pump	$	**6,358**
Versus Fixed Pump with Load Sense	$	**3,059**
Versus Variable Pump - Pressure Compens	$	**1,998**
Versus Variable Pump with Load Sense	$	**503**

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EXAMPLE - BALER

	Function	Pressure	Flow	Time	Time
		psi	GPM	sec	%
1	HOLD DOWN CYLINDER CLOSE.	500	60	3	6.7%
2	CRUSH DOOR CYLINDER-1 CLOSE	1100	60	2.5	5.6%
3	CRUSH DOOR CYLINDER-2 CLOSE	1400	60	2.5	5.6%
4	BALER CYLINDER CLOSE	2000	45	20	44.4%
5	BALER CYLINDER DECOMP	500	6	0.5	1.1%
6	BALER CYLINDER RETURN	1000	40	1	2.2%
7	HOLD DOWN CYLINDER RETRACT	1200	50	1.5	3.3%
8	BALER CYLINDER CLOSE	900	45	3.5	7.8%
9	BALER CYLINDER RET.	1200	40	8	17.8%
10	CRUSH CYLINDER 1&2 OPEN	500	55	2.5	5.6%

Relief set	2200	psi
Pump Flow	60	GPM
Motor HP	75	HP
Efficiency Type	Standard	

Shift	2
Week	6 days
Working week annually	48

EXAMPLE - BALER

Microsoft Excel - 1bALER2.2.xls

File Edit View Insert Format Tools Data Window Help

Arial 10 80%

C49

INPUT

INPUTS

Operation:		
Hours Per Day of Operation	16	hrs
Days Per Week of Operation	6	day
Weeks Per Year of Operation	48	week
Total Annual Hours of Operation	4608	hrs
Cost per kWhr	$ 0.10	

Permissible Minimum Pump Speed	300	rpm
Pump Data:		
Pump Rated Flow	60	gpm
Relief Valve / Compensator set Pressure	2200	psi
Load sense compensator set Pressure	200	psi
Possible Minimum Pump Flow	10.0	gpm

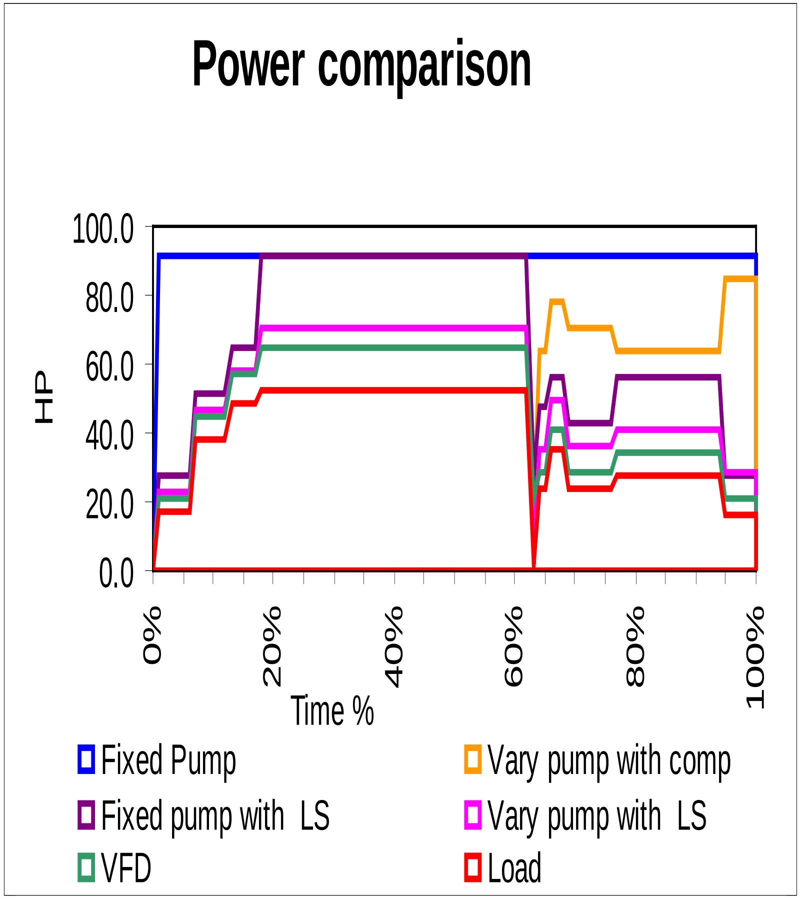
SET PRESSURE - MIN 2200 PSI

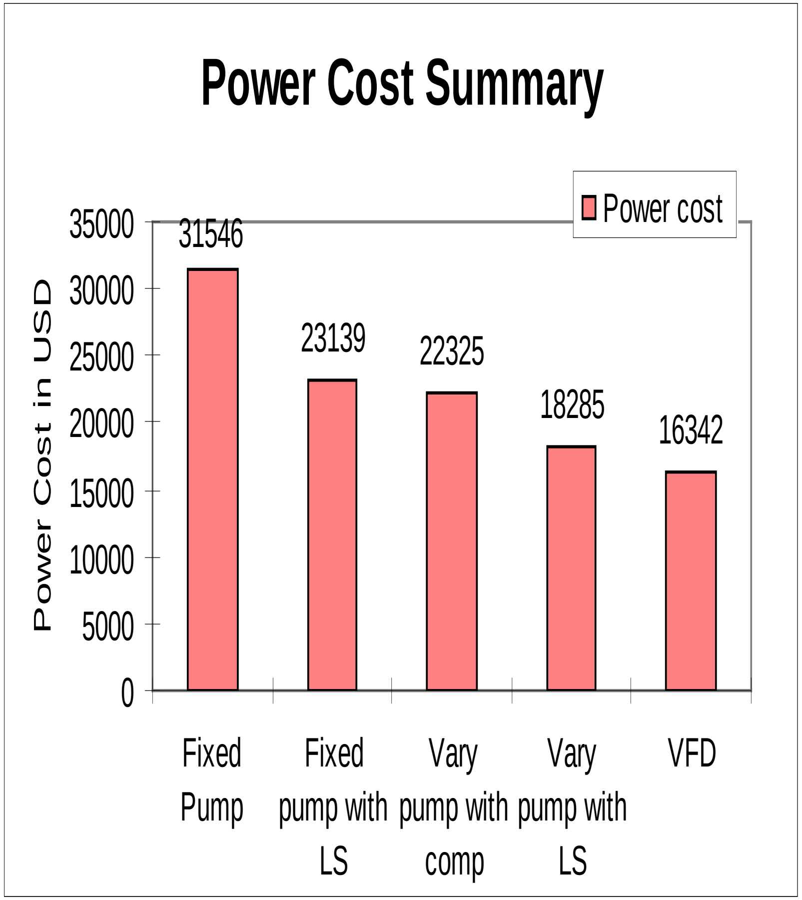
Electrical Motor Data:		
Electric Motor Power	75	HP
Motor Speed	1800	rpm
Motor Type - Efficiency	STD EFF	
VFD Data :		
VFD Efficiency	97%	
VFD Cost		

Duty Cycle Pump-1

Sl No	Pressure psi	Flow gpm	Time %
1	500	60	7%
2	1100	60	6%
3	1400	60	6%
4	2000	45	44%
5	500	6	1%
6	1000	40	2%
7	1200	50	3%
8	900	45	8%
9	1200	40	18%
10	500	55	6%
			100%

EXAMPLE - BALER





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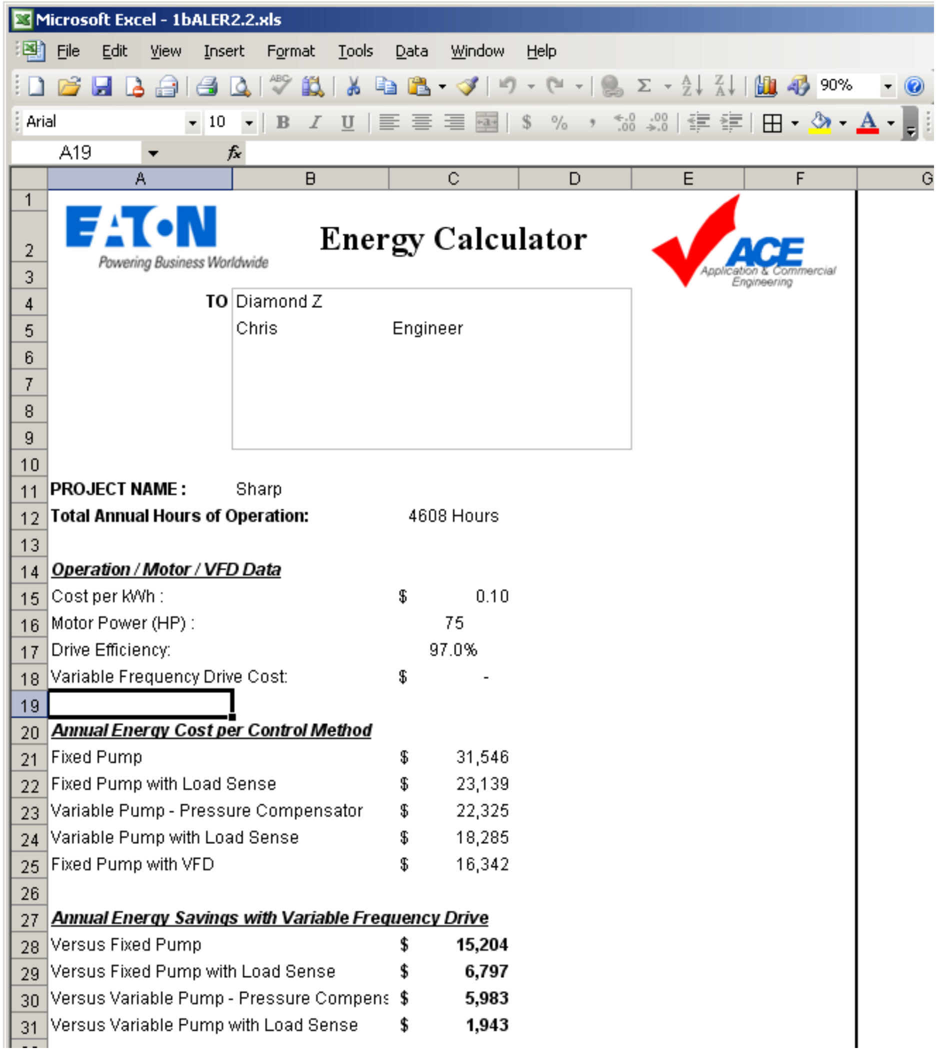
EXAMPLE - BALER

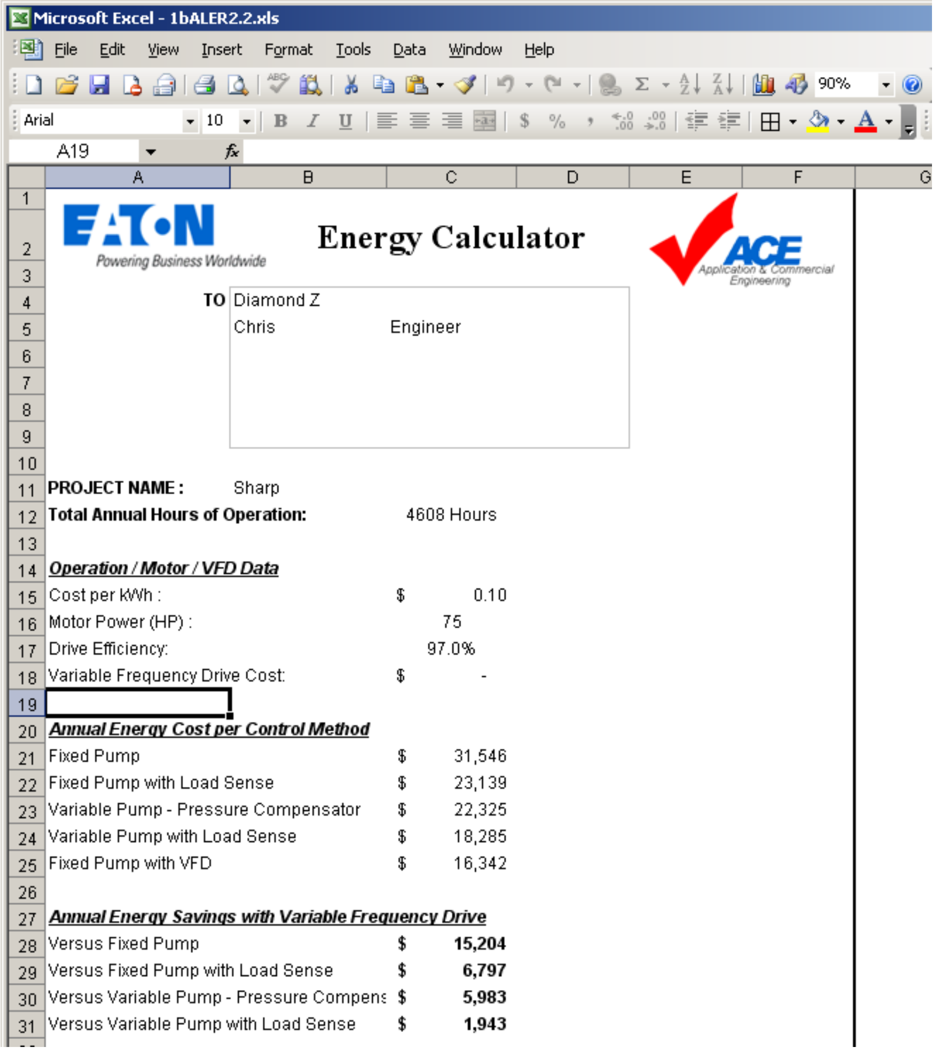


Microsoft Excel - 1bALER2.2.xls

Energy Calculator

TO	Diamond Z	
	Chris	Engineer
PROJECT NAME :	Sharp	
Total Annual Hours of Operation:		4608 Hours
Operation / Motor / VFD Data		
Cost per kWh :	$	0.10
Motor Power (HP) :		75
Drive Efficiency:		97.0%
Variable Frequency Drive Cost:	$	-
Annual Energy Cost per Control Method		
Fixed Pump	$	31,546
Fixed Pump with Load Sense	$	23,139
Variable Pump - Pressure Compensator	$	22,325
Variable Pump with Load Sense	$	18,285
Fixed Pump with VFD	$	16,342
Annual Energy Savings with Variable Frequency Drive		
Versus Fixed Pump	$	**15,204**
Versus Fixed Pump with Load Sense	$	**6,797**
Versus Variable Pump - Pressure Compens	$	**5,983**
Versus Variable Pump with Load Sense	$	**1,943**

EXAMPLE - BALER



Microsoft Excel - 1bALER2.2.xls

Energy Calculator

TO Diamond Z
Chris Engineer

PROJECT NAME :	Sharp	
Total Annual Hours of Operation:		4608 Hours
Operation / Motor / VFD Data		
Cost per kWh :	$	0.10
Motor Power (HP) :		75
Drive Efficiency:		97.0%
Variable Frequency Drive Cost:	$	-
Annual Energy Cost per Control Method		
Fixed Pump	$	31,546
Fixed Pump with Load Sense	$	23,139
Variable Pump - Pressure Compensator	$	22,325
Variable Pump with Load Sense	$	18,285
Fixed Pump with VFD	$	16,342
Annual Energy Savings with Variable Frequency Drive		
Versus Fixed Pump	$	**15,204**
Versus Fixed Pump with Load Sense	$	**6,797**
Versus Variable Pump - Pressure Compens	$	**5,983**
Versus Variable Pump with Load Sense	$	**1,943**

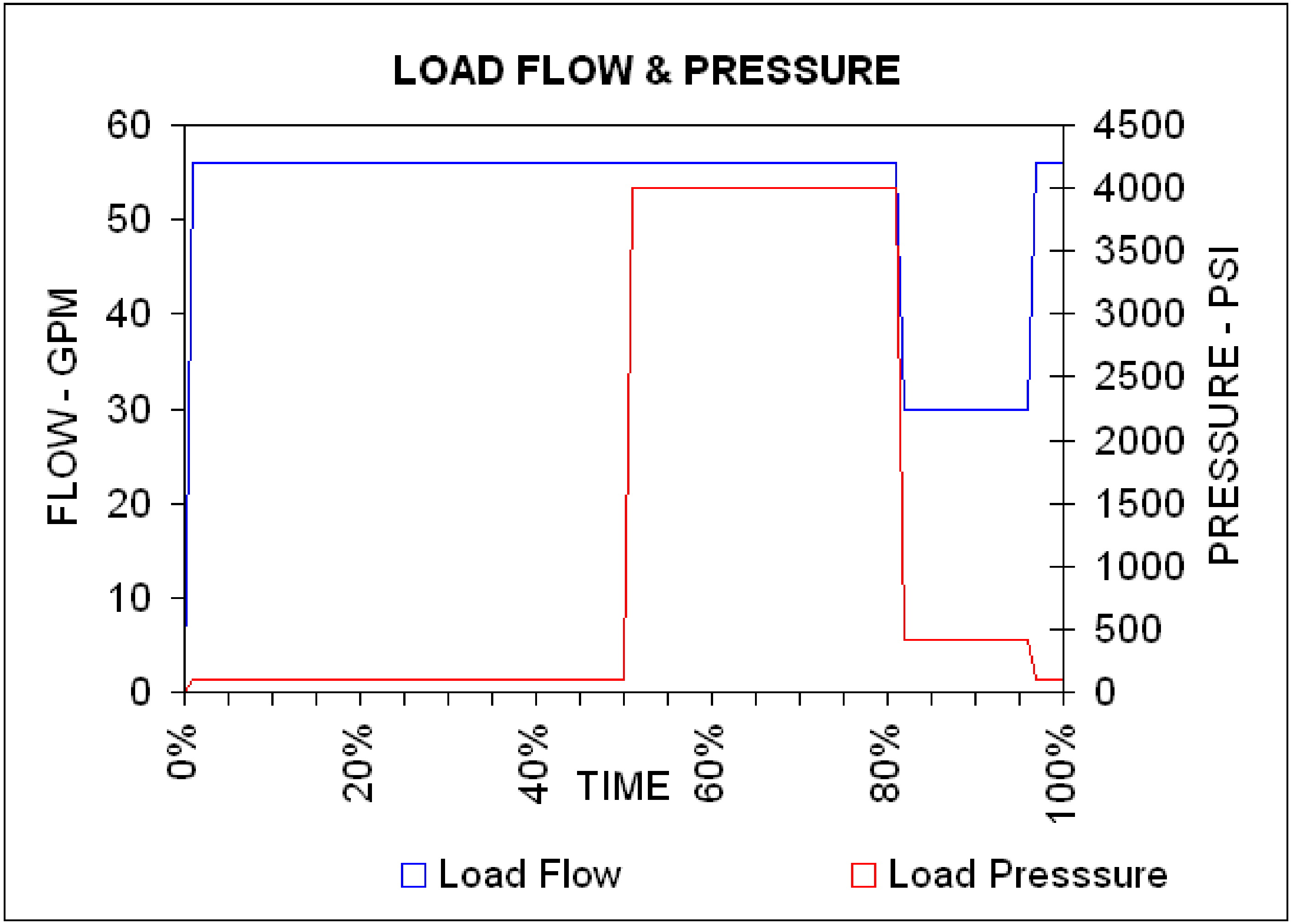
Down Acting Press Duty Cycle

	Time	Flow	Pressure	Power	
	sec	gpm	psi	HP	
Dwell (pump unloading)	5.00	56.84	100	4	39%
Fast Approach time	1.33	56.84	100	4	10%
Pressing time	4.00	56.84	4000	147	31%
Return time	2.00	30.60	420	8	16%
Decompression	0.50	56.84	100	4	4%
Total cycle time	12.83				100%

Hours Per Day of Operation	20	hrs
Days Per Week of Operation	6	day
Weeks Per Year of Operation	50	week
Total Annual Hours of Operation	6000	hrs
Cost per kWhr	0.1	

Relief Valve Set	4200	PSI
Pump Flow	56	GPM
Electric Motor	125	HP
Electric Motor Speed	1750	RPM
Efficiency Type	Std Eff	
Servo motor Power	100	HP
Servo motor Speed	1800	RPM

Press Duty Cycle – Flow & Pressure



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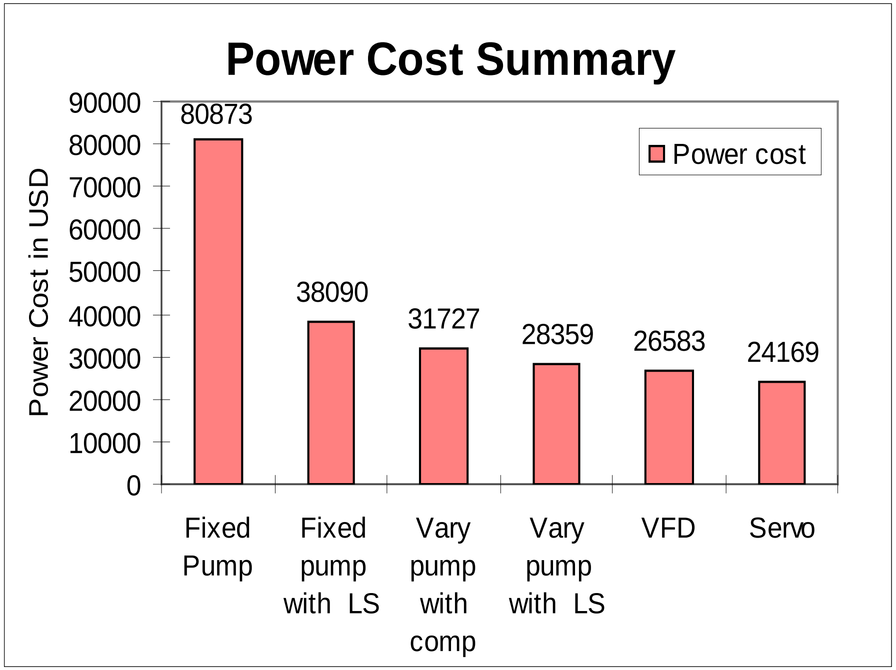
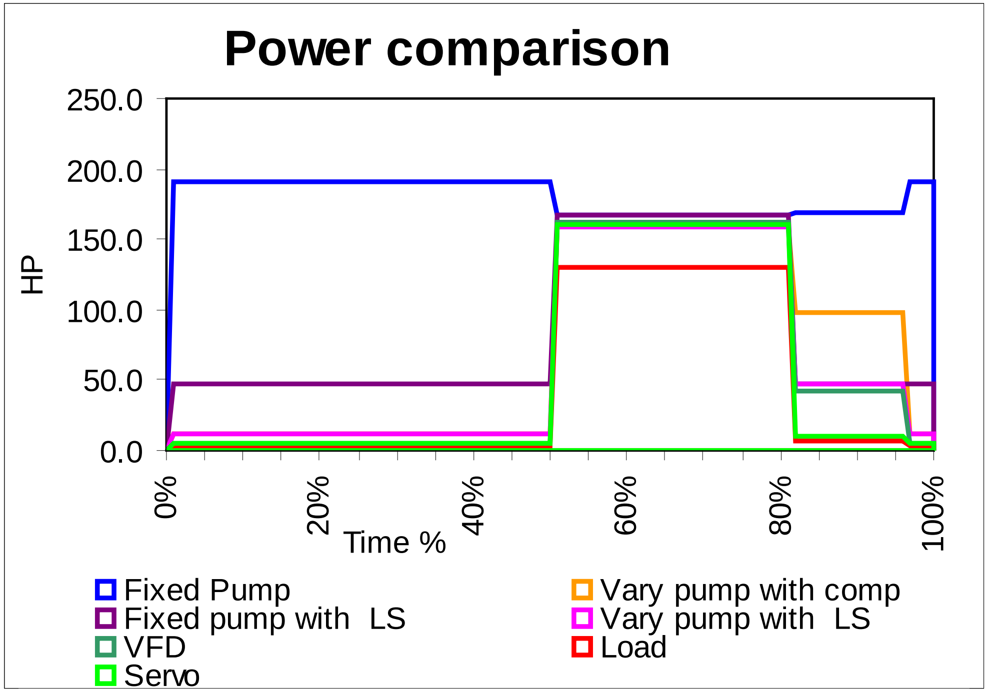
Power Consumption Results* – Press





*** Power / Energy Saving depends on Duty cycle**

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VMC Duty Cycle

CYCLE	TIME	FLOW	PRESSURE	% OF CYCLE
	sec	gpm	psi	
Dwell (Load Material)	3	3	50	6.82%
Chuck close	1	3	250	2.27%
Chuck close	1	3	300	2.27%
Chuck close	1	3	350	2.27%
Chuck close	1	3	400	2.27%
Chuck close	1	3	500	2.27%
Spindle on, chuck held closed	4	0.5	500	9.09%
Chuck held closed, Tailstock Extend	4	3	500	9.09%
chuck held closed, Tailstock Extend, Machine Part	20	0.5	500	45.45%
chuck and tailstock open	4	6	250	9.09%
Spindle Off and remove part	4	3	50	9.09%
Total	44			100%

Hours Per Day of Operation	**20**	**hrs**
Days Per Week of Operation	**6**	**day**
Weeks Per Year of Operation	**50**	**week**
Total Annual Hours of Operation	**6000**	**hrs**
Cost per kWhr	**0.1**	

Relief Valve Set	**700**	**PSI**
Pump Flow	**6**	**GPM**
Electric Motor	**2**	**HP**
Electric Motor Speed	**1750**	**RPM**
Efficiency Type	**Std Eff**	
Servo motor Power	**1**	**HP**
Servo motor Speed	**1800**	**RPM**

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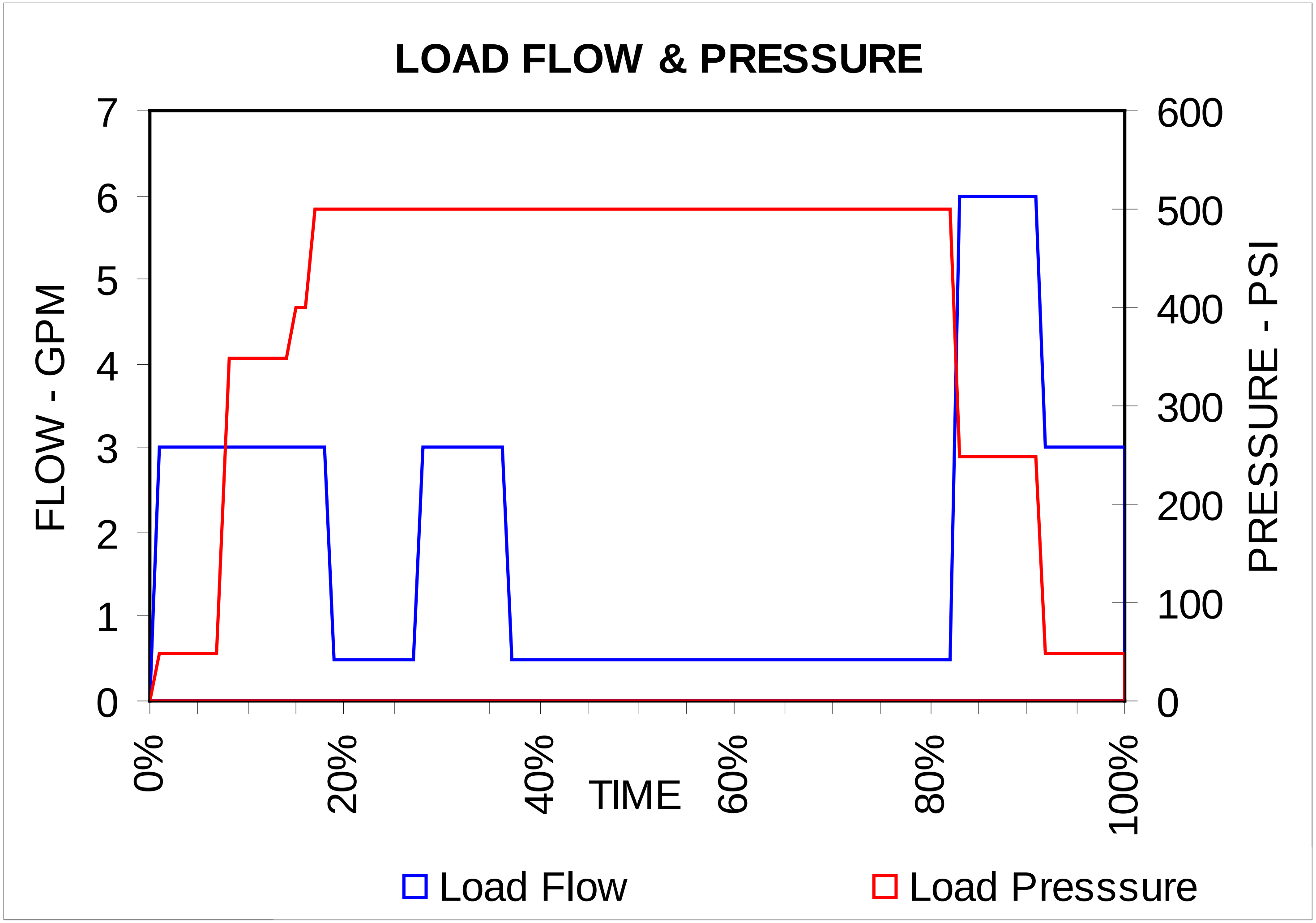
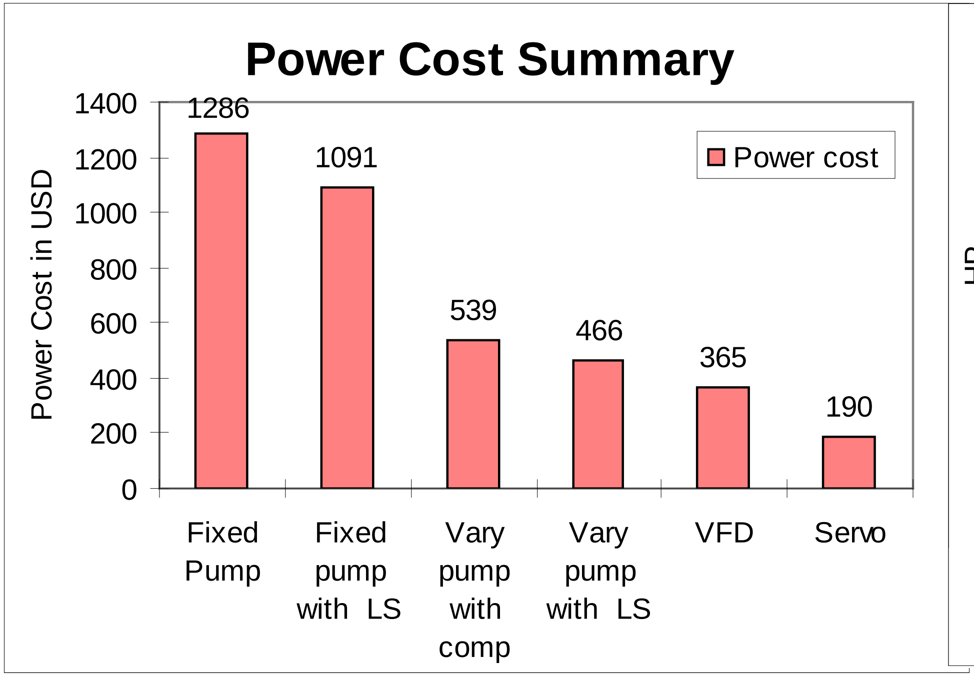
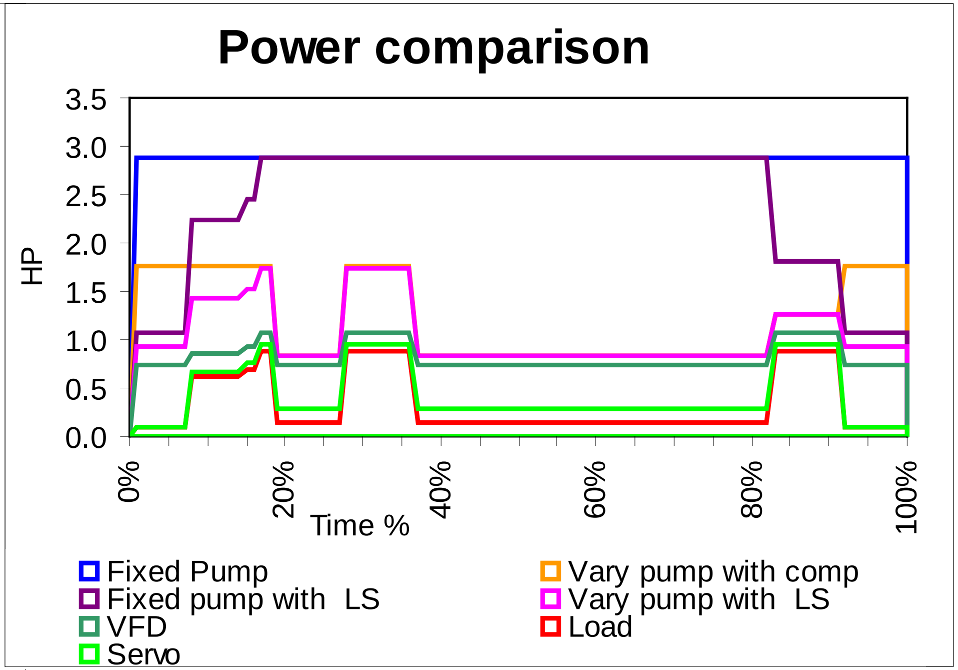
VMC Duty Cycle – Flow & Pressure



Power Consumption Results* – VMC





*** Power / Energy Saving depends on Duty cycle**

Questions?

Energy Efficient Hydraulics and Pneumatics Conference

November 27-29, 2012

Chicago Marriott O'Hare Hotel, Chicago, IL

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