ENERGY EFFICIENCY ON PUMP SYSTEMS

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Pumps and Pumping System

2.1 Introduction

2.2 Type of pumps

2.3 Assessment of pumps

2.4 Energy efficiency opportunities

Introduction

- 20% of world's electrical energy demand
- 25-50% of energy usage in some industries
- Used for
  - Domestic, commercial, industrial and agricultural services
  - Municipal water and wastewater services

Objective of Pumping System

- **Transfer liquid from source to destination**
- **Circulate liquid around a system**

What Are Pumping Systems

- Main pump components
  - Pumps
  - Prime movers: electric motors, diesel engines, air system
  - Piping to carry fluid
  - Valves to control flow in system
  - Other fittings, control, instrumentation
- End-use equipment
  - Heat exchangers, tanks, hydraulic machines

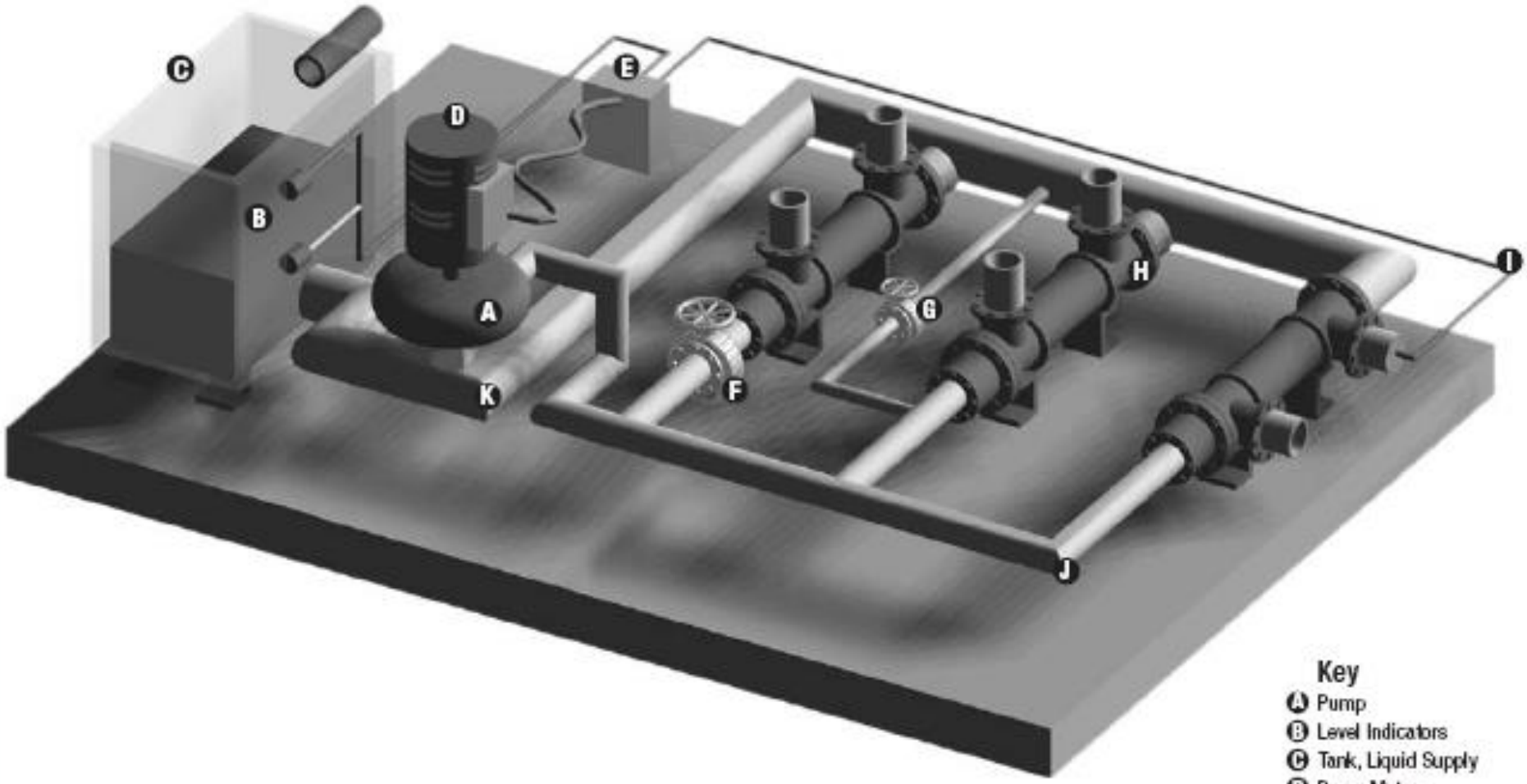
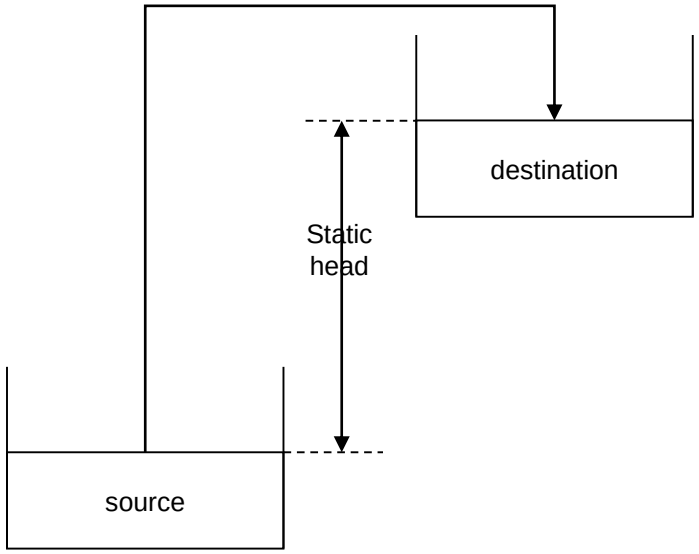


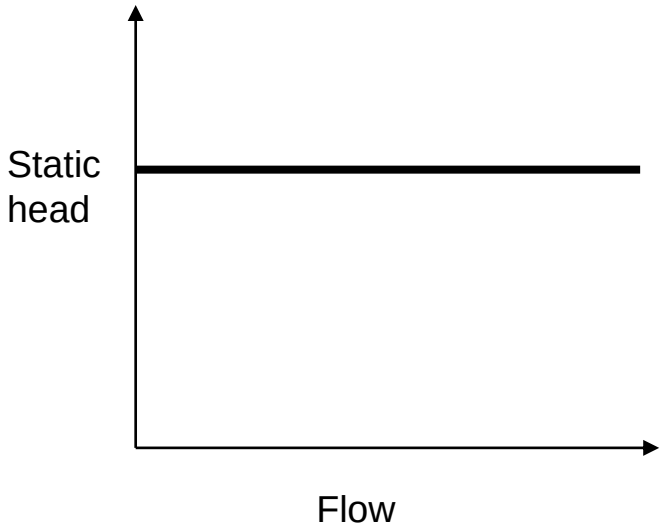
Figure 1. Typical Pumping System Components

Pumping Head

- **Head**
  - **Resistance of the system**
  - **Two types: static and friction**



- **Static head**
  - **Difference in height between source and destination**
  - **Independent of flow**



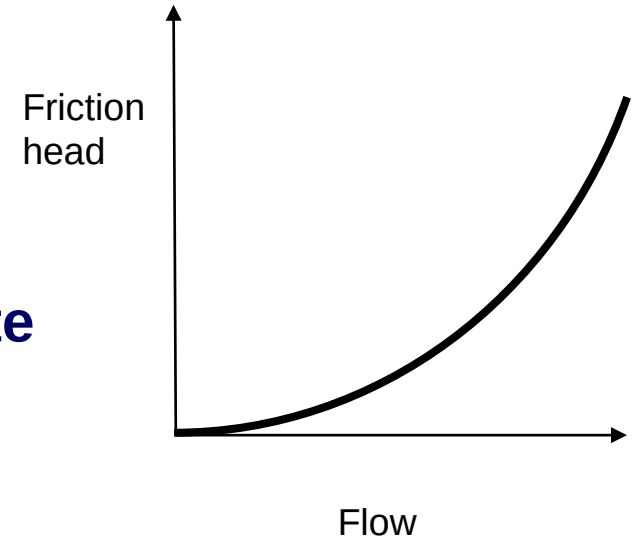
Pumping System Characteristics

- **Static head consists of**
  - **Static suction head (hS): lifting liquid relative to pump center line**
  - **Static discharge head (hD) vertical distance between centerline and liquid surface in destination tank**
- **Static head at certain pressure**

$$\text{Head (in feet)} = \frac{\text{Pressure (psi) X 2.31}}{\text{Specific gravity}}$$

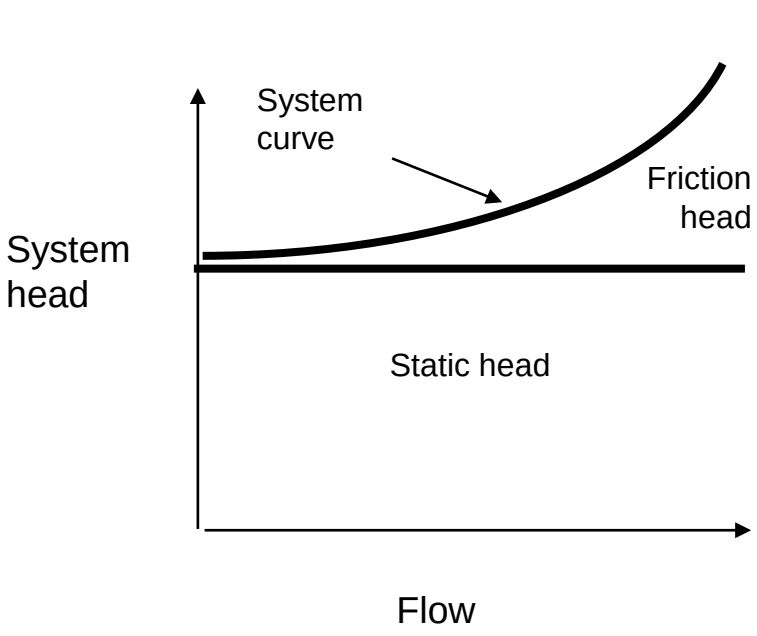
Friction Head

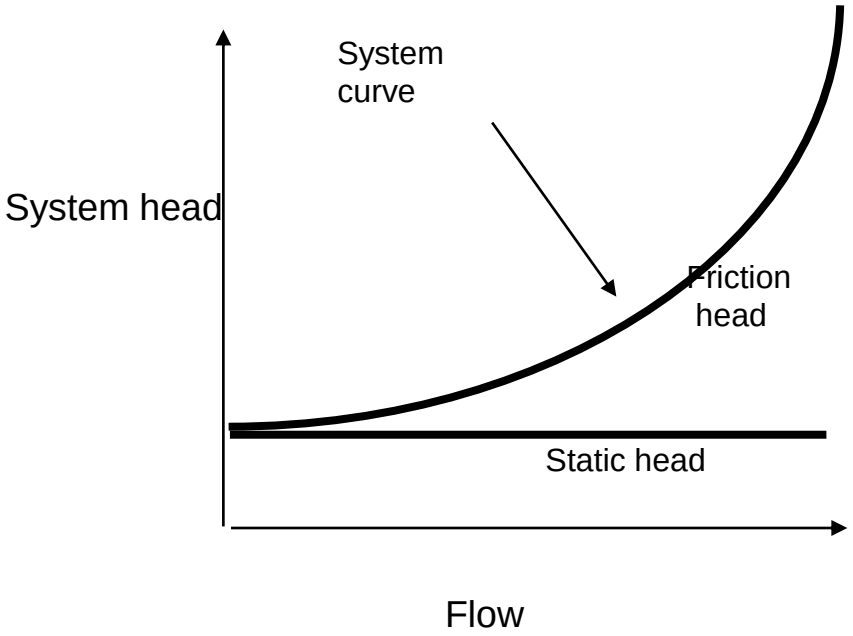
- **Resistance to flow in pipe and fittings**
- **Depends on size, pipes, pipe fittings, flow rate, nature of liquid**
- **Proportional to square of flow rate**
- **Closed loop system only has friction head (no static head)**



In most cases:

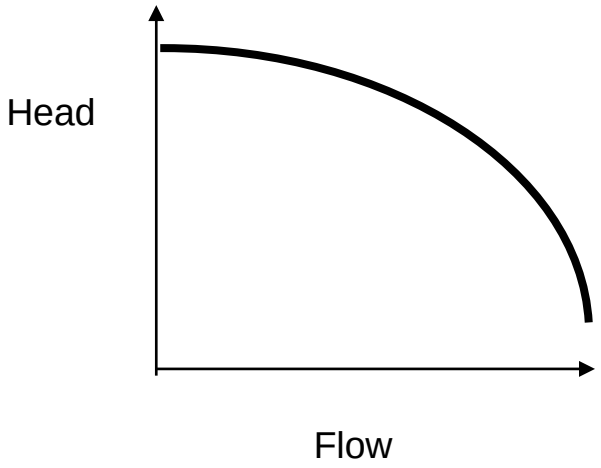
Total head = Static head + friction head





Pump Performance Curve

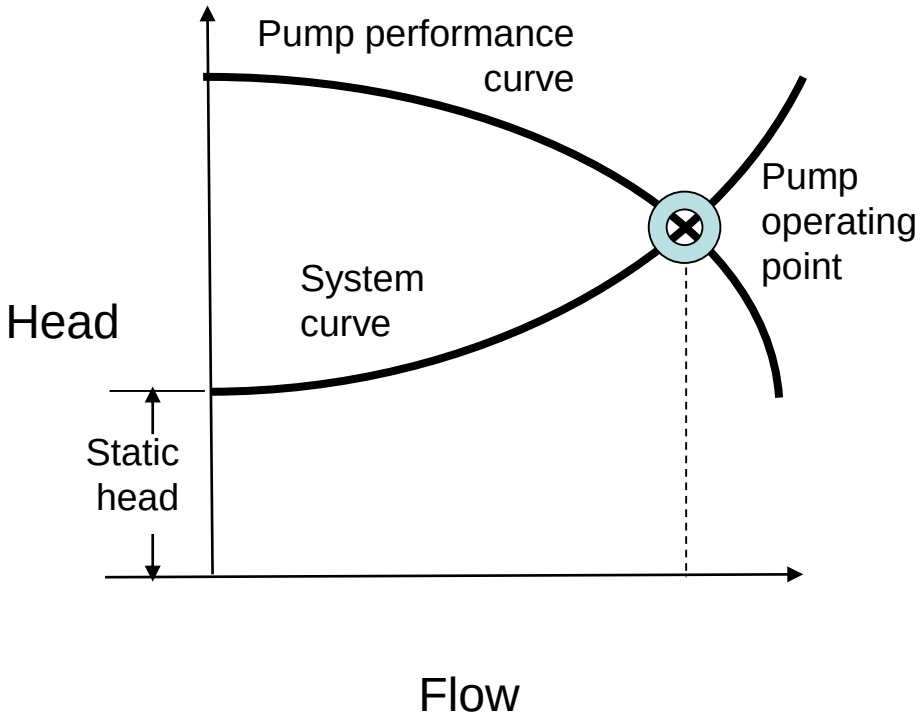
- **Relationship between head and flow**
  - **Flow increase**
  - **System resistance increases**
  - **Head increases**
  - **Flow decreases to zero**
- **Zero flow rate: risk of pump burnout**



Performance curve for centrifugal pump

Pump Operating Point

- **Duty point: rate of flow at certain head**
- **Pump operating point: intersection of pump curve and system curve**



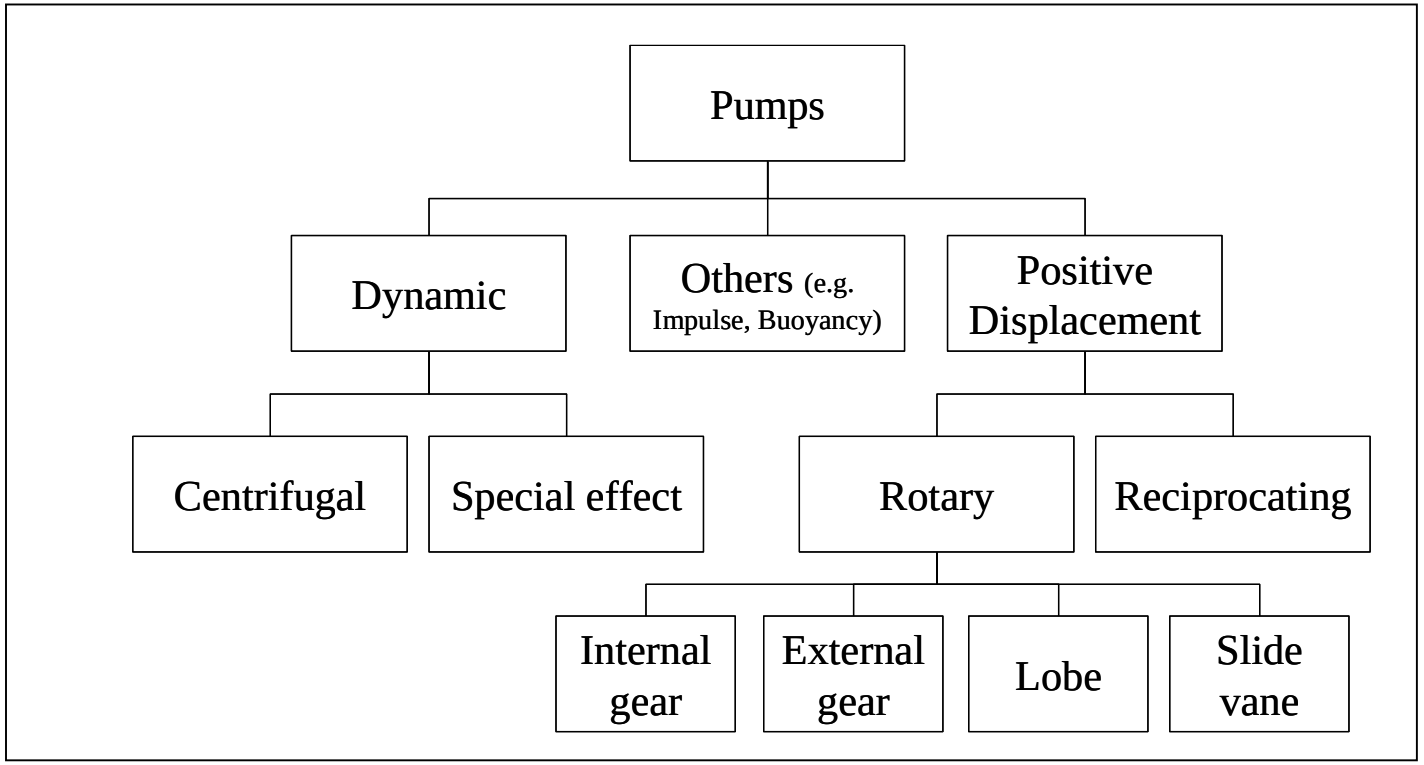
Pump Suction Performance (NPSH)

- Cavitation or vaporization: bubbles inside pump
- If vapor bubbles collapse
  - Erosion of vane surfaces
  - Increased noise and vibration
  - Choking of impeller passages
- Net Positive Suction Head
  - NPSH Available: how much pump suction exceeds liquid vapor pressure
  - NPSH Required: pump suction needed to avoid cavitation

Type of Pumps

Pump Classification

Classified by operating principle



Positive Displacement Pumps

- For each pump revolution
  - Fixed amount of liquid taken from one end
  - Positively discharged at other end
- If pipe blocked
  - Pressure rises
  - Can damage pump
- Used for pumping fluids other than water

Positive Displacement Pumps

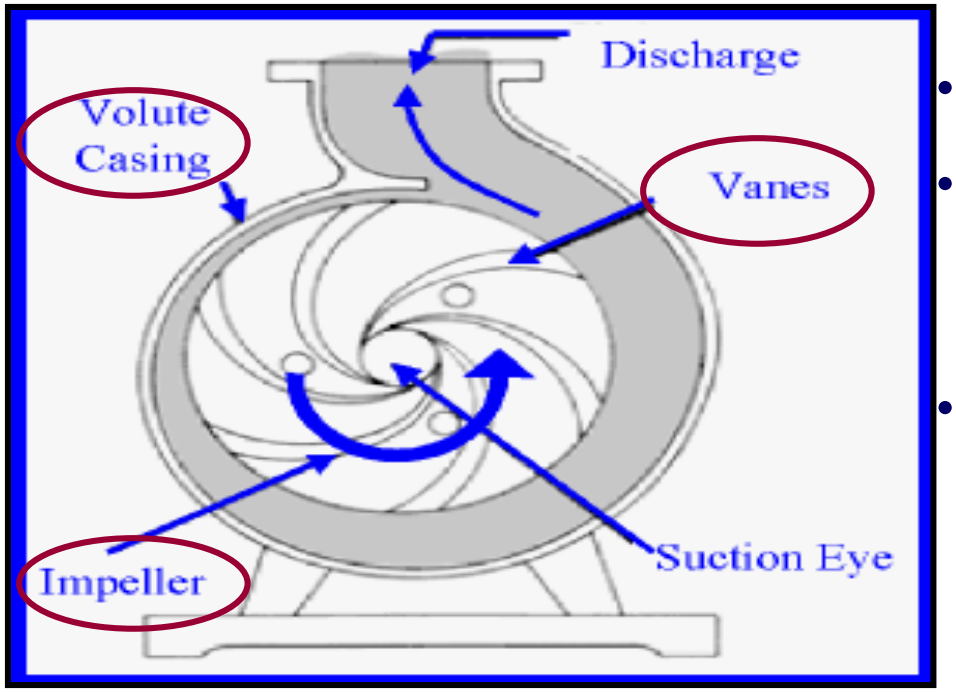
- **Reciprocating pump**
  - **Displacement by reciprocation of piston plunger**
  - **Used only for viscous fluids and oil wells**
- **Rotary pump**
  - **Displacement by rotary action of gear, cam or vanes**
  - **Several sub-types**
  - **Used for special services in industry**

Dynamic Pumps

- **Mode of operation**
  - **Rotating impeller converts kinetic energy into pressure or velocity to pump the fluid**
- **Two types**
  - **Centrifugal pumps: pumping water in industry – 75% of pumps installed**
  - **Special effect pumps: specialized conditions**

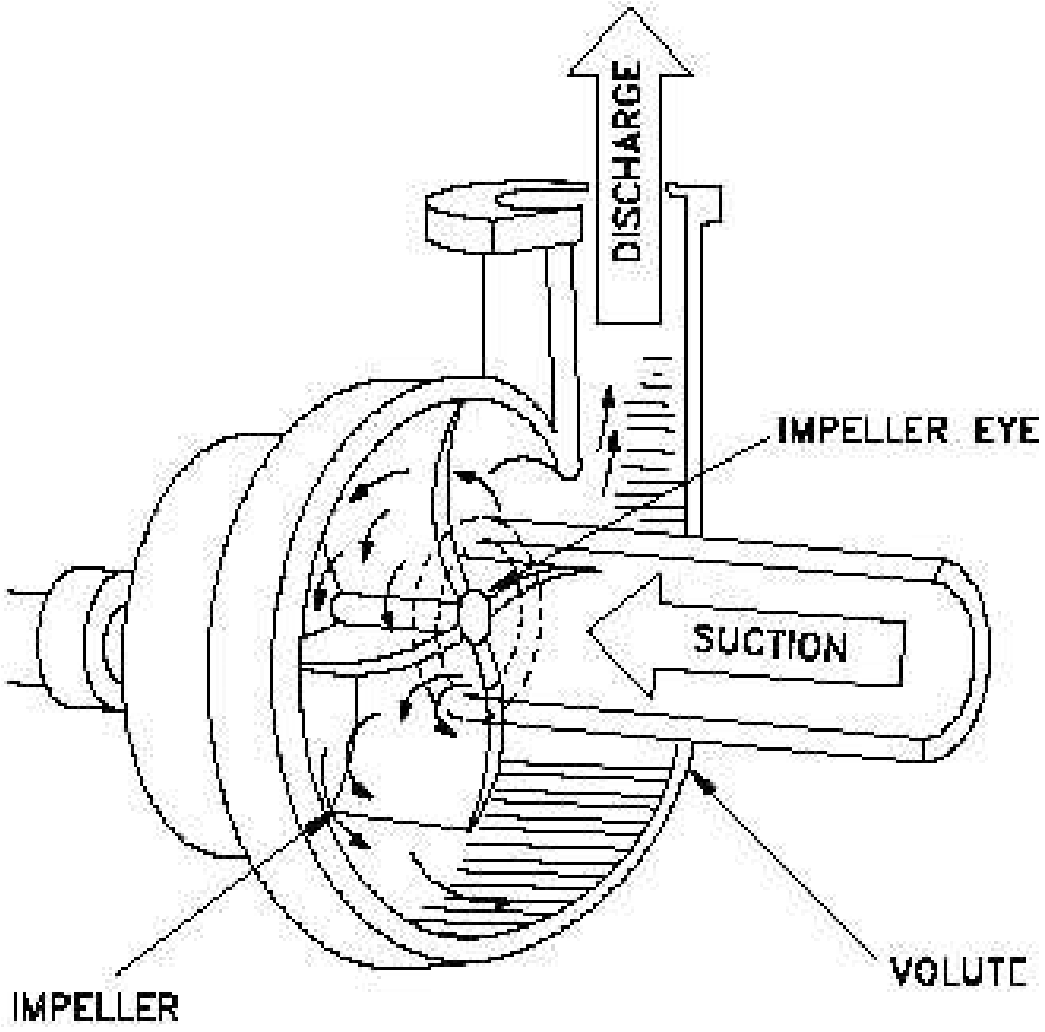
Centrifugal Pumps

How do they work?



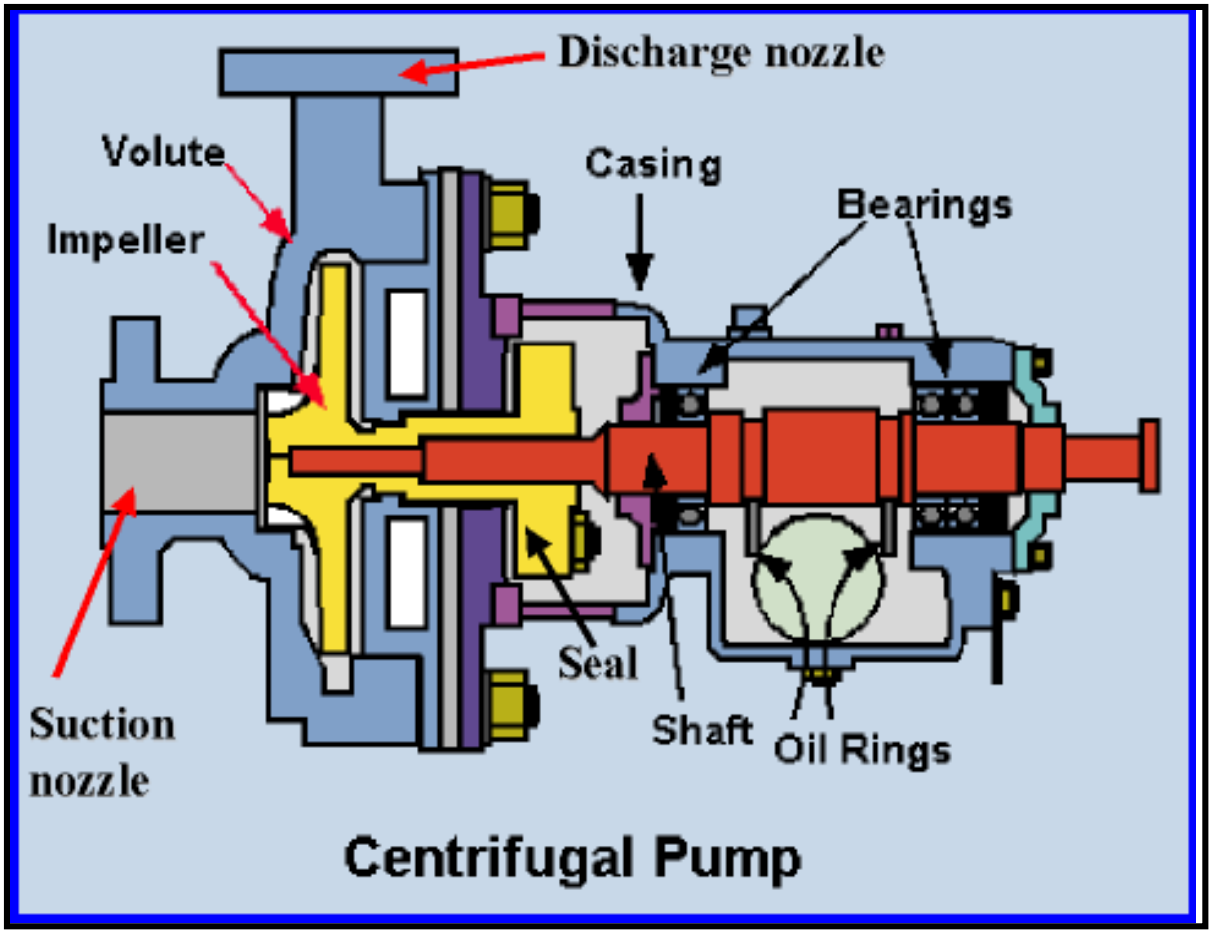
- Liquid forced into impeller
- Vanes pass kinetic energy to liquid: liquid rotates and leaves impeller
- Volute casing converts kinetic energy into pressure energy

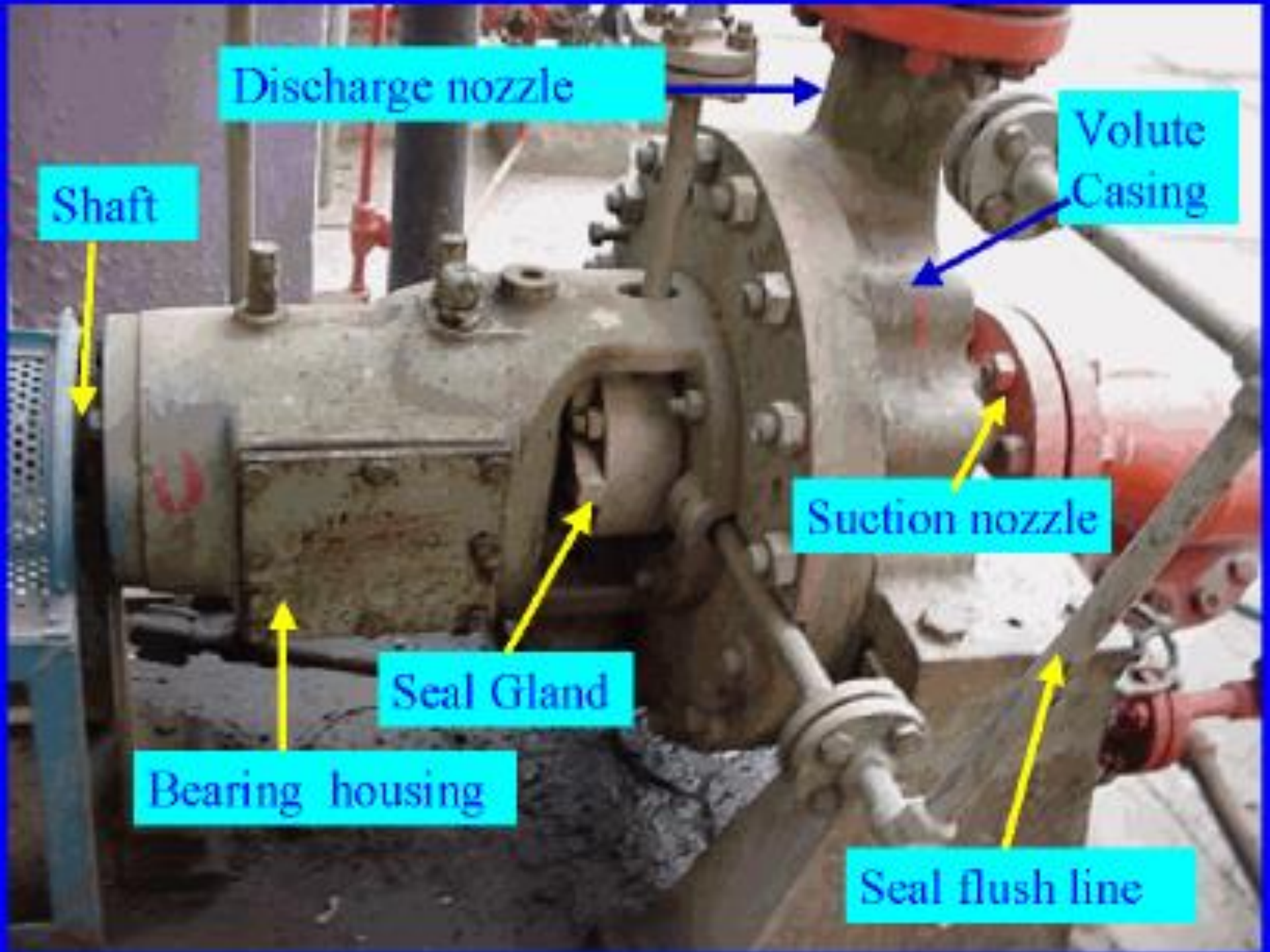
CENTRIFUGAL PUMP



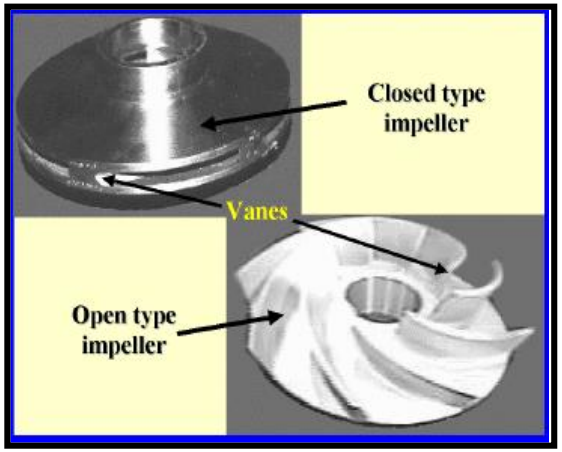
Centrifugal Pumps

Rotating and stationary components




Discharge nozzle
Volute Casing
Shaft
Suction nozzle
Seal Gland
Bearing housing
Seal flush line

Centrifugal Pumps



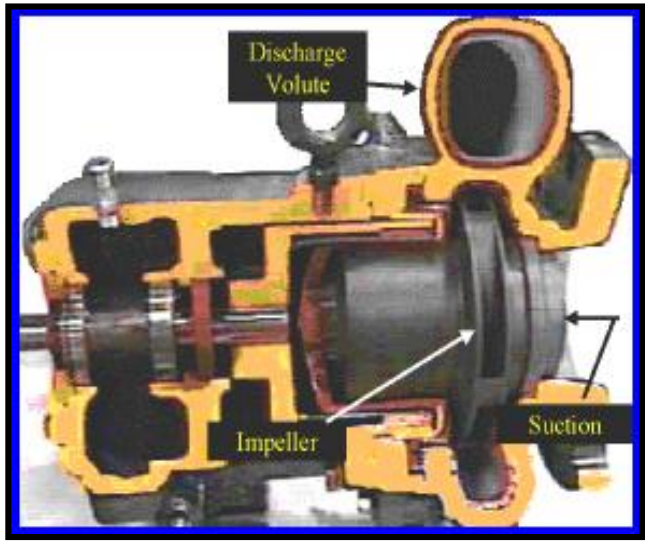
Impeller

- Main rotating part that provides centrifugal acceleration to the fluid
- Number of impellers = number of pump stages
- Impeller classification: direction of flow, suction type and shape/mechanical construction

Shaft

- Transfers torque from motor to impeller during pump start up and operation

Centrifugal Pumps



Casings

- **Functions**
  - Enclose impeller as “pressure vessel”
  - Support and bearing for shaft and impeller
- **Volute case**
  - Impellers inside casings
  - Balances hydraulic pressure on pump shaft
- **Circular casing**
  - Vanes surrounds impeller
  - Used for multi-stage pumps

PUMP CALCULATIONS

$$\text{Pump Efficiency} = \frac{\text{Hydrolic power, } P_h \times 100}{\text{Power input to the pump shaft}}$$

Where,

Hydraulic power $P_h(kW) = Q(m^3/s) \times$ Total head,$(h_d - h_s)(m) \times p(kg/m^3) \times g(m/s^2)/1000$

Q=Volume flow rate, p=density of the fluid, g=acceleration due to gravity

h_d = Delivery head, h_s = Suctionhead

POWER CALCULATIONS

Assume that we need to pump 68 m3/hr to a 47 meter head with a pump that is 60% efficient at that point, motor efficiency 90%.

Calculate motor power.

Liquid Power = 68 * 47 *1000*9.81/ 3600*1000

= 8.7 kW

Shaft Power = 8.7 / 0.60 = 14.5 kW

Motor Power = 14.5 / 0.9 = 16.1 kW

Pump Efficiency Example

Illustration of calculation method outlined

A chemical plant operates a cooling water pump for process cooling and refrigeration applications. During the performance testing the following operating parameters were measured;

Measured Data

Pump flow, Q	0.40 m^3/ s
Power absorbed, P	325 kW
Suction head (Tower basin level), h_1	+1 M
Delivery head, h_2	55 M
Height of cooling tower	5 M
Motor efficiency	88 %
Type of drive	Direct coupled
Density of water	996 kg/ m^3

Pump Efficiency Example

Flow delivered by the pump : 0.40 m^3/s

Total head, h2 -(+h1) : 54 M

Hydraulic power : 0.40 x 54 x 996 x 9.81/1000 = 211 kW

Actual power consumption : 325 kW

Overall system efficiency : (211 x 100) / 325 = 65 %

Pump efficiency : 65/0.88 = 74 %

Assessment of Pumps

How to Calculate Pump Performance

- **Pump shaft power (Ps) is actual horsepower delivered to the pump shaft**

Pump shaft power (Ps):
Ps = Hydraulic power Hp / pump efficiency ηPump

Pump Efficiency (ηPump):
ηPump = Hydraulic Power / Pump Shaft Power

- **Pump output/Hydraulic/Water horsepower (Hp) is the liquid horsepower delivered by the pump**

Hydraulic power (Hp):
Hp = Q (m3/s) x Total head, hd - hs (m) x ρ (kg/m3) x g (m/s2) / 1000

hd - discharge head
ρ - density of the fluid
hs – suction head,
g – acceleration due to gravity

Difficulties in Pump Assessment

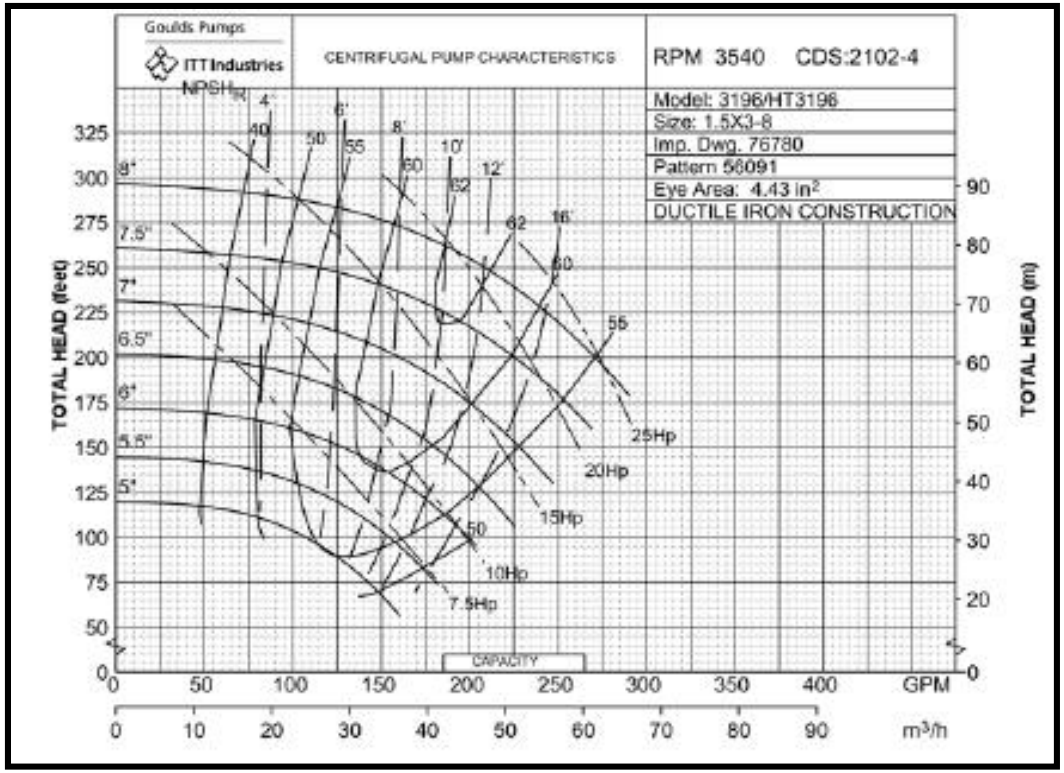
- Absence of pump specification data to assess pump performance
- Difficulties in flow measurement and flows are often estimated
- Improper calibration of pressure gauges & measuring instruments
  - Calibration not always carried out
  - Correction factors used

Energy Efficiency Opportunities

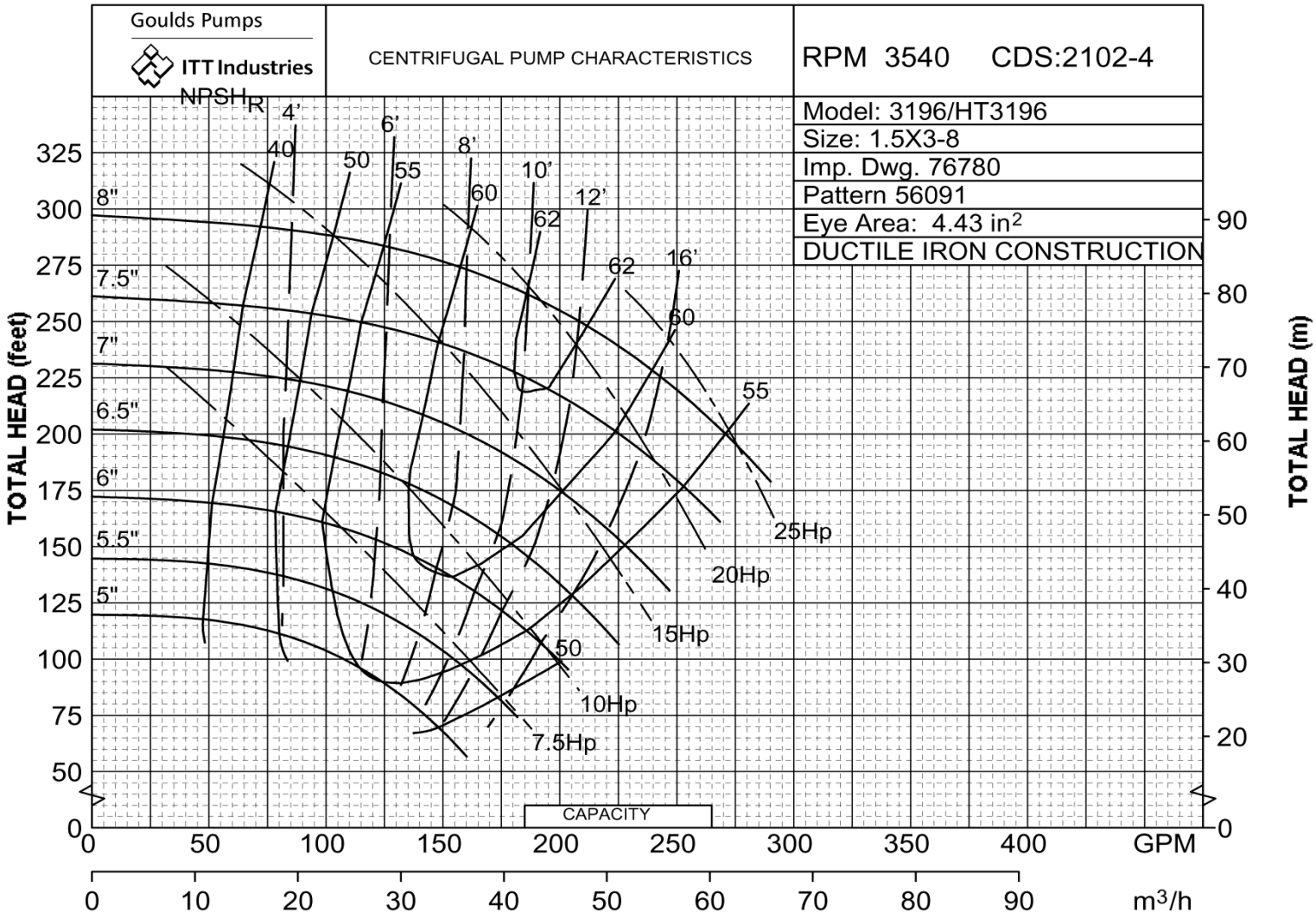
1. Selecting the right pump
2. Controlling the flow rate by speed variation
3. Pumps in parallel to meet varying demand
4. Eliminating flow control valve
5. Eliminating by-pass control
6. Start/stop control of pump
7. Impeller trimming

1. Selecting the Right Pump

Pump performance curve for centrifugal pump



TYPICAL PUMP CHARACTERISTIC CURVES



- **Oversized pump**
  - **Requires flow control (throttle valve or by-pass line)**
  - **Provides additional head**
  - **System curve shifts to left**
  - **Pump efficiency is reduced**
- **Solutions if pump already purchased**
  - **VSDs or two-speed drives**
  - **Lower RPM**
  - **Smaller or trimmed impeller**

2. Controlling Flow: speed variation

Explaining the effect of speed

- **Affinity laws: relation speed N and**
  - **Flow rate Q α N**
  - **Head H α N^2**
  - **Power P α N^3**
- **Small speed reduction (e.g. ½) = large power reduction (e.g. 1/8)**

2. Controlling Flow: speed variation

Variable Speed Drives (VSD)

- Speed adjustment over continuous range
- Power consumption also reduced!
- Two types
  - Mechanical: hydraulic clutches, fluid couplings, adjustable belts and pulleys
  - Electrical: eddy current clutches, wound-rotor motor controllers, Variable Frequency Drives (VFDs)

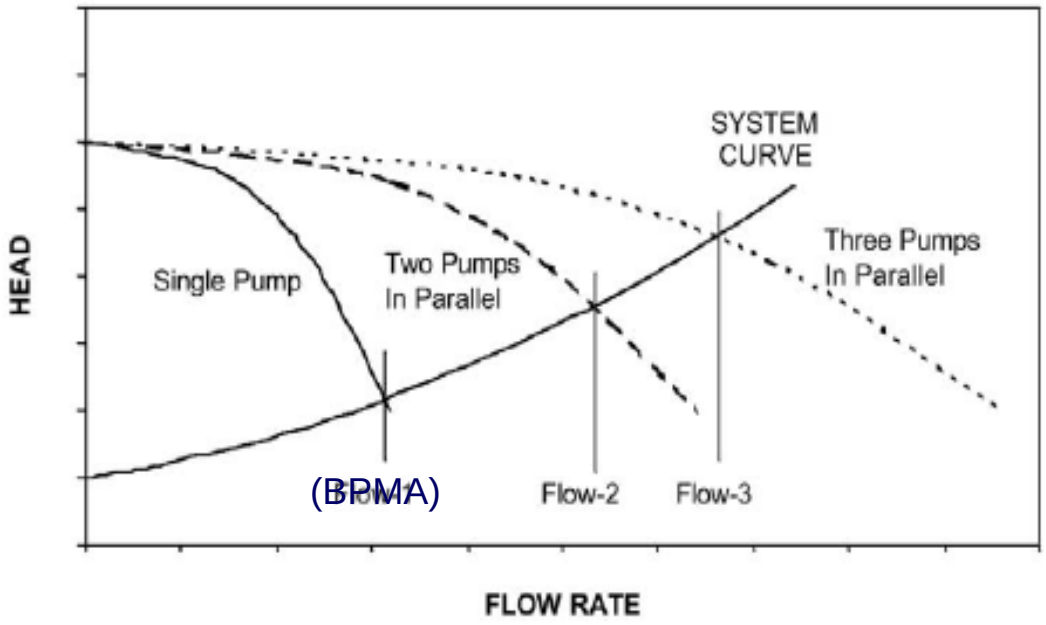
2. Controlling Flow: speed variation

Benefits of VSDs

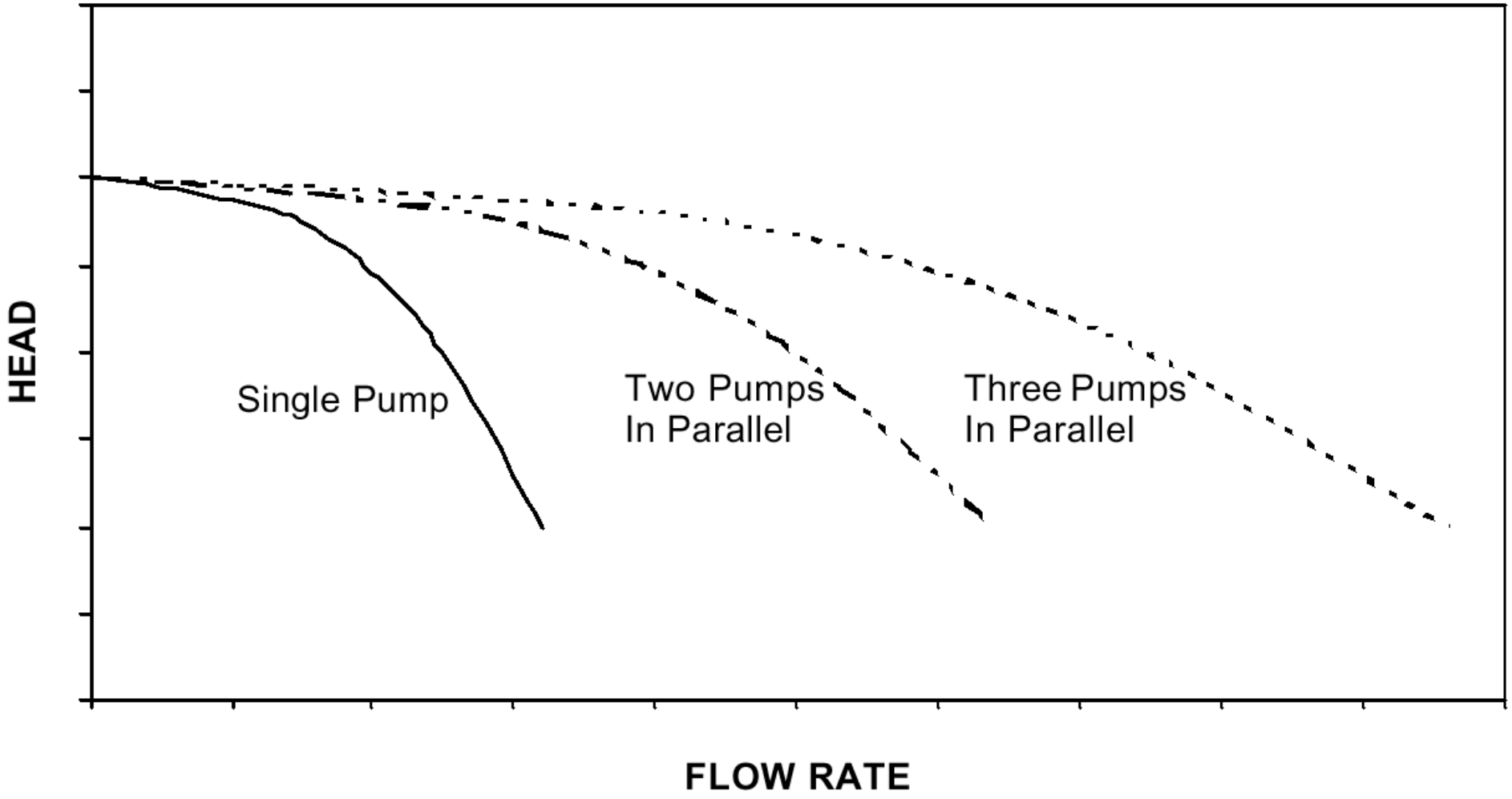
- **Energy savings** ***(not just reduced flow!)***
- **Improved process control**
- **Improved system reliability**
- **Reduced capital and maintenance costs**
- **Soft starter capability**

3. Parallel Pumps for Varying Demand

- **Multiple pumps: some turned off during low demand**
- **Used when static head is > 50% of total head**
- **System curve does not change**
- **Flow rate lower than sum of individual flow rates**



PUMPS IN PARALLEL OPERATION



CENTRIFUGAL PUMPS IN PARALLEL

- The total head for the **combination** is the same as the total head for each pump

$$\Delta h_T = \Delta h_1 = \Delta h_2$$

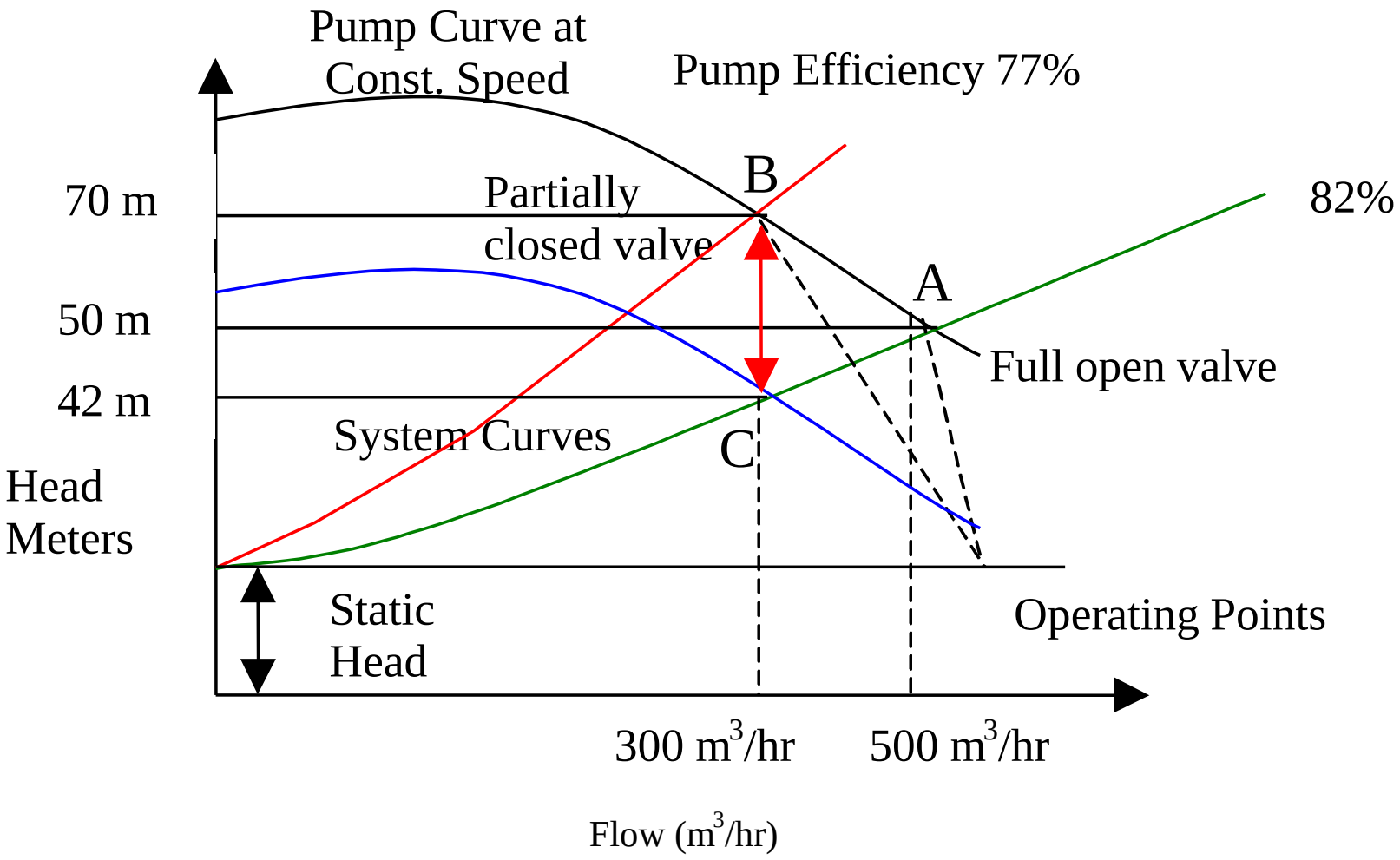
- The flowrate or capacity is the sum of the two pumps

$$Q_T = Q_1 + Q_2$$

4. Eliminating By-pass Control

- **Pump discharge divided into two flows**
  - **One pipeline delivers fluid to destination**
  - **Second pipeline returns fluid to the source**
- **Energy wastage because part of fluid pumped around for no reason**

EFFECT OF THROTTLING



5. Eliminating By-pass Control

- **Pump discharge divided into two flows**
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6. Start/Stop Control of Pump

- Stop the pump when not needed
- Example:
  - Filling of storage tank
  - Controllers in tank to start/stop
- Suitable if not done too frequently
- Method to lower the maximum demand (pumping at non-peak hours)

7. Impeller Trimming

- **Changing diameter: change in velocity**
- **Considerations**
  - **Cannot be used with varying flows**
  - **No trimming >25% of impeller size**
  - **Impeller trimming same on all sides**
  - **Changing impeller is better option but more expensive and not always possible**

THE AFFINITY LAW FOR A CENTRIFUGAL PUMP

Flow:

$Q1 / Q2 = N1 / N2$

Example:

$100 / Q2 = 1750/3500$

$Q2 = 200\ m^3/hr$

Head:

$H1/H2 = (N1^2) / (N2^2)$

Example:

$100 /H2 = 1750^{\ 2}/ 3500^{\ 2}$

$H2 = 400\ m$

Power :

$P1 / P2 = (N1^3) / (N2^3)$

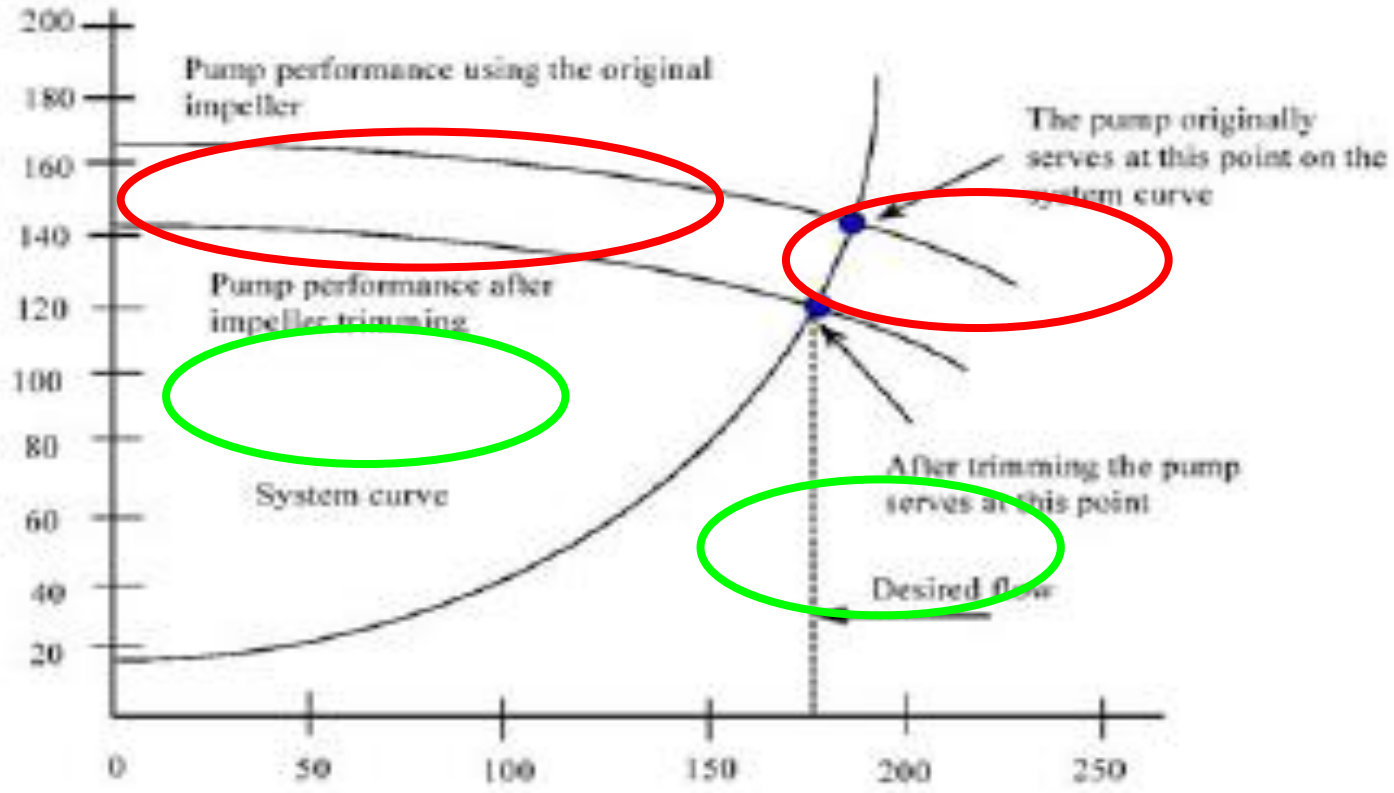
Example:

$5/P2 = 1750^3 / 3500^3$

$P2 = 40$

7. Impeller Trimming

Impeller trimming and centrifugal pump performance



Comparing Energy Efficiency Options

Parameter	Change control valve	Trim impeller	VFD
Impeller diameter	430 mm	375 mm	430 mm
Pump head	71.7 m	42 m	34.5 m
Pump efficiency	75.1%	72.1%	77%
Rate of flow	80 m^3/hr	80 m^3/hr	80 m^3/hr
Power consumed	23.1 kW	14 kW	11.6 kW

THANK YOU

for your attention

REFERENCES

1. **A. Thumann and W. J. Younger**. *Handbook of Energi Audits*, 7th ed., The Fairmont Press, Inc., Lilburn, USA, 2007.
2. **T. Amstrong et al**. *Energy Audit Manual New Zealand*, Energy Efficiency and Conservation Authority, Wellington, 2007.
3. **S. A. Parker and W. D. Hunt**. Strategic Energi Management Plan for Fort Buchanan, Puerto Rico, U. S. Dept. Of Energy, October 2001.
4. **A. P. Rossiter and B. P. Jones**. *Energy Management and Efficiency for the Process Industries*, American Institute of Chemical Engineers and John Wiley & Sons, Inc. Hoboken, New Jersey, 2015.
5. **Badan Pengkajian Industri Hijau dan Lingkungan Hidup, Kementerian Perindustrian RI**. *Pedoman Teknis Audit Energi dalam Implementasi Konservasi Energi dan Pengurangan Emisi CO2 di Sektor Industri* (Fase 1), Jakarta, 2011.
6. **Departemen Penelitian dan Pengaturan Perbankan, Otoritas Jasa Keuangan (OJK)**. Buku Pedoman Pembiayaan Efisiensi Energi di Industri untuk Lembaga Jasa Keuangan, OJK, Jakarta, 2015.
7. **Awaludin, W. Panuntun, W.S. Alam, N. Sinaga**. *Pemilihan Mesin Penggerak Generator Pada Sistem Pembangkit Listrik Tenaga Biogas (PLTBG)*, Seminar Nasional Teknik Kimia, Jurusan Teknik Kimia FT Undip, 2003.
8. **Sinaga, Nazaruddin, R. Ismail, R. Perangin-angin dan O. A. Wicaksono**. *Pembangkitan Listrik Menggunakan Bahan Bakar Biogas dari Hasil Fermentasi Kotoran Ternak*, Seminar Nasional Teknik Kimia, Jurusan Teknik Kimia FT Undip, 2003.
9. **Sinaga, Nazaruddin, A. Suwono, Sularso, and P. Sutikno**. *Simulation of Fin Arrangement Effect on Performance of Staggered Circular Finned-Tube Heat Exchanger*, Proceeding, International Conference on Fluid and Thermal Energy Conversion, Bali, 2003
10. **Sinaga, Nazaruddin, A. Suwono, Sularso, and P. Sutikno**. *Kaji Numerik dan Eksperimental Pembentukan Horseshoe Vortex pada Pipa Bersirip Anular*, Prosiding, Seminar Nasional Teknik Mesin II, Universitas Andalas, Padang, Desember 2003
11. **Sinaga, Nazaruddin, A. Suwono dan Sularso**. *Pengamatan Visual Pembentukan Horshoe Vortex pada Susunan Gormetri Pipa Bersirip*

Anular, Prosiding, Seminar Nasional Teknik Mesin II, Universitas Andalas, Padang, Desember 2003.

12. **Sinaga, Nazaruddin**. *Perancangan Mixer Biogas-Udara Untuk Mesin Diesel Dual Fuel Pembangkit Listrik Tenaga Biogas*, Majalah Teknik, Tahun ke XXV, Edisi I, 2005.
13. **Sinaga, Nazaruddin**. *Analisa dan Pemilihan Mesin Untuk Mesin Dual Fuel Campuran Biogas-Solar*, Majalah Rotasi, Jurusan Teknik Mesin FT Undip, Vol. 7 No. 2, April, 2005.
14. **Sinaga, Nazaruddin**. *Perancangan Conversion Kit Untuk Modifikasi Mesin Diesel Dual Fuel Pembangkit Listrik Tenaga Biogas*, Jurnal Ilmiah Nasional Efisiensi dan Konservasi Energi, Jurusan Teknik Mesin, FT Undip, Vol. 1 No. 1, September, 2005.
15. **Sinaga, Nazaruddin**. *Peluang dan Strategi Penghematan Energi Sektor Transportasi di Indonesia*, Prosiding, Seminar Nasional Efisiensi dan Konservasi Energi (FISERGI) 2005, Jurusan Teknik Mesin FT Undip, ISSN 1907-0063, Desember, 2005.
16. **Sinaga, Nazaruddin**. *Pengaruh Parameter Geometri dan Konfigurasi Berkas Pipa Bersirip Anular Terhadap Posisi Separasi di Permukaan Sirip*, Jurnal Ilmiah Poros, Jurusan Teknik Mesin FT Universitas Tarumanegara, Vol. 9 No. 1, Januari, 2006.
17. **Sinaga, Nazaruddin**. *Energy Efficiency As Research and Business Opportunity*, Proceeding, International Workshop on Improvement of UNDIP Research Ability and Networking to Stimulate Sustainable Energy, Grand Candi Hotel, Semarang, October 2009.
18. **Cahyono, Sukmaji Indro, Gwang-Hwan Choe, and Nazaruddin Sinaga**. *Numerical Analysis Dynamometer (Water Brake) Using Computational Fluid Dynamic Software*. Proceedings of the Korean Solar Energy Society Conference, 2009.
19. **Sinaga, Nazaruddin**. *Energy Efficiency On Boiler And Pump Systems*, Technical Papers, International Workshop on Energy Audit Diponegoro University, Casindo Project, Semarang, August 2010 .
20. **Sinaga, Nazaruddin**. *Pengaruh Model Turbulensi Dan Pressure-Velocity Copling Terhadap Hasil Simulasi Aliran Melalui Katup Isap Ruang Bakar Motor Bakar*, Jurnal Rotasi, Volume 12, Nomor 2, ISSN:1411-027X, April 2010.
21. **I. N. Widiasa, N. Sinaga dan D. Ariyanti**. *Improving Performance Of Low Pressure Reverse Osmosis Systems By Intermittent Autoflushing*, Jurnal Teknik Kimia Indonesia Vol. 9 No. 1, April 2010.

22. **Priangkoso, Tabah dan N. Sinaga**. *Tinjauan Beberapa Model Mekanistik Tingkat Konsumsi Bahan Bakar Untuk Diterapkan Pada Program Simulator Mengemudi Hemat Energi Smart Driving*, Prosiding, Seminar Nasional Sains dan Teknologi ke-2, Fakultas Teknik Universitas Wahid Hasyim Semarang, Juni 2011.
23. **Mrihardjono, Juli dan N. Sinaga**. *Pengujian Model Driving Cycle Kendaraan Honda City Berbahan Bakar Premium*, Majalah Gema Teknologi, Volume 16, Nomor 3, April - Oktober 2011, ISSN : 0852 0232.
24. **Sinaga, Nazaruddin dan Tabah Priangkoso**. *Tinjauan/Review Model Empirik Konsumsi Bahan Bakar Kendaraan*, Journal Momentum, Vol. 7, No. 1, April 2011.
25. **Supriyo dan N. Sinaga**. *Perencanaan Daya Pendingin pada Dinamometer Arus Eddy*, Eksergi, Jurnal Teknik Eergi POLINES, Volume 7, Nomor 3, ISSN : 0216-8685, September 2011.
26. **Supriyo dan N. Sinaga**. *Perancangan Dinamometer Arus Eddy Kapasitas 250 KW*, Majalah Eksergi, Volume 7, Nomor 3, ISSN : 0216-8685, September 2011.
27. **Sinaga, Nazaruddin**. *Pengujian Teknik Mengemudi Hemat Energi pada Kendaraan Penumpang untuk Mendukung Program Smart Driving di Indonesia*, Prosiding, Seminar Nasional Teknik Mesin X (SNTTM X), Jurusan Teknik Mesin, Fakultas Teknik Universitas Brawijaya, Malang, November 2011.
28. **Yunianto, Bambang dan N. Sinaga**. *Peningkatan Efisiensi Pembakaran Tungku Kayu Bakar Tradisional Dengan Modifikasi Disain*, Prosiding, Seminar Nasional Teknik Mesin X (SNTTM X), Jurusan Teknik Mesin, Fakultas Teknik Universitas Brawijaya, Malang, November 2011.
29. **Sinaga, Nazaruddin, T. Priangkoso, D. Widayana dan K. Abdurrohman**. *Kaji Eksperimental Pengaruh Beberapa Parameter Berkendaraan Terhadap Tingkat Konsumsi Bahan Bakar Kendaraan Penumpang Kapasitas Silinder 1500-2000cc*, Prosiding, Seminar Nasional Teknik Mesin X (SNTTM X), Jurusan Teknik Mesin, Fakultas Teknik Universitas Brawijaya, Malang, November 2011.
30. **Sinaga, Nazaruddin dan B. Prasetiyo**. *Kaji Eksperimental Karakteristik Sebuah Dinamometer Sasis Arus Eddy*, Eksergi, Jurnal Teknik Energi POLINES, Volume 8, Nomor 2, Mei 2012, ISSN : 0216-8685.

31. **Sinaga, Nazaruddin dan A. Dewangga**. *Pengujian Dan Pembuatan Buku Petunjuk Operasi Chassis Dinamometer Tipe Water Brake*, Majalah Rotasi, Volume 14, Nomor 3, Juli 2012, ISSN:1411-027X.
32. **Sinaga, Nazaruddin**. *Smart Driving : Menghemat Bahan Bakar, Meningkatkan Kualitas Emisi Dan Menurunkan Resiko Kecelakaan*, Makalah, Seminar Astra – Jurusan Teknik Mesin Undip, Jurusan Teknik Mesin FT UNDIP, November 2012.
33. **Sinaga, Nazaruddin dan Mulyono**. *Kaji Eksperimental Dampak Pemakaian Pertamax Dan Pertamax-Plus Terhadap Emisi Gas Buang Pada Sepeda Motor*, Prosiding, Seminar Nasional Unit Penelitian dan Pengabdian Kepada Masyarakat Politeknik Negeri Semarang 2013, ISBN : 978-979-3514-66-6, Halaman 168-172.
34. **Sinaga, Nazaruddin, dan M. H. Sonda**. *Pemilihan Kawat Enamel Untuk Pembuatan Selenoid Dinamometer Arus Eddy Dengan Torsi Maksimum 496 Nm*, Eksergi, Jurnal Teknik Energi Vol 9 No.1 Januari 2013.
35. **Sinaga, Nazaruddin dan S. J. Purnomo**. *Hubungan Antara Posisi Throttle, Putaran Mesin dan Posisi Gigi Terhadap Konsumsi Bahan Bakar pada Beberapa Kendaraan Penumpang*, Eksergi, Jurnal Teknik Energi, Vol.9 No. 1, Januari 2013.
36. **Sinaga, Nazaruddin**. Pelatihan Teknik Mengemudi Smart Driving Untuk Menurunkan Emisi Gas Rumah Kaca Dan Menekan Biaya Transportasi Angkutan Darat, Prosiding, Seminar Nasional Teknik Mesin XII (SNTTM XII), Fakultas Teknik Universitas Lampung, Oktober 2013.
37. **Sinaga, Nazaruddin, S. J. Purnomo dan A. Dewangga**. *Pengembangan Model Persamaan Konsumsi Bahan Bakar Efisien Untuk Mobil Penumpang Berbahan Bakar Bensin Sistem Injeksi Elektronik (EFI)*, Prosiding, Seminar Nasional Teknik Mesin XII (SNTTM XII), Fakultas Teknik Universitas Lampung, Oktober 2013.
38. **Yunianto, Bambang dan N. Sinaga**. Pengembangan Disain Tungku Bahan Bakar Kayu Rendah Polusi Dengan Menggunakan Dinding Beton Semen, Majalah Rotasi, Volume 16, Nomor 1, Januari 2014, ISSN:1411-027X.
39. **Sinaga, Nazaruddin dan Y.N. Rohmat**. *Perbandingan Kinerja Sepeda Motor Berbahan Bakar Lpg Dan Bensin, Prosiding, Seminar Nasional Teknologi Industri Hijau*, Semarang 21 Mei 2014, Balai Besar Teknologi Pencegahan Pencemaran Industri (BBTPPI) Semarang, BPKIMI, Kementrian Perindustrian, Mei 2014.

40. **Syachrullah, L.I, dan N. Sinaga**. *Optimization and Prediction of Motorcycle Injection System Performance with Feed-Forward Back-Propagation Method Artificial Neural Network (ANN)*, Prosiding, Seminar Nasional Perkembangan Riset dan Teknologi di Bidang Industri ke-2, Fakultas Teknik Universitas Gajah Mada Yogyakarta, Juni 2014.
41. **Paridawati dan N. Sinaga**. *Penurunan Konsumsi Bahan Bakar Sepeda Motor Sistem Injeksi Menggunakan Metode Optimasi Artificial Neural Network Dengan Algoritma Back-Propagation*, Prosiding, Seminar Nasional Perkembangan Riset dan Teknologi di Bidang Industri ke-2, Fakultas Teknik Universitas Gajah Mada Yogyakarta, Juni 2014.
42. **Nazaruddin Sinaga, Abdul Zahri.** *Simulasi Numerik Perhitungan Tegangan Geser Dan Momen Pada Fuel Flowmeter Jenis Positive Displacement Dengan Variasi Debit Aliran Pada Berbagai Sudut Putar Rotor*, Jurnal Teknik Mesin S-1, Vol. 2, No. 4, Tahun 2014.
43. **Haryanto, Ismoyo, MSKTS Utomo, N. Sinaga, C. A. Rosalia dan A. P. Putra**. *Optimization Of Maximum Lift To Drag Ratio On Airfoil Design Based On Artificial Neural Network Utilizing Genetic Algorithm*, International Journal on Applied Mechanics and Materials Vol. 493, pp 123-128, 2014.
44. **M. Rifal dan N. Sinaga**. *Impact of Methanol-Gasoline Fuel Blend on The Fuel Consumption and Exhaust Emission of an SI Engine*, Proceeding, The 3rd International Conference on Advanced Materials Science and Technology (ICAMST 2015), Universitas Negeri Semarang, April 2015.
45. **Sinaga, Nazaruddin dan Mulyono**. *Studi Eksperimental Karateristik Kinerja Sepeda Motor Dengan Variasi Jenis Bahan Bakar Bensin*, Majalah Eksergi, Volume 11, Nomor 1, ISSN:0216-8685, Halaman 1-6 Januari 2015.
46. **Septianto, Fajar, A. Widodo dan N. Sinaga**. *Analisa Penurunan Efisiensi Motor Induksi Akibat Cacat Pada Cage Ball Bantalan*, Jurnal Teknik Mesin S-1, Vol. 4, No. 4, Tahun 2015.
47. **Syahrullah, L. I. dan N. Sinaga**. *Optimization and Prediction of Motorcycle Injection System Performance with Feed-Forward Back-Propagation Method Artificial Neural Network (ANN)*, American Journal of Engineering and Applied Sciences, Volume 9, Issue 2, ISSN: 1941-7039, Halaman 222-235, Februari 2016.
48. **Rojak, Amirur dan N. Sinaga**. *Pengaruh Penggunaan Bahan Bakar LGV Pada Mobil Penumpang 1200 CC Dan 1500 CC Terhadap Kebutuhan Udara Dan Bahan Bakar*, Politeknosains, Volume XV, Nomor 1, ISSN: 1829-6181, Maret 2016.

49. **Fajrin, D. H. dan N. Sinaga**. *Efek Variasi Kandungan Air Terhadap Kerja Gas Engine Cooler Suatu PLTB Limbah Organik Pasar Induk*, Politeknosains, Volume XV, Nomor 1, ISSN: 1829-6181, Maret 2016.

50. **Khudhoibi dan N. Sinaga**. *Pengaruh Engine Remap Terhadap Beberapa Parameter Operasi Mobil Berbahan Bakar LGV*, Jurnal Ilmiah Momentum, Volume 12, Nomor 1, ISSN : 0216-7395, April 2016.

51. **Rifal, Mohamad dan N. Sinaga**. *Impact of Methanol-Gasoline Fuel Blend on The Fuel Consumption and Exhaust Emission of an SI Engine*, AIP Conf. Proc. 1725, 020070-1–020070-6; Published by AIP Publishing, 978-0-7354-1372-6, Maret 2016.

52. **Sinaga, Nazaruddin dan A. S. B. Nasution**. *Simulasi Pengaruh Komposisi Limbah Cair Pabrik Kelapa Sawit (Pome) Terhadap Kandungan Air Biogas dan Daya Listrik yang Dihasilkan Sebuah Pembangkit Listrik Tenaga Biogas*, Eksergi, Jurnal Teknik Energi POLINES, Vol. 12 No. 3, September 2016.

53. **Sinaga, Nazaruddin dan D. Alcita**. *Perbandingan Beberapa Parameter Operasi Mesin Mobil Injeksi Terhadap Penggunaan Bahan Bakar Bensin dan Campuran Metanol-Bensin M15*, Eksergi, Jurnal Teknik Energi POLINES, Vol. 12 No. 3, September 2016.

54. **Fatichuddin, Mochamad dan N.Sinaga**. *Pengaruh Komposisi Air Terhadap Kebutuhan Daya Kompresor Pada Sistem Pembangkit Listrik Biogas Dari Limbah Tandan Kosong Kelapa Sawit*, Jurnal Ilmiah Momentum, Vol. 12 No. 2, Oktober 2016.

55. **Nazaruddin Sinaga**. *Perancangan Awal Conventer Kit LPG Sederhana untuk Konversi Mesin Bensin Skala Kecil*, Eksergi, Jurnal Teknik Energi POLINES, Vol. 13, No. 1, Januari 2017.

56. **Nazaruddin Sinaga**. *Kaji Numerik Aliran Jet-Swirling Pada Saluran Annulus Menggunakan Metode Volume Hingga*, Jurnal Rotasi Vol. 19, No. 2, April 2017.

57. **Nazaruddin Sinaga dan M. Rifal**. *Pengaruh Komposisi Bahan Bakar Metanol-Bensin Terhadap Torsi Dan Daya Sebuah Mobil Penumpang Sistem Injeksi Elektronik 1200 CC*, Jurnal Rotasi Vol. 19, No. 3, Juli 2017.

58. **Nazaruddin Sinaga**. *Analisis Aliran Pada Rotor Turbin Angin Sumbu Horisontal Menggunakan Pendekatan Komputasional*, Eksergi, Jurnal Teknik Energi POLINES, Vol. 13, No. 3, September 2017.

59. **Nazaruddin Sinaga.** *Perancangan dan Pembuatan Data Logger Sederhana untuk Dinamometer Sasis Sepeda Motor*, Jurnal Rotasi, Vol. 20, No. 1, Januari 2018.

60. **Mohamad Rifal dan Nazarudin Sinaga**. *Kaji Eksperimental Rasio Metanol-Bensin Terhadap Konsumsi Bahan Bakar, Emisi Gas Buang, Torsi Dan Daya*, Gorontalo Journal of Infrastructure and Science Engineering, Vol 1 (1), April 2018, pp. 47-54.

61. **Nazaruddin Sinaga, Maizirwan Mel, Rezeki Pakpahan, Nor Azwadi Che Sidik**. *Influence of Volatile Fatty Acid Concentration on Biogas Production in Synthropic Anaerobic Digestion*, Journal of Advanced Research in Biofuel and Bioenergy, Vol. 1 No. 1, June 2018

62. **Sinaga, N., Nasution, S.B., Mel, M**. *Process Optimization of Biogas Production From Palm Oil Mill Effluent: A Case Study of a Crude Palm Oil Factory in Muaro Jambi, Indonesia*, Journal of Advanced Research in Fluid Mechanics and Thermal Sciences, Vol. 49, Issue 2, pp. 155-169 , September 2018, ISSN: 2289-7879

63. **Nurjehan Ezzatul Ahmad, Maizirwan Mel, Nazaruddin Sinaga**. *Design of Liquefaction Process of Biogas Using Aspen HYSYS Simulation*, pp. 10-15, Journal of Advanced Research in Biofuel and Bioenergy, Vol. 2 No.1, September 2018.

64. **Nugroho, A., Sinaga, N., Haryanto, I**. *Performance of a Compression Ignition Engine Four Strokes Four Cylinders on Dual Fuel (Diesel-LPG)*, Proceeding, The 17th International Conference on Ion Sources, Vol. 2014, 2018, 21 September 2018, AIP Publishing.

65. **Nazaruddin Sinaga, P. Paryanto, Susilo A. Widyanto, R. Rusnaldy, Alexander Hetzner, and Jorg Franke.** *An Analysis of the Effect of Gravitational Load on the Energy Consumption of Industrial Robots*, 6th CIRP Global Web Conference, Procedia CIRP 78 (2018), pp. 8 – 12, September 2018.

66. **Syaiful, Sinaga, N., Wulandari, R., Bae, M.W**. *Effect of Perforated Concave Delta Winglet Vortex Generators on Heat Transfer Augmentation of Fluid Flow Inside a Rectangular Channel: An Experimental Study*. International Mechanical and Industrial Engineering Conference 2018 (IMIEC 2018), MATEC Web of Conferences Vol.204 , 2018 , 21-Sep-18 , EDP Sciences 12 , ISSN: 2261-236X

67. **Muchammad, M., Sinaga, N., Yunianto, B., Noorkarim, M.F., Tauviqirrahman, M.** *Optimization of Texture of The Multiple Textured Lubricated Contact with Slip*, International Conference on Computation in Science and Engineering, Journal of Physics: Conf. Series 1090-

012022, 5 November 2018, IOP Publishing, Online ISSN: 1742-6596 Print ISSN: 1742-6588.

68. **Nazaruddin Sinaga, B. Yunianto, Syaiful, W.H. Mitra Kusuma**. *Effect of Addition of 1,2 Propylene Glycol Composition on Power and Torque of an EFI Passenger Car Fueled with Methanol-Gasoline M15*, Proceeding of International Conference on Advance of Mechanical Engineering Research and Application (ICOMERA 2018), Malang, October 2018.
69. **Nazaruddin Sinaga, Mohammad Tauiviqirrahman, Arif Rahman Hakim, E. Yohana.** *Effect of Texture Depth on the Hydrodynamic Performance of Lubricated Contact Considering Cavitation*, Proceeding of International Conference on Advance of Mechanical Engineering Research and Application (ICOMERA 2018), Malang, October 2018.
70. **Syaiful, N. Sinaga, B. Yunianto, M.S.K.T. Suryo**. *Comparison of Thermal-Hydraulic Performances of Perforated Concave Delta Winglet Vortex Generators Mounted on Heated Plate: Experimental Study and Flow Visualization*, Proceeding of International Conference on Advance of Mechanical Engineering Research and Application (ICOMERA 2018), Malang, October 2018.
71. **Nazaruddin Sinaga, K. Hatta, N. E. Ahmad, M. Mel**. *Effect of Rushton Impeller Speed on Biogas Production in Anaerobic Digestion of Continuous Stirred Bioreactor*, Journal of Advanced Research in Biofuel and Bioenergy, Vol. 3 (1), December 2019, pp. 9-18.
72. **Nazaruddin Sinaga, Syaiful, B. Yunianto, M. Rifal**. Experimental and Computational Study on Heat Transfer of a 150 KW Air *Cooled Eddy Current Dynamometer*, Proc. The 2019 Conference on Fundamental and Applied Science for Advanced Technology (Confast 2019), Yogyakarta, Januari 21, 2019.
73. **Nazaruddin Sinaga**. *CFD Simulation of the Width and Angle of the Rotor Blade on the Air Flow Rate of a 350 kW Air-Cooled Eddy Current Dynamometer*, Proc. The 2019 Conference on Fundamental and Applied Science for Advanced Technology (Confast 2019), Yogyakarta, Januari 21, 2019.
74. **Ahmad Faoji, Syaiful Laila, Nazaruddin Sinaga**. *Consumption and Smoke Emission of Direct Injection Diesel Engine Fueled by Diesel and Jatropha Oil Blends with Cold EGR System*, Proc. The 2019 Conference on Fundamental and Applied Science for Advanced Technology (Confast 2019), Yogyakarta, Januari 21, 2019.
75. **Johan Firmansyah, Syaiful Laila, Nazaruddin Sinaga**. *Effect of Water Content in Methanol on the Performance and Smoke Emissions*

of Direct Injection Diesel Engines Fueled by Diesel Fuel and Jatropha Oil Blends with EGR System, Proc. The 2019 Conference on Fundamental and Applied Science for Advanced Technology (Confast 2019), Yogyakarta, Januari 21, 2019.

76. **Syaiful, Anggie Restue, Saputra, Nazaruddin Sinaga**. *2-D Modeling of Interaction between Free-Stream Turbulence and Trailing Edge Vortex*, Proc. The 2019 Conference on Fundamental and Applied Science for Advanced Technology (Confast 2019), Yogyakarta, Januari 21, 2019.
77. **Anggie Restue, Saputra, Syaiful, and Nazaruddin Sinaga**. *2-D Modeling of Interaction between Free-Stream Turbulence and Trailing Edge Vortex*, Proc. The 2019 Conference on Fundamental and Applied Science for Advanced Technology (Confast 2019), Yogyakarta, January 21, 2019.
78. **Sinaga, Nazaruddin, M. Mel, D.A Purba, Syaiful, and Paridawati**. *Comparative Study of the Performance and Economic Value of a Small Engine Fueled with B20 and B20-LPG as an Effort to Reduce the Operating Cost of Diesel Engines in Remote Areas*, Joint Conference of 6th Annual Conference on Industrial and System Engineering (6th International Conference of Risk Management as an Interdisciplinary Approach (1st ICRMIA) 2019 on April 23-24, 2019 in Semarang, Central Java, Indonesia.
79. **Sinaga, Nazaruddin, B. Yunianto, D.A Purba, Syaiful and A. Nugroho**. *Design and Manufacture of a Low-Cost Data Acquisition Based Measurement System for Dual Fuel Engine Researches*, Joint Conference of 6th Annual Conference on Industrial and System Engineering (6th International Conference of Risk Management as an Interdisciplinary Approach (1st ICRMIA) 2019 on April 23-24, 2019 in Semarang, Central Java, Indonesia.
80. **Y Prayogi, Syaiful**, **and N Sinaga**. *Performance and Exhaust Gas Emission of Gasoline Engine Fueled by Gasoline, Acetone and Wet Methanol Blends*, International Conference on Technology and Vocational Teacher (ICTVT-2018), IOP Conf. Series: Materials Science and Engineering 535 (2019) 012013 doi:10.1088/1757-899X/535/1/012013.
81. **E. Yohana, B. Farizki, N. Sinaga, M. E. Julianto, I. Hartati**. *Analisis Pengaruh Temperatur dan Laju Aliran Massa Cooling Water Terhadap Efektivitas Kondensor di PT. Geo Dipa Energi Unit Dieng*, Journal of Rotasi, Vol. 21 No. 3, 155-159.

82. **B. Yunianto, F. B. Hasugia, B. F. T. Kiono, N. Sinaga**. *Performance Test of Indirect Evaporative Cooler by Primary Air Flow Rate Variations*, Prosiding SNTTM XVIII, 9-10 Oktober 2019, 1-7.