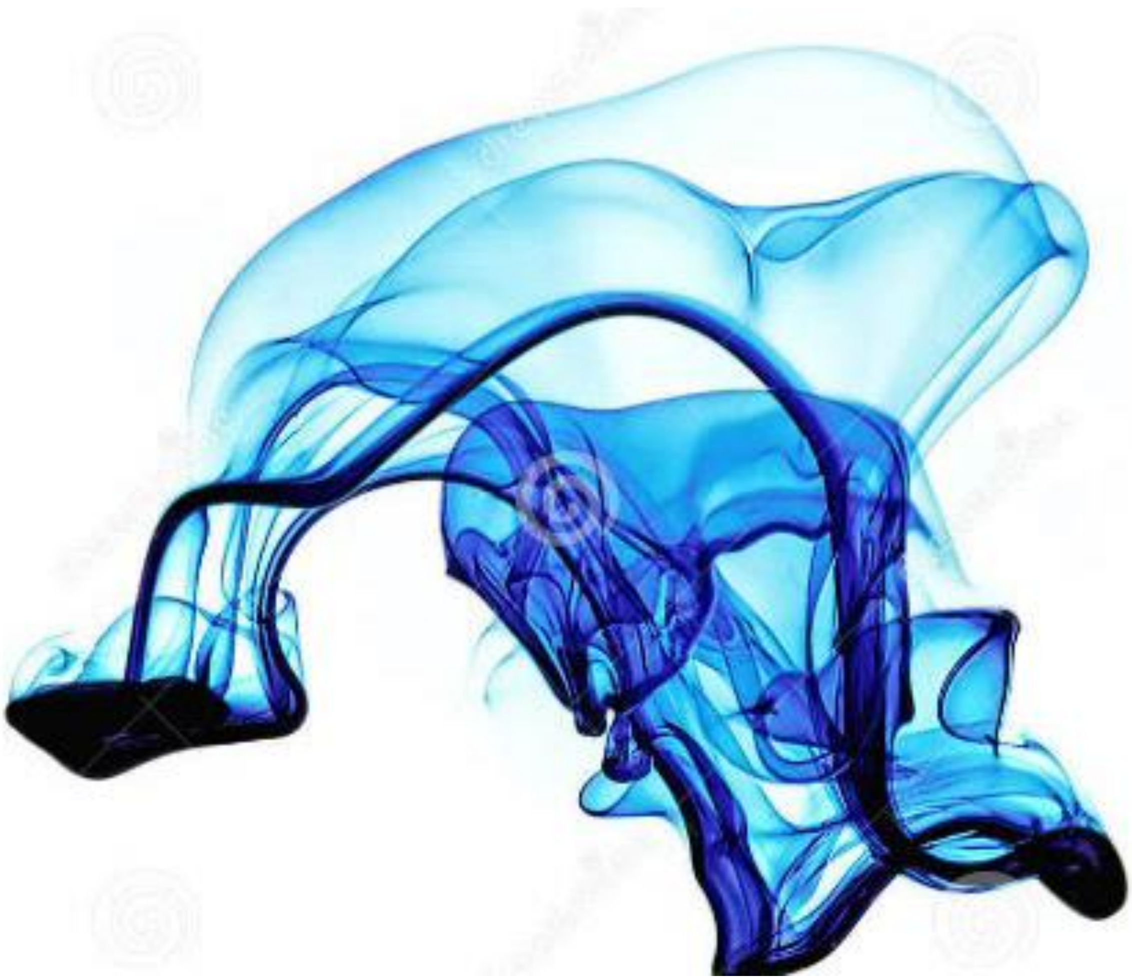
TURBO MACHINARY LAB



Lab 1 (losses coefficient -K- calculation)

Introduction

The main goal for this lab is to calculate minor and major loss coefficients in our system to be able to draw the system curve that will help us to choose a pump.

We have found about 10 minor losses sources in our system that we will find K_L for each one.

- **System equation is:** $\boldsymbol{H = H_{st} + KQ^2}$

To get K we will follow the following steps:

⇒ Minor loss

$$h_{minor} = \frac{\sum K + 1}{2\ g\ A^2}\ Q^2$$

⇒ Major loss

$$h_{major} = \frac{0.81fl}{gd^5}\ Q^2$$

We calculate the Q^2 factor in each equation and get the K value that is in the system equation.

- Minor loses caused by the disruption of the flow due to the installation of appurtenances, such as valves, bends, and other fittings.
- Major losses occur due to friction within a pipe.

delivery line minor losses

suction line minor losses

Minor losses:

1) Foot valve with strainer poppet disk(worst assumption) **k=7.1**

2) Elbow threated regular 90° k**=1.5**

3) Gate valve,0.5 closed **k=2.1**

4) Area change k= $\left(1-\frac{D_1^2}{D_2^2}\right)^2$,(as D_1 = 3", D_2=4") **k=0.1914**

5) Venturi: as(D_{th}=6.85cm, CD=0.91, D_{pipe}= 10.16cm)

- Construction section: K=0.5$(1-\frac{A_s}{A_l})^{0.75}$ **K=0.3173**
- Enlargement section: K= $(1-\frac{A_s}{A_l})^2$ **K=0.2975**
- ∴ Venturi K = 0.3173 + 0.2975 = **K=0.6148**

6) Tee threated dividing branch flow **k=2**

7) Tee threated dividing line flow **k=0.9**

8) And 10) long radius bend 90° **k=0.9**

9) Gate valve fully open **k=0.15**

Component in suction line	K
Foot valve with strainer poppet disk	7.1
Elbow threated regular 90°	1.5
K in suction line = 7.1+1.5 = 8.6 m	
Area (d = 4` = 0.1016 m) = $\frac{\pi}{4}\, d^2$ = 8.1* $10^{-3}\, m^2$	

$$c_{minor\ 1} = \frac{\sum K+1}{2\ g\ A^2} = 7457.65\ s^2/m^5$$

Component in delivery line before area change	K
Gate valve,50% closed	2.1
Reduction in diameter	0.1914
K in suction line = 2.1 + .1914 = 2.2914 m	
Area (d = 4` = 0.1016 m) = $\frac{\pi}{4}\, d^2$ = 8.1* $10^{-3}\, m^2$	

$$c_{minor\ 2} = \frac{\sum K+1}{2\ g\ A^2} = 2556.89\ s^2/m^5$$

Component in delivery line after area change	K
Long radius bend 90° (1)	0.9
venturi	0.6148
Tee threated dividing branch flow	2
Tee threated dividing line flow	0.9
Long radius bend 90° (2)	0.9
Gate valve,100% open	0.15
K in suction line = 0.9 + 0.6148 + 2 + 0.9 + 0.9 + 0.15 = 5.4648 m	
Area (d = 3` = 0.0762 m) = $\frac{\pi}{4}\, d^2$ = 4.56* $10^{-3}\, m^2$	

$$c_{minor\ 3} = \frac{\sum K+1}{2\ g\ A^2} = 15846.246\ s^2/m^5$$

$$c_{minor\ t} = c_{minor\ 1} + c_{minor\ 2} + c_{minor\ 3} = 25860.786\ s^2/m^5$$

Pipe and Tube System Fittings - Minor (Dynamic) Loss Coefficients	
Type of Component or Fitting	**Minor Loss Coefficient - ξ -**
Tee, Flanged, Dividing Line Flow	0.2
Tee, Threaded, Dividing Line Flow	0.9
Tee, Flanged, Dividing Branched Flow	1.0
Tee, Threaded , Dividing Branch Flow	2.0
Union, Threaded	0.08
Elbow, Flanged Regular 90°	0.3
Elbow, Threaded Regular 90°	1.5
Elbow, Threaded Regular 45°	0.4
Elbow, Flanged Long Radius 90°	0.2
Elbow, Threaded Long Radius 90°	0.7
Elbow, Flanged Long Radius 45°	0.2
Return Bend, Flanged 180°	0.2
Return Bend, Threaded 180°	1.5
Globe Valve, Fully Open	10
Angle Valve, Fully Open	2
Gate Valve, Fully Open	0.15
Gate Valve, 1/4 Closed	0.26
Gate Valve, 1/2 Closed	2.1
Gate Valve, 3/4 Closed	17

Fitting	L/D	Minimum Velocity for Full Disc Lift		Nominal Pipe Size									
				1/2"	3/4"	1	1-1/4"	1-1/2"	2	2-1/2"-3	4	6	8-10
		General ft/sec	Water ft/sec	K Value									
Swing Check Valve	100	35	4.40	2.70	2.50	2.30	2.20	2.10	1.90	1.80	1.70	1.50	1.40
	50	48	6.06	1.40	1.30	1.20	1.10	1.10	1.00	0.90	0.90	0.75	0.70
Lift Check Valve	600	40	5.06	16.2	15.0	13.08	13.2	12.6	11.4	10.8	10.2	9.0	8.4
	55	140	17.7	1.50	1.40	1.30	1.20	1.20	1.10	1.00	0.94	0.83	0.77
Tilting Disc Check Valve	5	80	10.13						0.76	0.72	0.68	0.60	0.56
	15	30	3.80						2.30	2.20	2.00	1.80	1.70
Foot Valve with Strainer Poppet Disc	420	15	1.90	11.3	10.5	9.70	9.30	8.80	8.00	7.60	7.10	6.30	5.90
Foot Valve with Strainer Hinged Disc	75	35	4.43	2.00	1.90	1.70	1.70	1.70	1.40	1.40	1.30	1.10	1.10

Major losses

- **Before area change**

Friction losses:(Highly turbuant flow, **PVC** material, inside diameter=4")

PVC Pipe: ϵ=0.003334mm, D_{in}=4"=101.6mm

Relative roughness=$\frac{\epsilon}{D}$ = $\frac{0.003334}{101.6}$= 3.288×10^{-5} ⟹ f(friction factor)=0.009

Length= 0.7 + 0.2 = 0.9 m

$$C_{major2} = \frac{0.81fl}{gd^5} = \frac{0.81 \times 0.009 \times 0.9}{9.81 \times 0.1016^5} = 61.78 \text{ s}^2/\text{m}^5$$

- **After area change**

Friction losses:(Highly turbuant flow, **PVC** material, inside diameter=4")

PVC Pipe: ϵ=0.003334mm, D_{in}=3"= 76.2mm

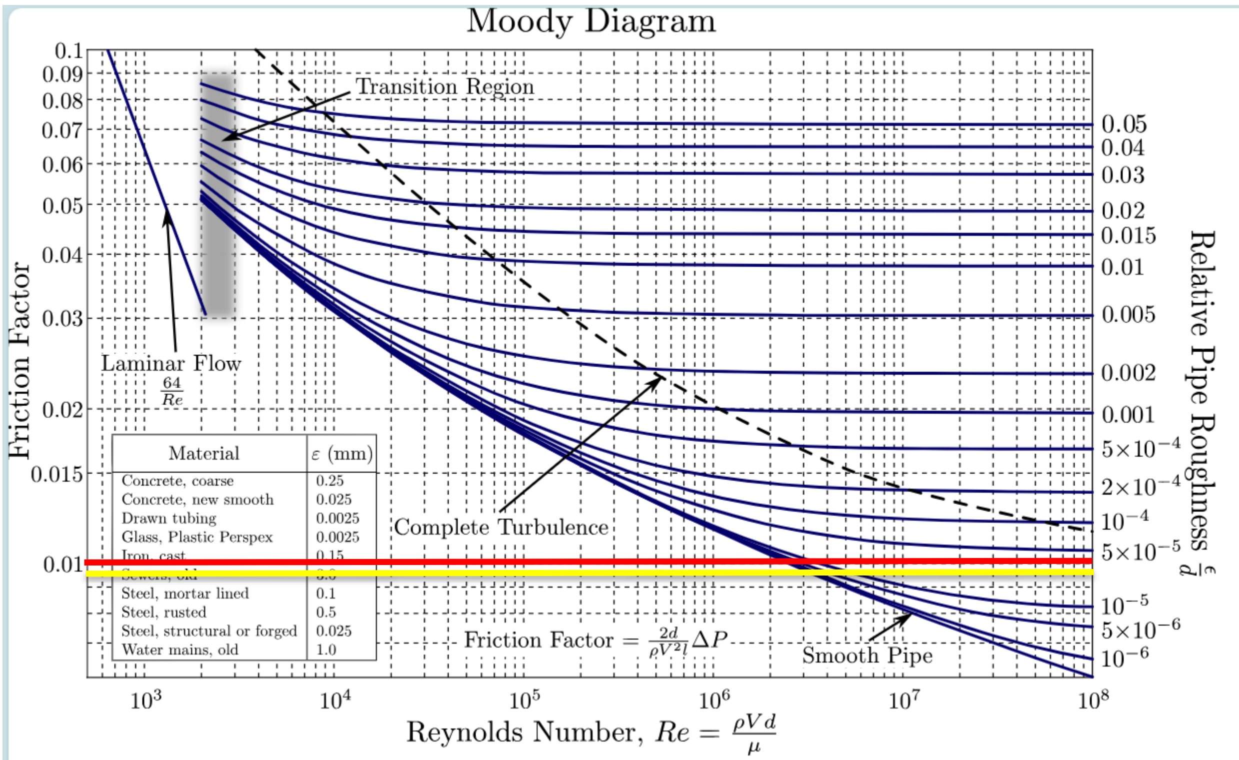
Relative roughness=$\frac{\epsilon}{D}$ = $\frac{0.003334}{76.2}$= 4.375×10^{-5} ⟹ f(friction factor)=0.01

Length= 5.3 - 0.9 = 4.4 m

$$C_{major2} = \frac{0.81fl}{gd^5} = \frac{0.81 \times 0.01 \times 4.4}{9.81 \times 0.0762^5} = 1414.144 \text{ s}^2/\text{m}^5$$

$$C_{major\,T} = C_{major1} + C_{major2} = 1475.924 \text{ s}^2/\text{m}^5$$

$$\boxed{C_T = C_{minor\,T} + C_{major\,T} = 27336.71 \text{ s}^2/\text{m}^5}$$

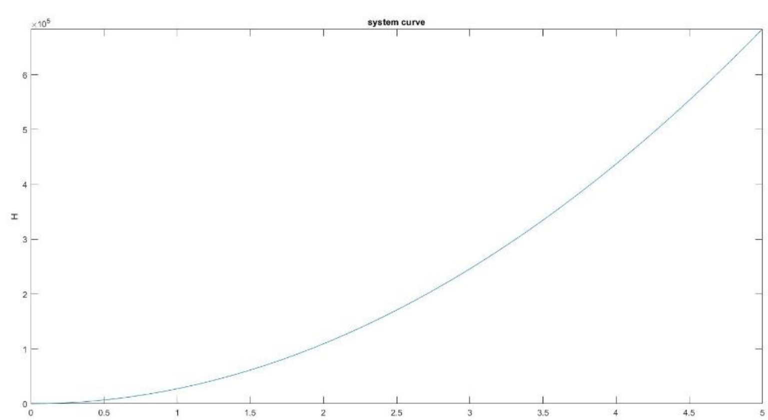


Material	DN (mm)	Di (mm)	ε (mm)	ε/D
PVC	35	35.71	0.003334	0.00009
	50	47.56		0.00007
	75	72.05		0.00005
LLDPE	10	9.55	0.008116	0.0008
	13	13.12		0.0006
	16	16.81		0.0005
	20	20.72		0.0004
	26	27.24		0.0003

Source: Adapted from Rocha et al. (2017).

❖ System curve

```
clc
clear
syms Q
H(Q) = 27336.71*Q^2  %system equation
fplot (H)
title('system curve')
xlabel ('Q')
ylabel('H')
```



Lab 2 (pump performance curves)

Introduction

The main purpose for this lab is to draw the (H-Q curve, ETA-Q, Power -Q) for the measured data at 1250 RPM

Experiment Steps

⇒ close gate valve and the delivery valve is 50% open.

⇒ Measurement devices:

- U tube manometer at venture: to get **Y** (the difference level between mercury levels) and use it to get **Q**.

  At start Q = 0 because of closed gate valve.

- Pressure gauge at suction line: to get **Hms**.
- Pressure gauge at delivery line: to get **Hmd**.
- Force meter: to get the **force**.
- Tachometer: to measure **RPM.**

⇒ We start open the valve gradually at the certain flow rate; we will find RPM will be increased, we will reduce it using control RPM box to 1250 rpm again at start to collect data which are mentioned before, we will repeat this steps again at different valve open to draw the pump performance curves.

⇒ Given data

y	hms(ft)	Hmd(ft)	Δh	F(kgwt)	F(N)	h(m)
0	-6.5	21	27.5	1.6	15.696	0
1	-8	20	28	1.9	18.639	0.126
2.5	-9.5	16	25.5	2.7	26.487	0.315
4	-11	10	21	3	29.43	0.504
5	-12	7	19	3.2	31.392	0.63

Equations that we will use:

- Hm = Hmd – Hms = Δh (which is in the above table)

- Q = $C_d \times \frac{A1 \times A2}{\sqrt{A1^2 - A2^2}} \times \sqrt{2 \times g \times h}$

Where

- C_d: venture discharge coefficient = 0.91
- A1: orifice cross sectional outer area = $8.1 \times 10^{-3}\ m^2$
- A2: orifice cross sectional inner area = $3.685 \times 10^{-3}\ m^2$
- $h = \left(\frac{density\ of\ mercury}{density\ of\ water} - 1\right) \times Y = 12.6Y$

- $Hydraulic\ power = H_m \times \rho \times g \times Q$

- $Mechanical\ power = T \times \omega$
  - $\omega = \frac{2\pi N}{60} = 130.899\ rad/s$, N = 1250RPM
  - $T = F \times r$, r = 0.3m

- $\eta = \frac{Hydraulic\ power}{Mechanical\ power}$

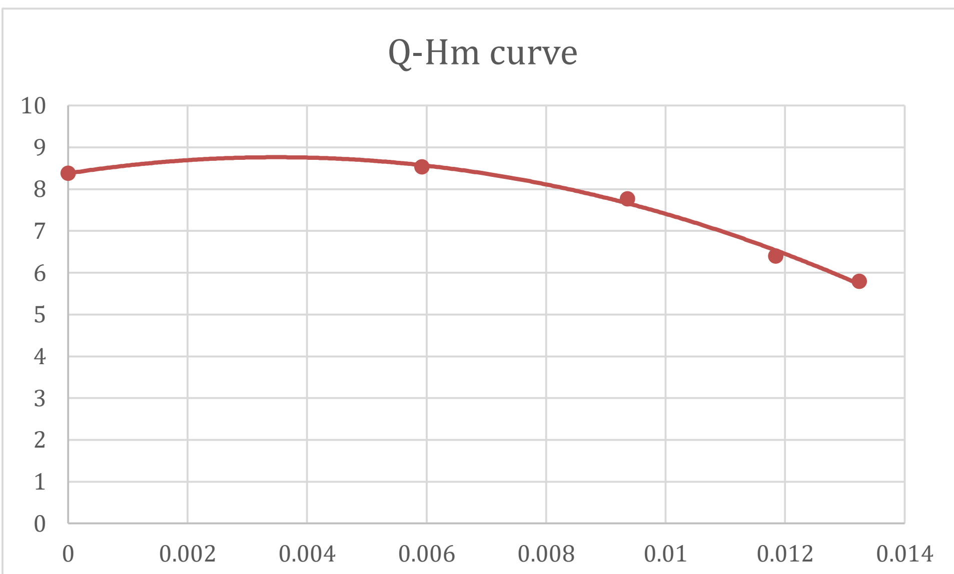
⇒ MATLAB code

```
clc
clear
H = [27.5;28;25.5;21;19];  %pump head in feet
Hm = H * 0.3048;      %pump head in metre
y = [0;1;2.5;4;5];  %difference level between mercury levels
h = 12.6*(y*10^-2); %difference level but with water as a liquid
C_d = 0.91;         %venture discharge coefficient
A_1 = 8.1*10^-3;    %orifice cross sectional outer area
A_2 = 3.685*10^-3;  %orifice cross sectional inner area
g = 9.81;
rho = 1000;         %water density
Q = C_d*((A_1*A_2)/sqrt(A_1^2-A_2^2))*sqrt(2*g*h);  %pump discharge
P_sh = rho * g * Hm .* Q;      %hydraulic power
N= 1250;
w = (2*pi*N)/60;
r = 0.3;
F = [15.696;18.639;26.487;29.43;31.392];
T = F*r;
P_mech = T*w;
eta = P_sh ./ P_mech;
t = table(Hm,Q,P_sh,eta)
```

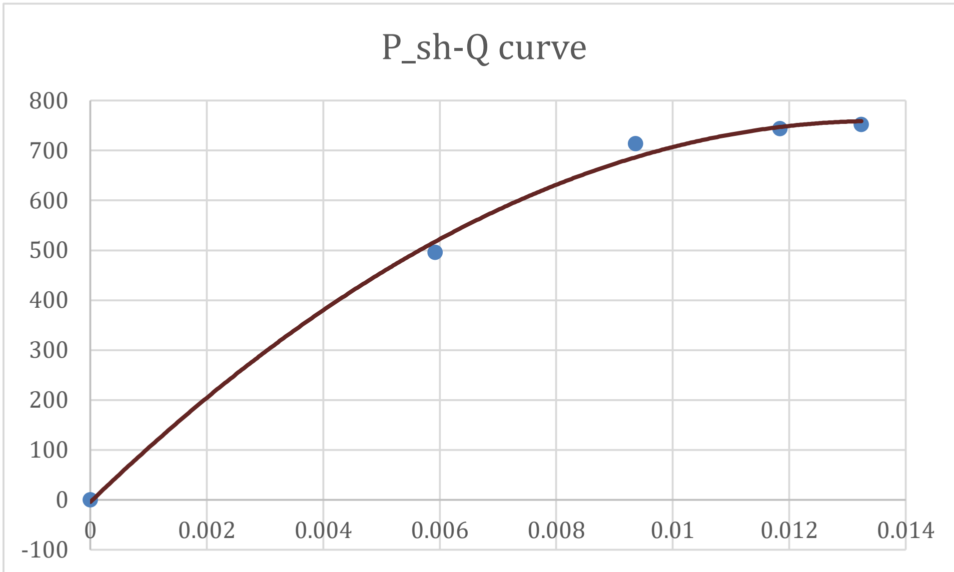
⟹ Results

	1 Hm	2 Q	3 P_sh	4 eta
1	8.3820	0	0	0
2	8.5344	0.0059	495.6904	0.6772
3	7.7724	0.0094	713.7772	0.6862
4	6.4008	0.0118	743.5356	0.6434
5	5.7912	0.0132	752.1269	0.6101

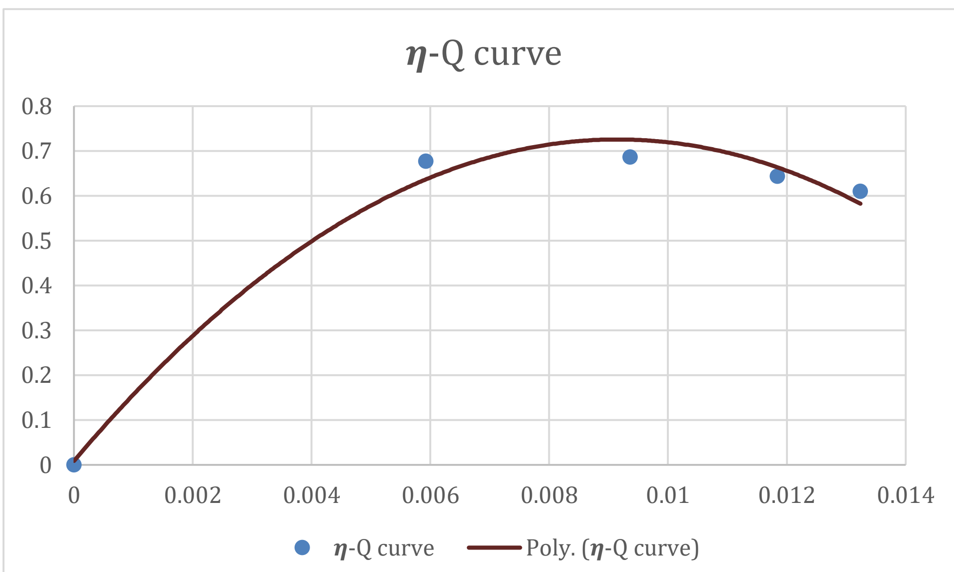
H-Q curve



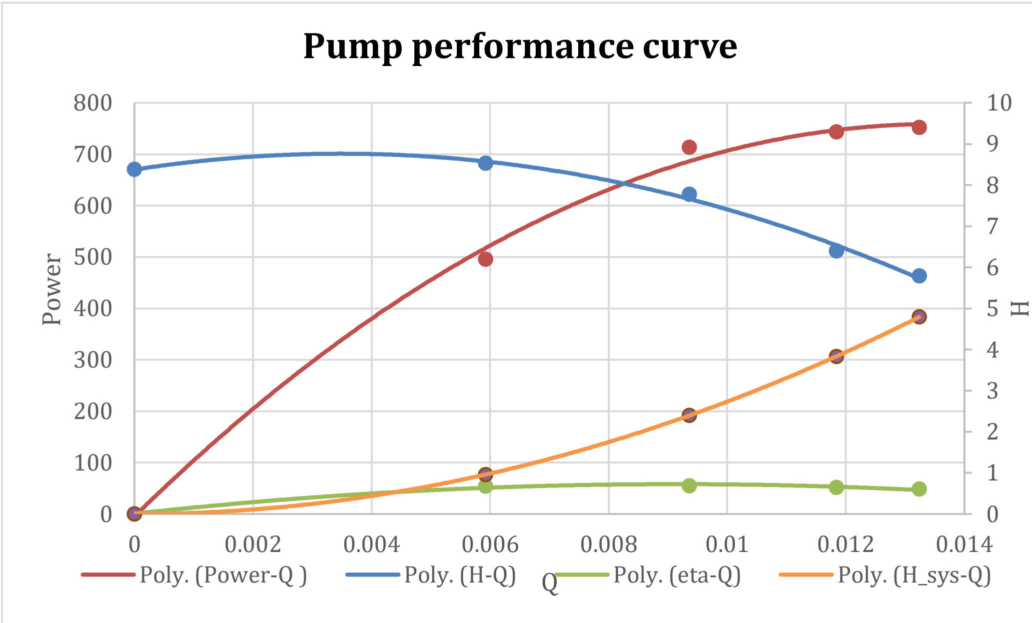
Power-Q curve



η -Q curve



Pump performance curve 1250 RPM



Lab 3 (similarity)

Introduction

The main purpose for this lab is to draw the (H-Q curve, ETA-Q, Power -Q) for the measured data at 1500 RPM & 1750 RPM from experimental results and drawing the curve theoretically using affinity law.

Experiment Steps

Same as Lab 2

1500 RPM

⇒Given data

Hms(ft)	Hmd(ft)	Hm(ft)	F(kgf)	N (rpm)	y(cm)	H(m)	w(rad/s)	T(N.m)	power(W)
-7	29	38	1.5	1500	0	0	157.0795	4.473	702.687
-9	26	35	3.1	1500	1.5	0.189	157.0795	9.114	1431.62256
-10	24	34	3.3	1500	3	0.378	157.0795	9.702	1523.98531
-12	22	34	3.9	1500	4	0.504	157.0795	11.466	1801.07355

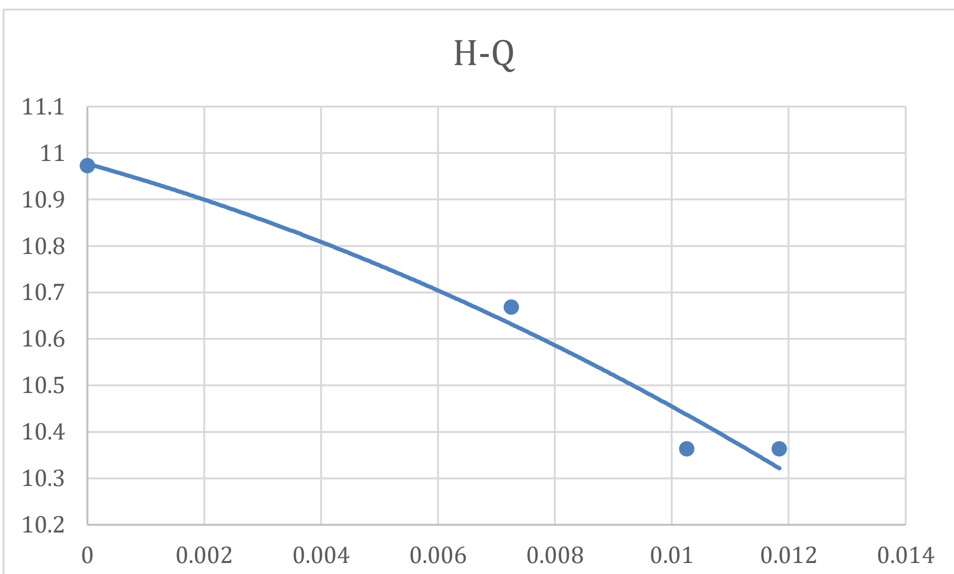
⇒MATLAB code

```
clc
clear
H = [36;35;34;34];  %pump head in feet
Hm = H * 0.3048;       %pump head in metre
y = [0;1.5;3;4];  %difference level between mercury levels
h = 12.6*(y*10^-2); %difference level but with water as a liquid
C_d = 0.91;         %venture discharge coefficient
A_1 = 8.1*10^-3;    %orifice cross sectional outer area
A_2 = 3.685*10^-3;  %orifice cross sectional inner area
g = 9.81;
rho = 1000;         %water density
Q = C_d*((A_1*A_2)/sqrt(A_1^2-A_2^2))*sqrt(2*g*h);  %pump discharge
P_sh = rho * g * Hm .* Q;       %hydraulic power
N= 1500;
w = (2*pi*N)/60;
r = 0.3;
f = [1.5;3.1;3.3;3.9];
F = f*9.807;
T = F*r;
P_mech = T*w;
eta = P_sh ./ P_mech;
t = table(Hm,Q,P_sh,P_mech,eta);
```

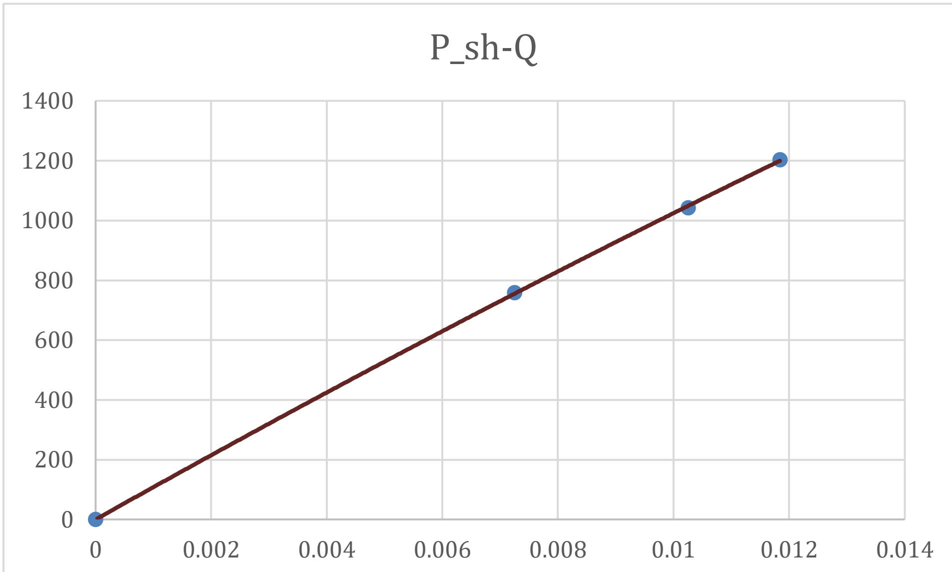
⇒Results

	1 Hm	2 Q	3 P_sh	4 P_mech	5 eta
1	11.5824	0	0	693.2160	0
2	10.6680	0.0073	758.8679	1.4326e+...	0.5297
3	10.3632	0.0103	1.0425e+...	1.5251e+...	0.6836
4	10.3632	0.0118	1.2038e+...	1.8024e+...	0.6679

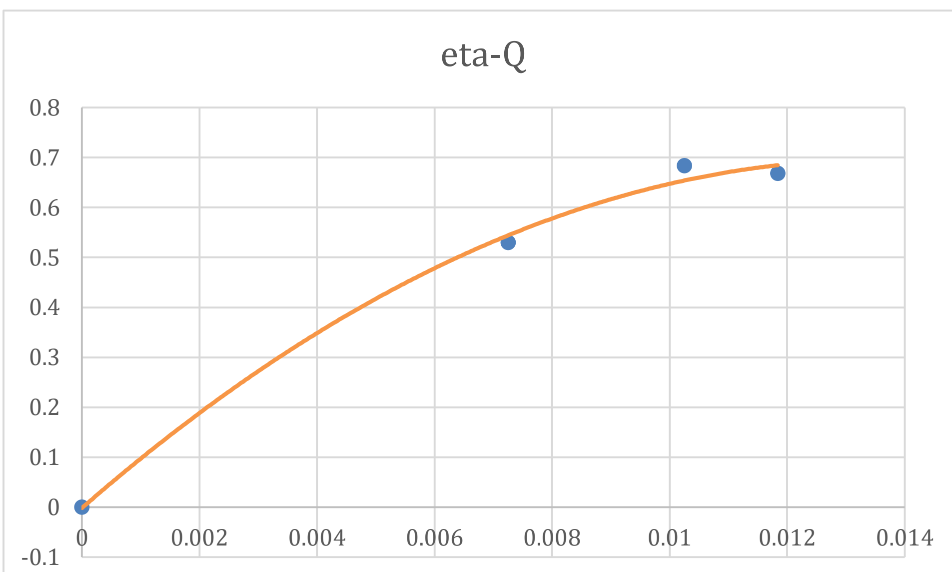
H-Q curve



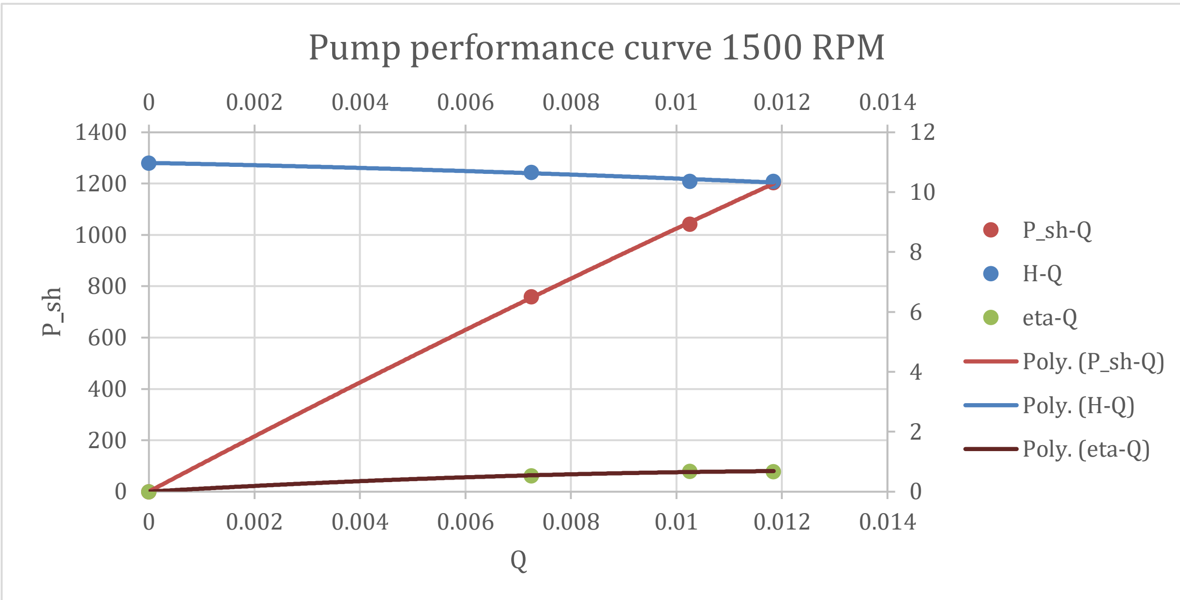
Power-Q curve



η -Q curve



Pump performance curve 1500 RPM



1500 RPM

⇒Given data

Hms(ft)	Hmd(ft)	Hm(ft)	F(kgf)	N (rpm)	y(cm)	H(m)	w(rad/s)	T(N.m)	power(W)
-8	42	50	2.3	1750	0	0	183.259417	6.762	1239.200176
-8.5	40	48.5	2.9	1750	1	0.126	183.259417	8.526	1562.469787
-10	37	47	4	1750	2	0.252	183.259417	11.76	2155.13074
-10.5	34	44.5	4.3	1750	3	0.378	183.259417	12.642	2316.765546

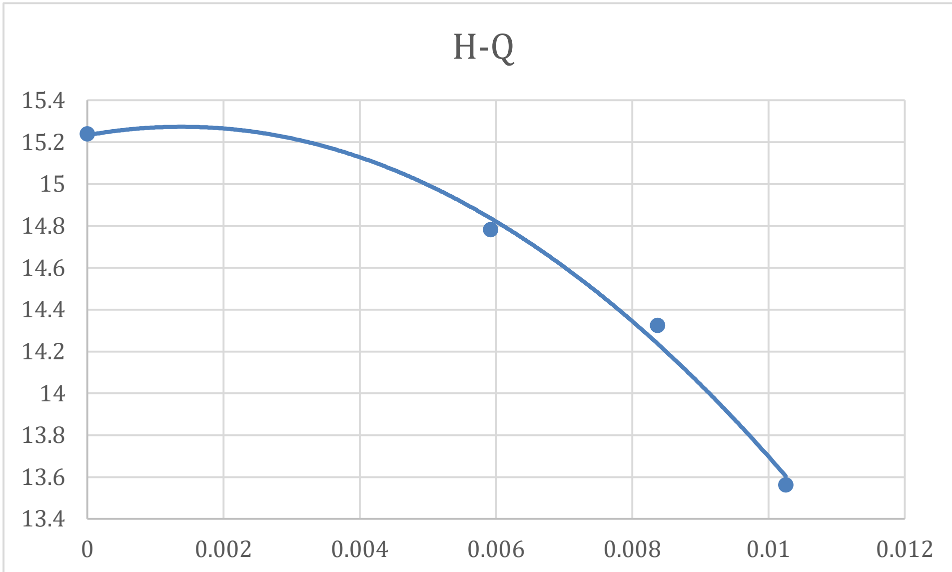
⇒ MATLAB code

```
clc
clear
H = [50;48.5;47;44.5];  %pump head in feet
Hm = H * 0.3048;        %pump head in metre
y = [0;1;2;3];  %difference level between mercury levels
h = 12.6*(y*10^-2); %difference level but with water as a liquid
C_d = 0.91;         %venture discharge coefficient
A_1 = 8.1*10^-3;    %orifice cross sectional outer area
A_2 = 3.685*10^-3;  %orifice cross sectional inner area
g = 9.81;
rho = 1000;         %water density
Q = C_d*((A_1*A_2)/sqrt(A_1^2-A_2^2))*sqrt(2*g*h);  %pump discharge
P_sh = rho * g * Hm .* Q;     %hydraulic power
N= 1750;
w = (2*pi*N)/60;
r = 0.3;
f = [2.3;2.9;4;4.3];
F = f*9.807;
T = F*r;
P_mech = T*w;
eta = P_sh ./ P_mech;
t = table(Hm,Q,P_sh,P_mech,eta);
```

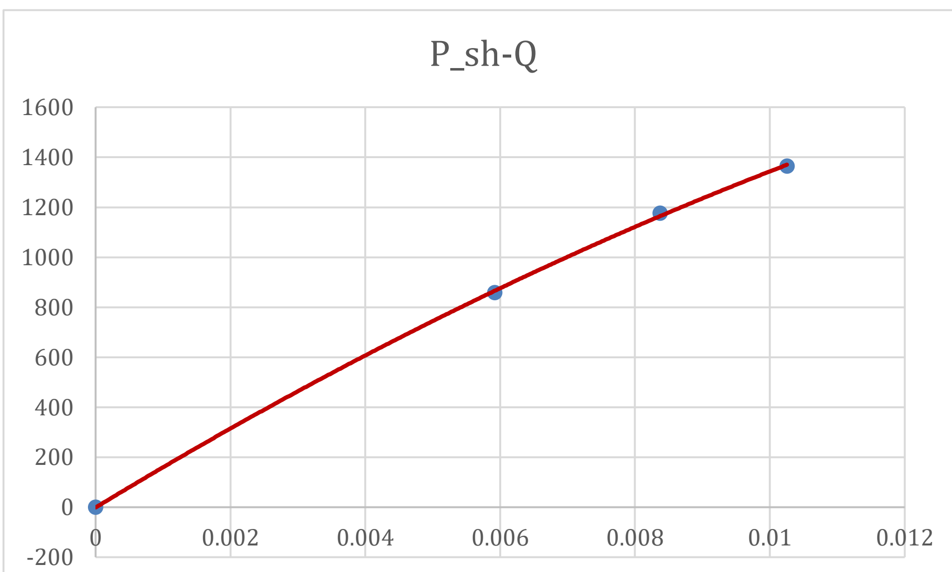
⇒ Results

	1 Hm	2 Q	3 P_sh	4 P_mech	5 eta
1	15.2400	0	0	1.2401e+03	0
2	14.7828	0.0059	858.6066	1.5636e+03	0.5491
3	14.3256	0.0084	1.1767e+03	2.1567e+03	0.5456
4	13.5636	0.0103	1.3645e+03	2.3184e+03	0.5885

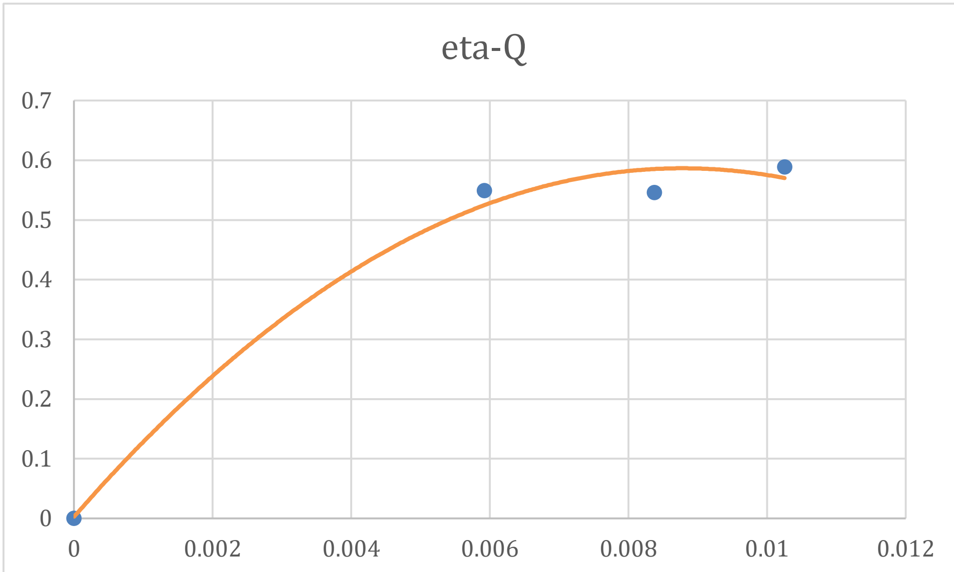
H-Q curve



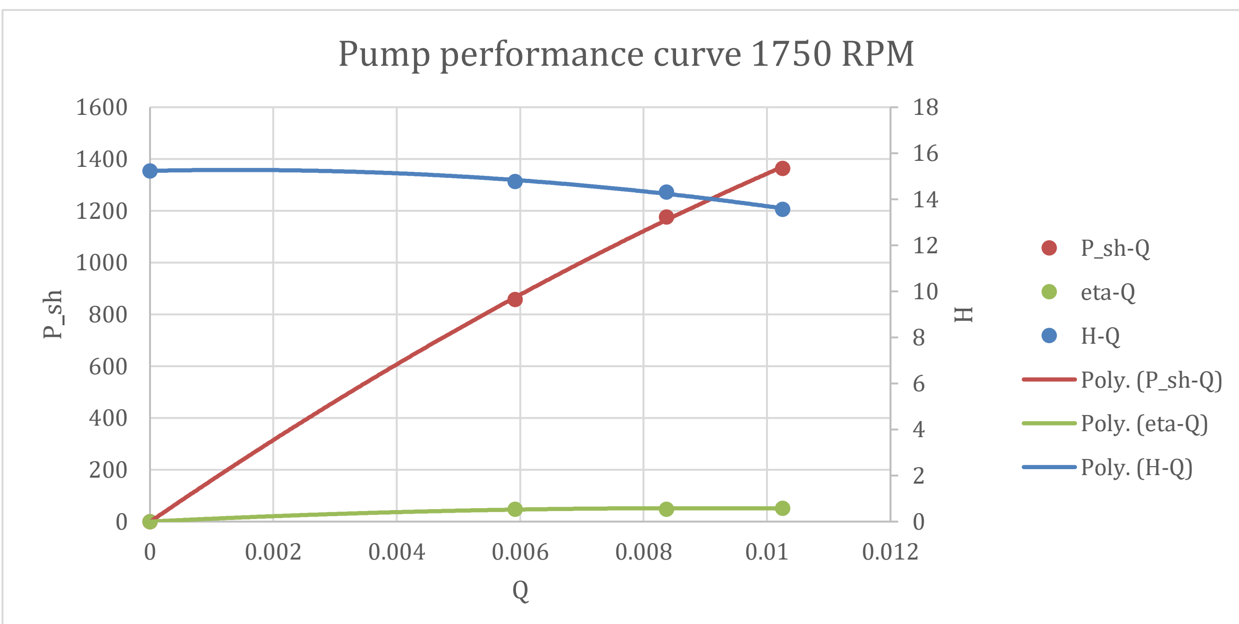
Power-Q curve



η -Q curve

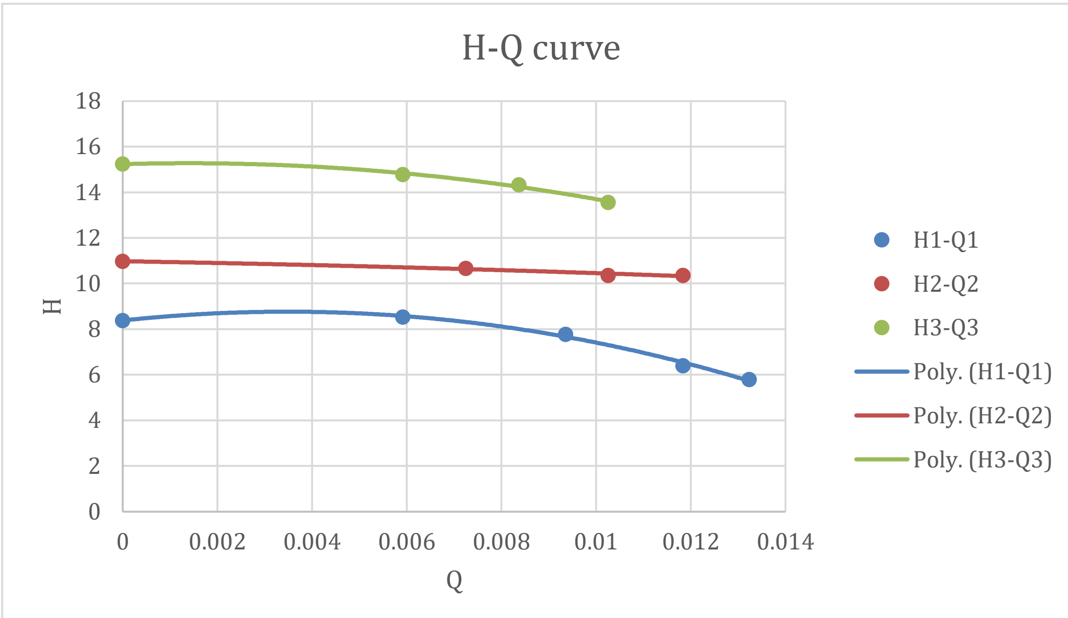


Pump performance curve 1500 RPM

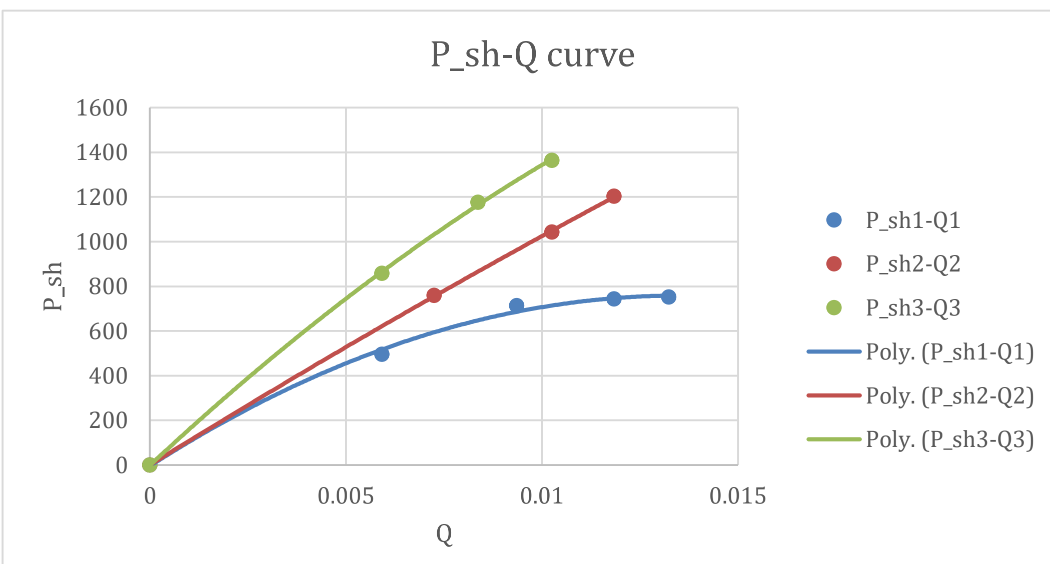


Comparison

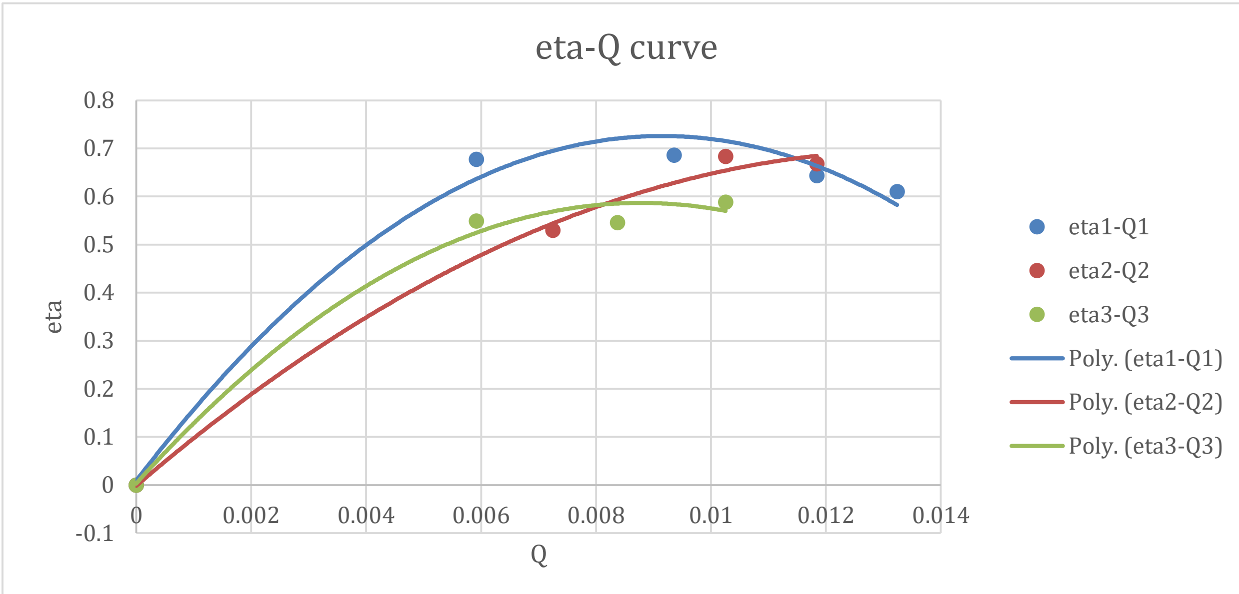
1st. H-Q curve



2nd. Power-Q curve



3rd. η -Q curve



Similarity

- Diameter is constant

$$\therefore \frac{Q_1}{Q_2} = \frac{N_2}{N_1}$$

$$\therefore \frac{Hm_1}{Hm_2} = (\frac{N_2}{N_1})^2$$

⇒ MATLAB code

```
clc
clear
H = [27.5;28;25.5;21;19];   %pump head in feet
Hm_1 = H * 0.3048;        %pump head in metre
y = [0;1;2.5;4;5];  %difference level between mercury levels
h = 12.6*(y*10^-2); %difference level but with water as a liquid
C_d = 0.91;         %venture discharge coefficient
A_1 = 8.1*10^-3;    %orifice cross sectional outer area
A_2 = 3.685*10^-3;  %orifice cross sectional inner area
g = 9.81;
rho = 1000;         %water density
Q_1 = C_d*((A_1*A_2)/sqrt(A_1^2-A_2^2))*sqrt(2*g*h);  %pump discharge

N_1= 1250;
N_2 = 1500;
N_3 = 1750;

Q_2 = (N_2/N_1)*Q_1;
Hm_2 = ((N_2/N_1)^2)*Hm_1;

Q_3 = (N_3/N_1)*Q_1;
Hm_3 = ((N_3/N_1)^2)*Hm_1;
t = table(Hm_1,Q_1,Hm_2,Q_2,Hm_3,Q_3);
```

⇒ Results

	1 Hm_1	2 Q_1	3 Hm_2	4 Q_2	5 Hm_3
1	8.3820	0	12.0701	0	16.4287
2	8.5344	0.0059	12.2895	0.0071	16.7274
3	7.7724	0.0094	11.1923	0.0112	15.2339
4	6.4008	0.0118	9.2172	0.0142	12.5456
5	5.7912	0.0132	8.3393	0.0159	11.3508

H-Q curve theoretical at 1500RPM & 1750RPM