Part - B (Actuators)

B6a

Objective : To study the inherent and installed characteristics of control valve

Theory : The control action taken by a controller is delivered by final control elements. One of the most frequently used final control elements is the control valve. A valve has 3 main components: Actuator, positioner and body. Control valves are automatic and are operated by electrical, hydraulic or pneumatic actuator. A piston and a cylinder are two main components of a pneumatic actuator. The valve stem which is connected to the internal components of the actuator, is moved by the piston, which is covered by a diaphragm, or seal, that allows air pressure to force the diaphragm and maintain the air inside the cylinder.

Inherent characteristics : All control valve have an inherent flow characteristic that define the relationship between valve opening and flow rate under constant pressure conditions.

The flow rate through a valve is expressed as follows:

$$Q = C\, f(x) \sqrt{\frac{\Delta P}{\rho}}$$

where,

$Q \equiv$ volumetric flow rate

$C \equiv$ Valve coefficient ; $x \equiv$ fractional valve opening

$\Delta P \equiv$ Pressure drop across the valve

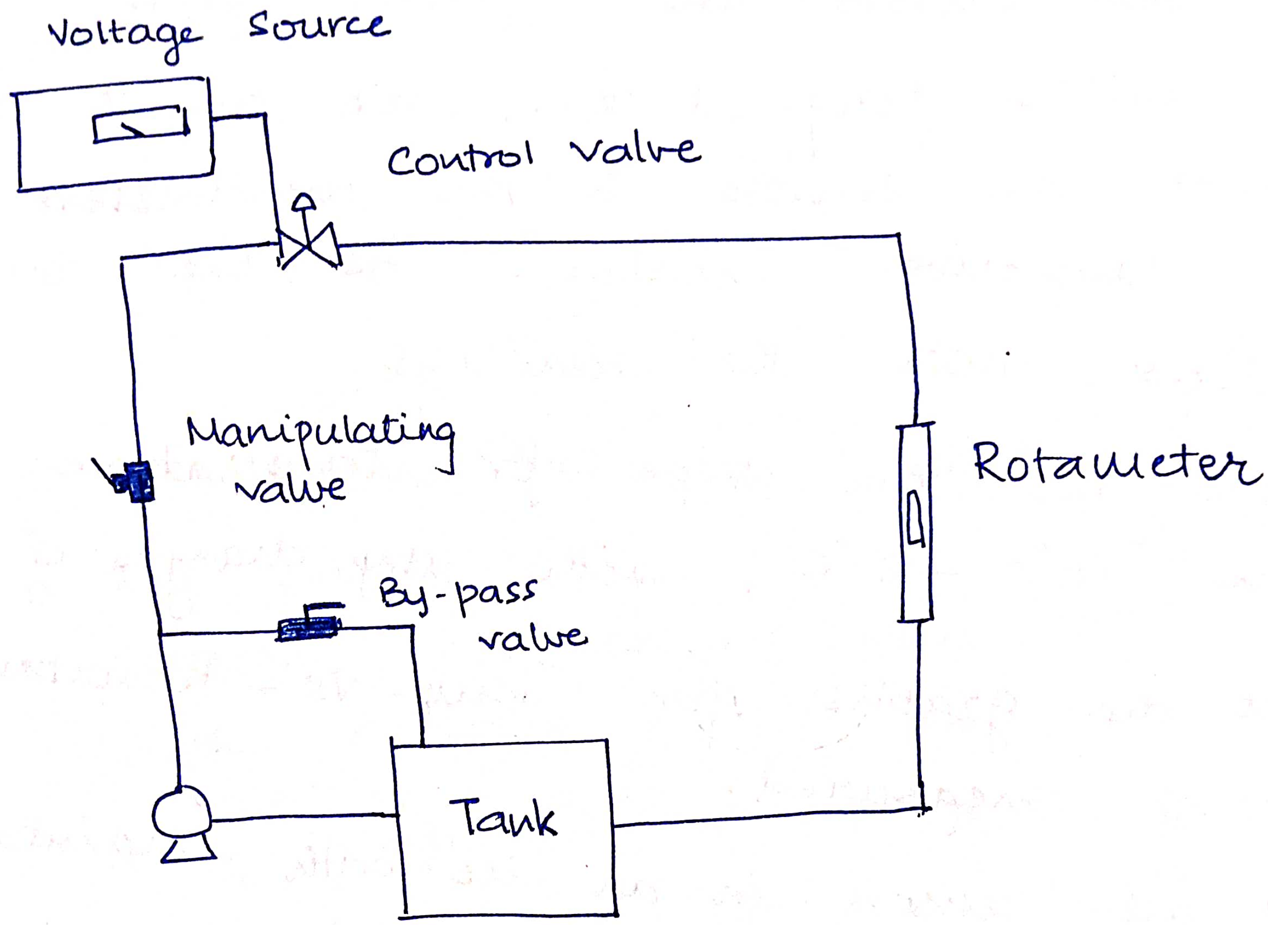
$\rho \equiv$ Density of fluid

Depending upon the shape of the plug we get different valve characteristics. Three main type are:

Quick opening	$\sqrt{x}$	$\leftarrow f(x)$
Linear	x	
Equal percentage	a^{x-1}	

Installed Characteristics: When the valve is installed in a plant, it does not exhibit its inherent characteristics and we get installed characteristics. This is because there will be additional frictional losses in the system.

SCHEMATIC DIAGRAM :



APPARATUS :

- Air-to-open control valve
- Rotameter
- Mercury Manometer
- Ball valve
- Centrifugal pump.

Procedure

→ Inherent Characteristics :

- We closed the by-pass valve and used the manipulated valve to keep the pressure drop constant.
- Set the voltage to 5V and started the experiment with 28 mmHg pressure drop and noted the flow rate.
- Decreased the voltage with step change of 0.2 V. The manipulated valve is then slightly closed to bring ΔP back to 28 mmHg and report flow rate
- The same procedure is repeated by changing voltage to 3V and back to 5V

→ Installed characteristics :

- By-pass valve is completely closed and manipulating valve is kept completely open.
- Opening of control valve is controlling voltage supply.
- We changed the voltage with a step of −0.2V till 3V and then +0.2V till 5V
- Flow rate and ΔP was measured at each step.

DATA SHEET

Course: CL 433

Date: 30/9/2022

Expt. Number & Name: CT 404

B6a

Actuators

Inherent

x Volt (V)	ΔP (mmHg)	Q (LPH)
5	24	296
4.8	24	269
4.6	24	225
4.4	24	193
4.2	24	156
4.0	24	137
3.8	24	119
3.6	24	100
3.4	24	85
3.2	24	75
3.0	24	59.5
3.2	24	74
3.4	24	87
3.6	24	98
3.8	24	114
4.0	24	130
4.2	24	152
4.4	24	185
4.6	24	218
4.8	24	252
5	24	295

Installed

x Volt (V)	ΔP1 (mmHg)	Q1 (LPH)
5	300	23
4.8	280	30
4.6	270	35
4.4	252	42
4.2	236	48
4.0	217	55
3.8	195	63
3.6	176	70
3.4	158	76
3.2	137	82
3.0	121	88
3.2	136	83
3.4	155	75
3.6	175	69
3.8	198	63
4.0	214	59
4.2	236	50
4.4	257	41
4.6	269	36
4.8	283	29
5.0	296	24

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Sample calculation :→

for Inherent characteristics 5V to 3V

Showing calculation for $V = 4V$

$$\Delta P = 24\,mmHg = 3199.73$$
$$\simeq 3200\ N/m^2$$

$$\text{flow rate} = 137\ \text{lit/hr}$$
$$= 3.805 \times 10^{-5}\ m^3/sec$$

Here, $\rho = 1000\ kg/m^3$ of water

We know that,

$$y = Q\sqrt{\rho/\Delta P}$$

$$y = 3.805 \times 10^{-5} \times \sqrt{\frac{1000}{7332.71}}$$

$$y = 2.127 \times 10^{-5}$$

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The predicted expression for volumetric flow rate is derived.

$$y = a\sqrt{\frac{\rho}{\Delta P}} = a b^{x-1}$$ (Equal percentage value)

~~$\log y = x \ell$~~

$$\ln y = x \ln b + (\ln a - \ln b)$$

By regression method on data points we will get slope $= 4$

so $\ln b = 4 \Rightarrow b = 54.6$

Also $\ln a = -9.961$
$\Rightarrow a = 4.720$

Error Calculations $\rightarrow$

$$E = \left| \frac{y_{actual} - y_{predicted}}{y_{actual}} \right| \times 100$$

$\rightarrow$ for $V = 4V$ $\quad y_{actual} = 2.137 \times 10^{-5}$

$y_{predicted} = 2.135 \times 10^{-5}$

Conclusion

$$E = \frac{(2.135 - 2.127)}{2.135} \times 100$$

$e = 1.138\ \%$

Error is very low for equal percentage valve mo

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for Installed Characteristics. from 3V to 5V

let's do for $V = 4V$

$$\Delta P = 55 \text{ mm Hg}$$

$$Q_{actual} = 217 \text{ LPH}$$

$$\rho = 1000 \text{ kg/m}^3 \qquad n =$$

$$y = Q\sqrt{\frac{\rho}{\Delta P}} \qquad Q_{predicted} = y\sqrt{\frac{\Delta P}{\rho}}$$

$$= a\, b^{n-1} \sqrt{\frac{\Delta P}{\rho}}$$

By regration of data points we get

$$a = 4.706 \;,\; b = 46.632$$

Now, $Q_{predicted} = 2.08 \times 10^{-5}$

$$E = \left| \frac{Q_{actual} - Q_{predicted}}{Q_{actual}} \right| \times 100 = 6.18\%$$

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Hence calculating the average values,

we get $a = 4.71 \times 10^{-5}$

$b = 51.7$

for $y = a\,b^{x-1}$

The error shown in the above model was observed to be quite less.

Another model $y = a x^{b}$ was tried

and the linear regression of $\ln y = \ln a + b \ln x$ was performed yielding $R^2 = 0.9962$ and avg error of 15.5126 which was less accurate than the previous model.

Calculation

Table 1: Inherent Characteristics

Voltage (v)	Opening fraction	Flow rate (LPH)	Flow rate (m3 /s)	Flow fraction Q_frac	ΔP (mmHg)	ΔP (N/m^2)	y = Q*sqrt(rho/ΔP)	ln(y)	Predcted y	Predicted Fractional Flow Rate	%Error
5	1	296	8.22222E-05	1.000	24	3199.74	4.59655E-05	-9.99	4.76037E-05	1.000	3.564
4.8	0.96	269	7.47222E-05	0.909	24	3199.74	4.17727E-05	-10.08	4.05516E-05	0.852	2.923
4.6	0.92	225	0.0000625	0.760	24	3199.74	3.494E-05	-10.26	3.45442E-05	0.726	1.133
4.4	0.88	193	5.36111E-05	0.652	24	3199.74	2.99708E-05	-10.42	2.94267E-05	0.618	1.815
4.2	0.84	156	4.33333E-05	0.527	24	3199.74	2.42251E-05	-10.63	2.50674E-05	0.527	3.477
4	0.8	137	3.80556E-05	0.463	24	3199.74	2.12746E-05	-10.76	2.13538E-05	0.449	0.372
3.8	0.76	119	3.30556E-05	0.402	24	3199.74	1.84794E-05	-10.90	1.81904E-05	0.382	1.564
3.6	0.72	100	2.77778E-05	0.338	24	3199.74	1.55289E-05	-11.07	1.54956E-05	0.326	0.214
3.4	0.68	85	2.36111E-05	0.287	24	3199.74	1.31996E-05	-11.24	1.32001E-05	0.277	0.004
3.2	0.64	75	2.08333E-05	0.253	24	3199.74	1.16467E-05	-11.36	1.12446E-05	0.236	3.452
3	0.6	59.5	1.65278E-05	0.201	24	3199.74	9.23969E-06	-11.59	9.57878E-06	0.201	3.670

Table 2: Inherent Characteristics

Voltage (v)	Opening fraction	Flow rate (LPH)	Flow rate (m3 /s)	Flow fraction Q_frac	ΔP (mm Hg)	ΔP (N/m ^2)	y = Q*sqrt(rho/Δ	ln(y)	Predicted y	Predicted Fractional Flow Rate	%ErrorP)
3	0.6	59.5	1.65278E-05	0.202	24	3199.74	9.23969E-06	-11.59	9.58223E-06	0.210	3.707
3.2	0.64	74	2.05556E-05	0.251	24	3199.74	1.14914E-05	-11.37	1.12018E-05	0.245	2.520
3.4	0.68	87	2.41667E-05	0.295	24	3199.74	1.35101E-05	-11.21	1.3095E-05	0.287	3.073
3.6	0.72	98	2.72222E-05	0.332	24	3199.74	1.52183E-05	-11.09	1.53082E-05	0.335	0.591
3.8	0.76	119	3.30556E-05	0.403	24	3199.74	1.84794E-05	-10.90	1.78955E-05	0.392	3.159
4	0.8	130	3.61111E-05	0.441	24	3199.74	2.01876E-05	-10.81	2.09201E-05	0.458	3.629
4.2	0.84	152	4.22222E-05	0.515	24	3199.74	2.36039E-05	-10.65	2.44559E-05	0.535	3.609
4.4	0.88	185	5.13889E-05	0.627	24	3199.74	2.87284E-05	-10.46	2.85892E-05	0.626	0.485
4.6	0.92	218	6.05556E-05	0.739	24	3199.74	3.3853E-05	-10.29	3.34212E-05	0.732	1.275
4.8	0.96	252	0.00007	0.854	24	3199.74	3.91328E-05	-10.15	3.90698E-05	0.855	0.161
5	1	295	8.19444E-05	1.000	24	3199.74	4.58102E-05	-9.99	4.56731E-05	1.000	0.299

Table 3: Installed Characteristics

Voltage (v)	Opening fraction	Flow rate (LPH)	Flow rate (m3 /s)	Flow fraction Q_frac	ΔP (mmHg)	ΔP (N/m^2)	y = Q*sqrt(rho/ΔP)	ln(y)	Predicted y	Predicted Fractional Flow Rate	%Error
5	1	300	8.33333E-05	1.00	23	3066.41	4.75886E-05	-9.95	4.54136E-05	1.000	4.57
4.8	0.96	280	7.77778E-05	0.93	30	3999.67	3.88905E-05	-10.15	3.88784E-05	0.856	0.03
4.6	0.92	270	0.000075	0.90	35	4666.28	3.47197E-05	-10.27	3.32837E-05	0.733	4.14
4.4	0.88	252	0.00007	0.84	42	5599.54	2.95816E-05	-10.43	2.8494E-05	0.627	3.68
4.2	0.84	236	6.55556E-05	0.79	48	6399.47	2.59142E-05	-10.56	2.43936E-05	0.537	5.87
4	0.8	217	6.02778E-05	0.72	55	7332.73	2.226E-05	-10.71	2.08833E-05	0.460	6.18
3.8	0.76	195	5.41667E-05	0.65	63	8399.31	1.869E-05	-10.89	1.78781E-05	0.394	4.34
3.6	0.72	176	4.88889E-05	0.59	70	9332.57	1.60033E-05	-11.04	1.53054E-05	0.337	4.36
3.4	0.68	158	4.38889E-05	0.53	76	10132.50	1.37878E-05	-11.19	1.31029E-05	0.289	4.97
3.2	0.64	137	3.80556E-05	0.46	82	10932.43	1.15096E-05	-11.37	1.12174E-05	0.247	2.54
3	0.6	121	3.36111E-05	0.40	88	11732.37	9.81273E-06	-11.53	9.60314E-06	0.211	2.14

Table 4: Installed Characteristics

Voltage (v)	Opening fraction	Flow rate (LPH)	Flow rate (m3 /s)	Flow fraction Q_frac	ΔP (mmHg)	ΔP (N/m^2)	y = Q*sqrt(rho/ΔP)	ln(y)	Predicted y	Predicted Fractional Flow Rate	%Error
3	0.6	121	3.36111E-05	0.41	88	11732.37	9.81273E-06	-11.53	9.92474E-06	0.211	1.14
3.2	0.64	136	3.77778E-05	0.46	83	11065.76	1.13565E-05	-11.39	1.1593E-05	0.247	2.08
3.4	0.68	155	4.30556E-05	0.52	75	9999.18	1.36159E-05	-11.20	1.35416E-05	0.289	0.55
3.6	0.72	175	4.86111E-05	0.59	69	9199.24	1.60273E-05	-11.04	1.58178E-05	0.337	1.31
3.8	0.76	198	0.000055	0.67	63	8399.31	1.89776E-05	-10.87	1.84766E-05	0.394	2.64
4	0.8	214	5.94444E-05	0.72	59	7866.02	2.1195E-05	-10.76	2.15822E-05	0.460	1.83
4.2	0.84	236	6.55556E-05	0.80	50	6666.12	2.53906E-05	-10.58	2.52099E-05	0.537	0.71
4.4	0.88	257	7.13889E-05	0.87	41	5466.22	3.05342E-05	-10.40	2.94474E-05	0.627	3.56
4.6	0.92	269	7.47222E-05	0.91	36	4799.61	3.41073E-05	-10.29	3.43972E-05	0.733	0.85
4.8	0.96	283	7.86111E-05	0.96	29	3866.35	3.99791E-05	-10.13	4.01789E-05	0.856	0.50
5	1	296	8.22222E-05	1.00	24	3199.74	4.59655E-05	-9.99	4.69325E-05	1.000	2.10

Table 5: Installed Characteristics for y=ax^b

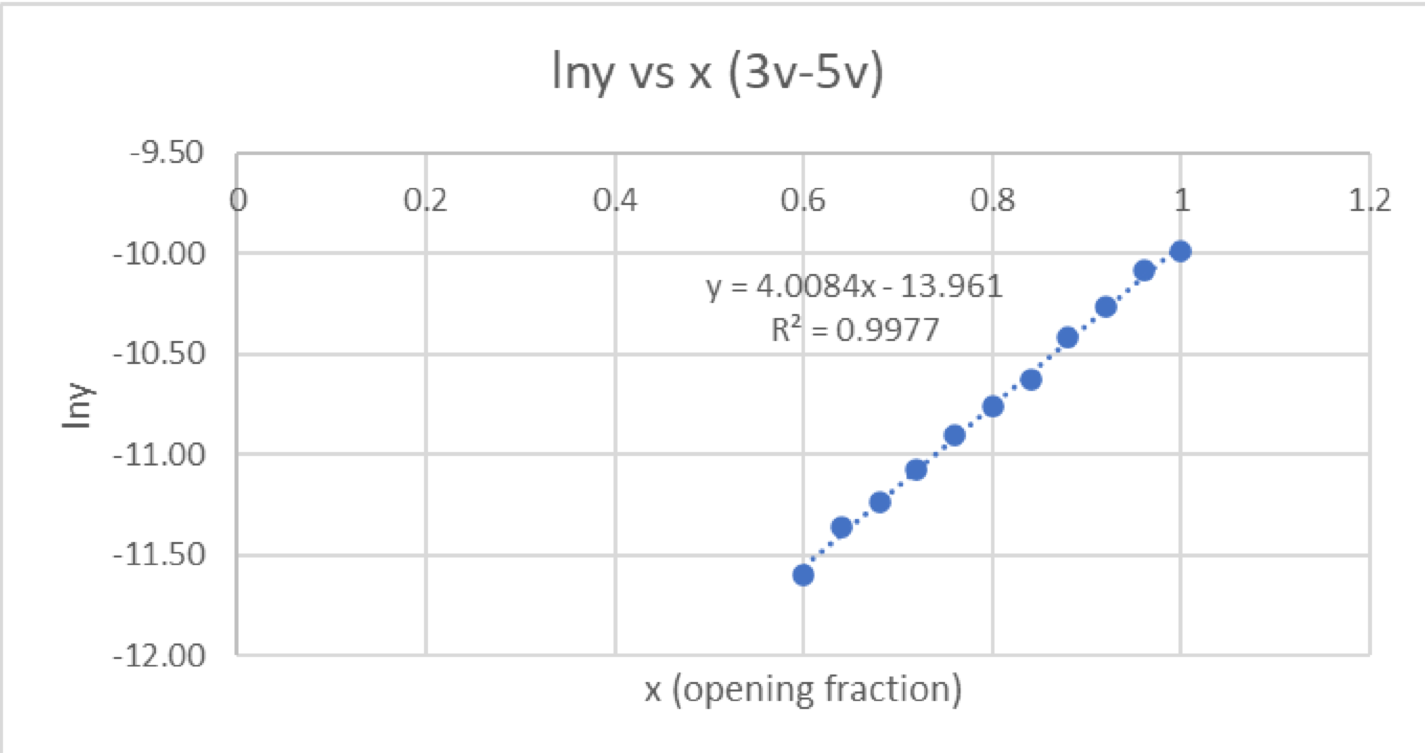
Also Corresponding to the values of Table 3:

ln(y)	ln(x)	Predicted y	%Error in y
-9.9529	0	4.97898E-05	4.62543
-10.155	-0.0408	4.42215E-05	13.7077
-10.268	-0.0834	3.90781E-05	12.5531
-10.428	-0.1278	3.43436E-05	16.0979
-10.561	-0.1744	3.00019E-05	15.7742
-10.713	-0.2231	2.60368E-05	16.967
-10.888	-0.2744	2.2432E-05	20.0212
-11.043	-0.3285	1.91712E-05	19.7951
-11.192	-0.3857	1.62379E-05	17.7694
-11.372	-0.4463	1.36156E-05	18.2975
-11.532	-0.5108	1.12876E-05	15.0306
		Mean Error=	15.5126

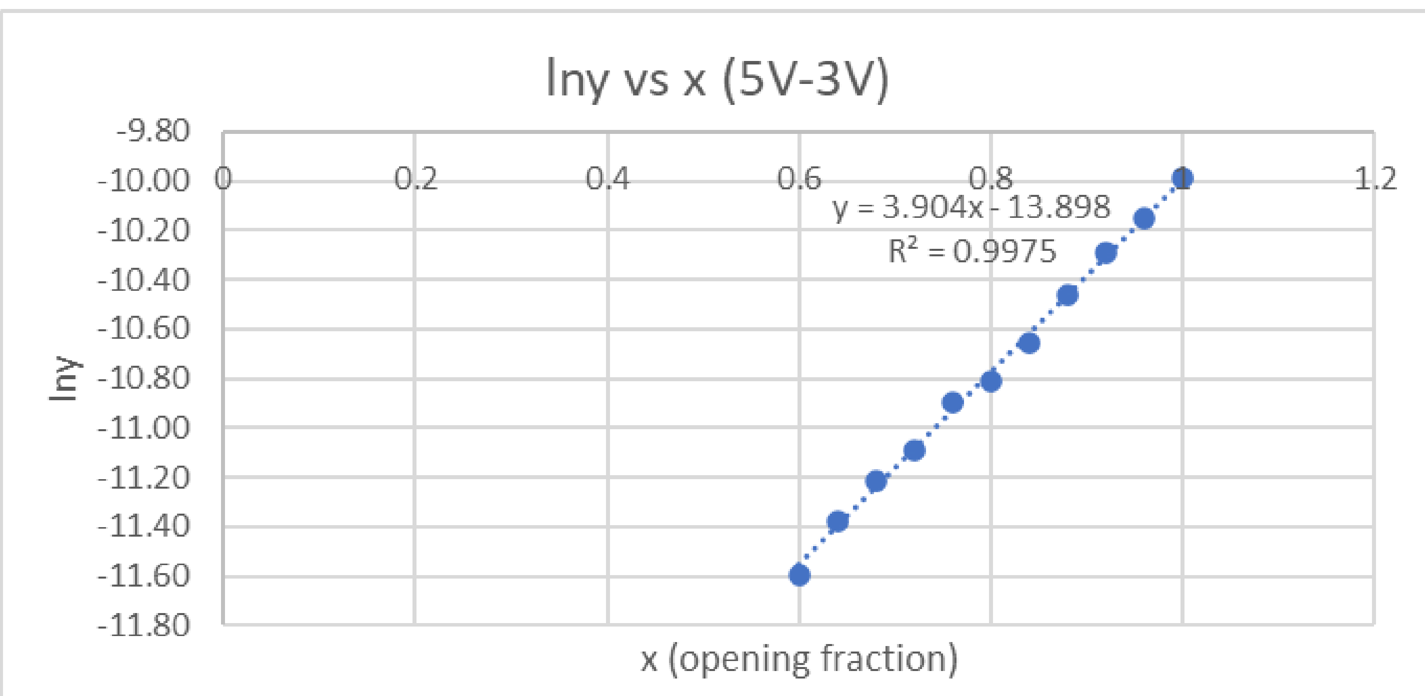
A regression model was fit for y = ax^b

Plots

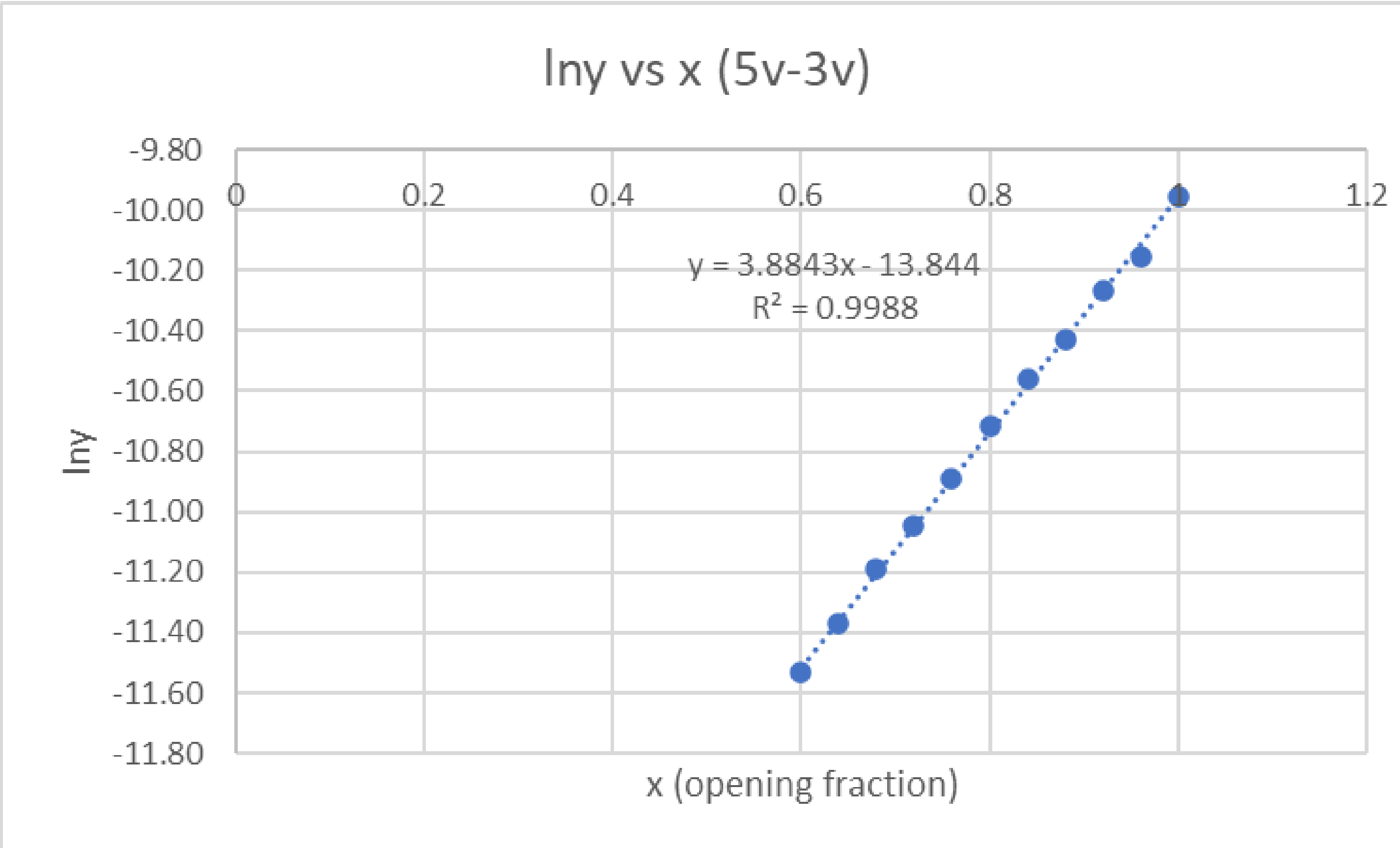
Corresponding with Table1: For inherent Characteristics



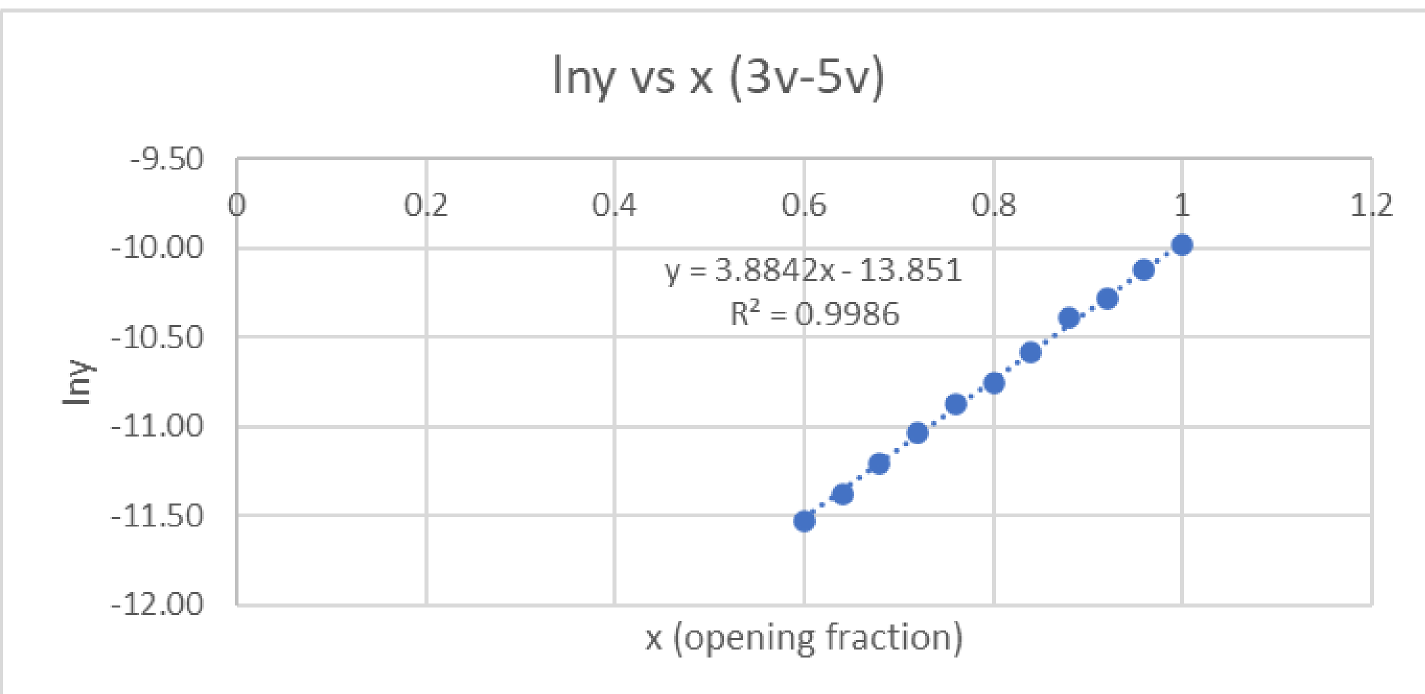
Corresponding with Table 2: For inherent Characteristics



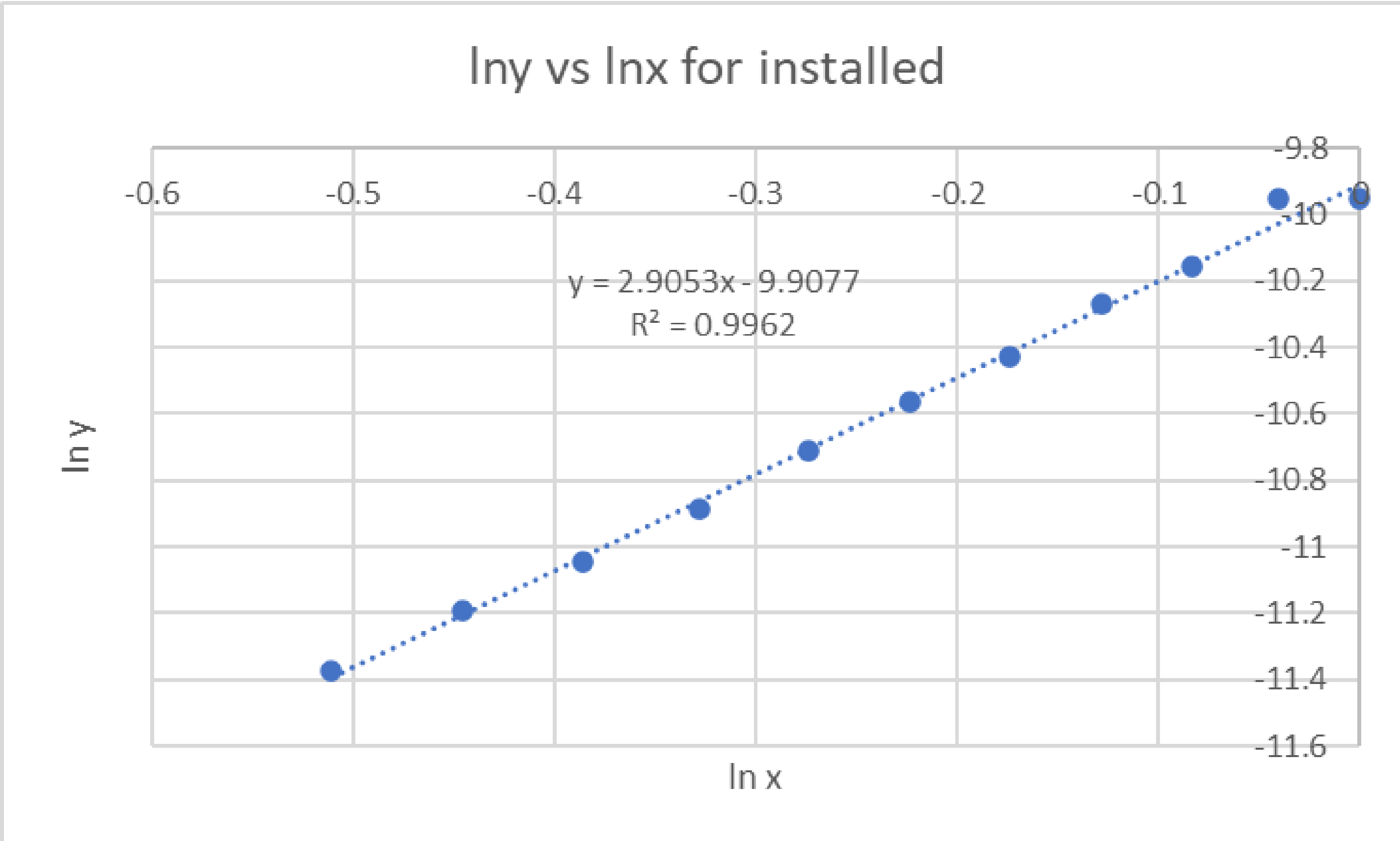
Corresponding with Table 3: For Installed Characteristics

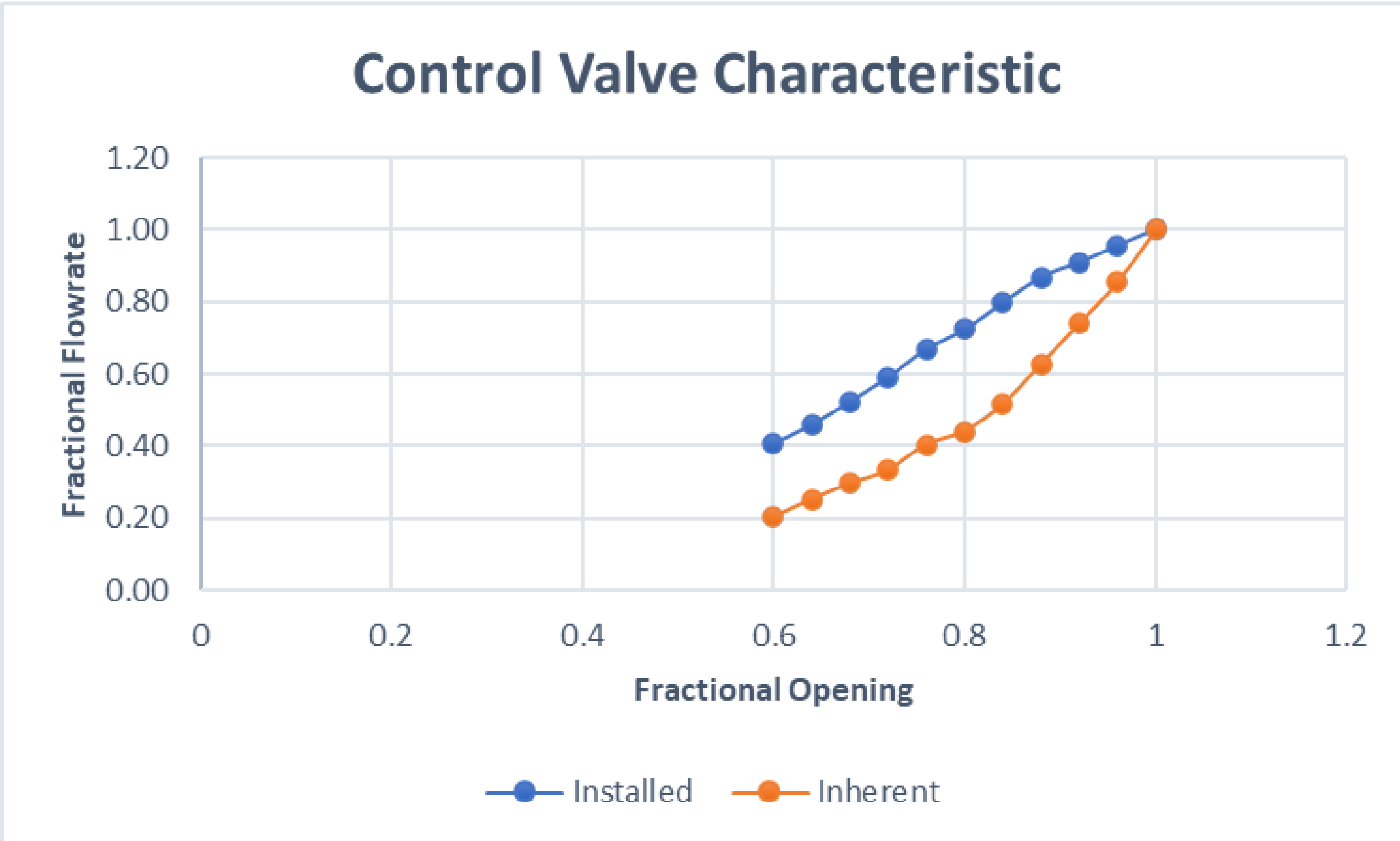


Corresponding with Table 4: For Installed Characteristics



Corresponding to Table 5: for $y = ax^b$





Plot for corresponding 3v - 5v values

Observations & Conclusions.

With maximum error lying well under 10%
the ~~f~~ model for equal % valve was validated.

as eqn : $(4.71 \times 10^{-5})(51.7)^{x-1} \sqrt{\Delta P / \rho}$

The model for equal % valve was used to fit the data obtained while studying the inherent characteristics.
It was observed that the model was able to predict the installed characteristics of the control valve.