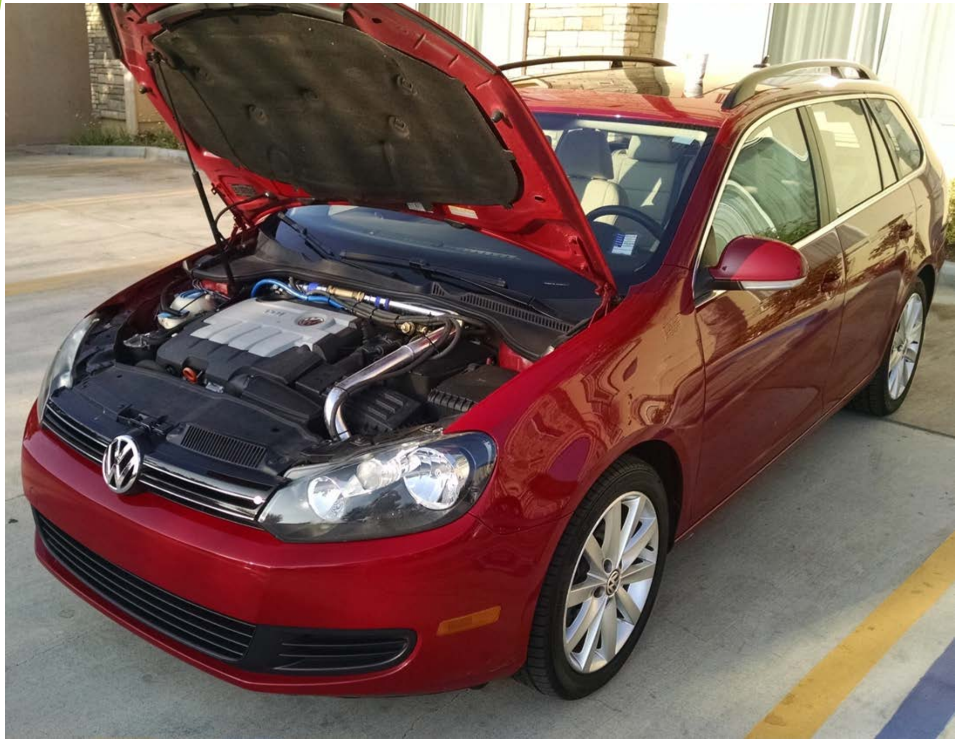
Cool Particulate Regeneration

Global Clean Diesel



Dr. Sesha Srinivasan, Matthew Lawyer, Mason Carroll, Florida Polytechnic University

Brett Bailey, Global Clean Diesel

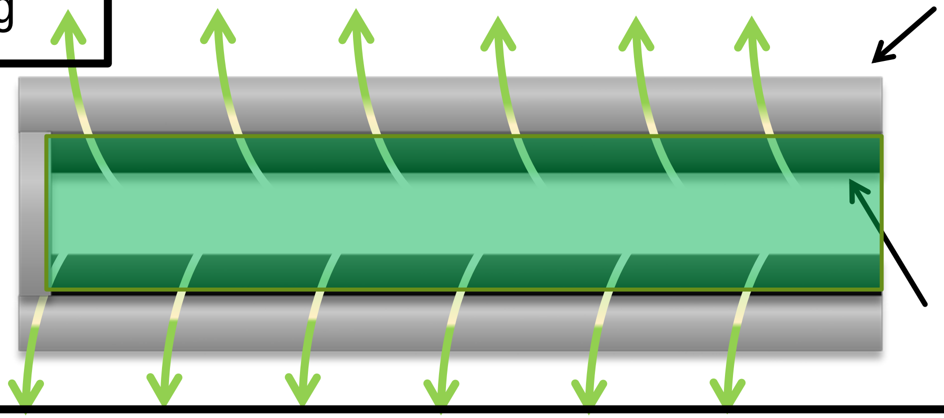
Motivation
Global Real World Emissions Reduction
Cool Particulate Regeneration (CPR)

- **Cost Saving** by Reduction in Engine and Aftertreatment Complexity, Size, and Weight.
- **Fuel Economy Improvement**– Regeneration Utilizes Unused Vehicle Kinetic Energy during Braking Conditions.
- **Real World Emissions Enhanced** – Quicker Light off of SCR Catalyst and Reduction of Particulate Number (PN#) emissions
- **Performance and Drivability** – Richer Air/Fuel Ratio Acceleration
- **Emerging Markets -** Ultra Low Cost Mechanical Engine (High Particulate Matter (PM)) and Fuel Tolerant Technology (Sulfur Tolerant) Solution
- **Durability/Reliability –** Reduction in catalyst thermal degradation and filter thermal stresses. Ongoing Ash removal. Aftertreatment Life Corresponding with Engine Life Expected.
- **Future Powertrain** - Hybrid, Exhaust Energy Recovery (EER) and Stop/Start enabler. Regeneration within Engine Operation

Cool Particulate Regeneration Fundamentals

Diesel Particulate Filter (DPF) Inner Workings (Single Channel)

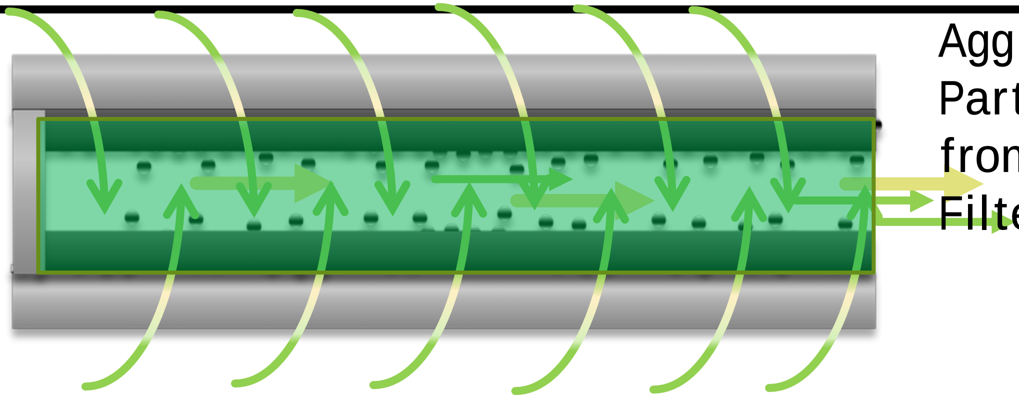
1. Filling



Particulate Matter (Black Smoke) Filtered

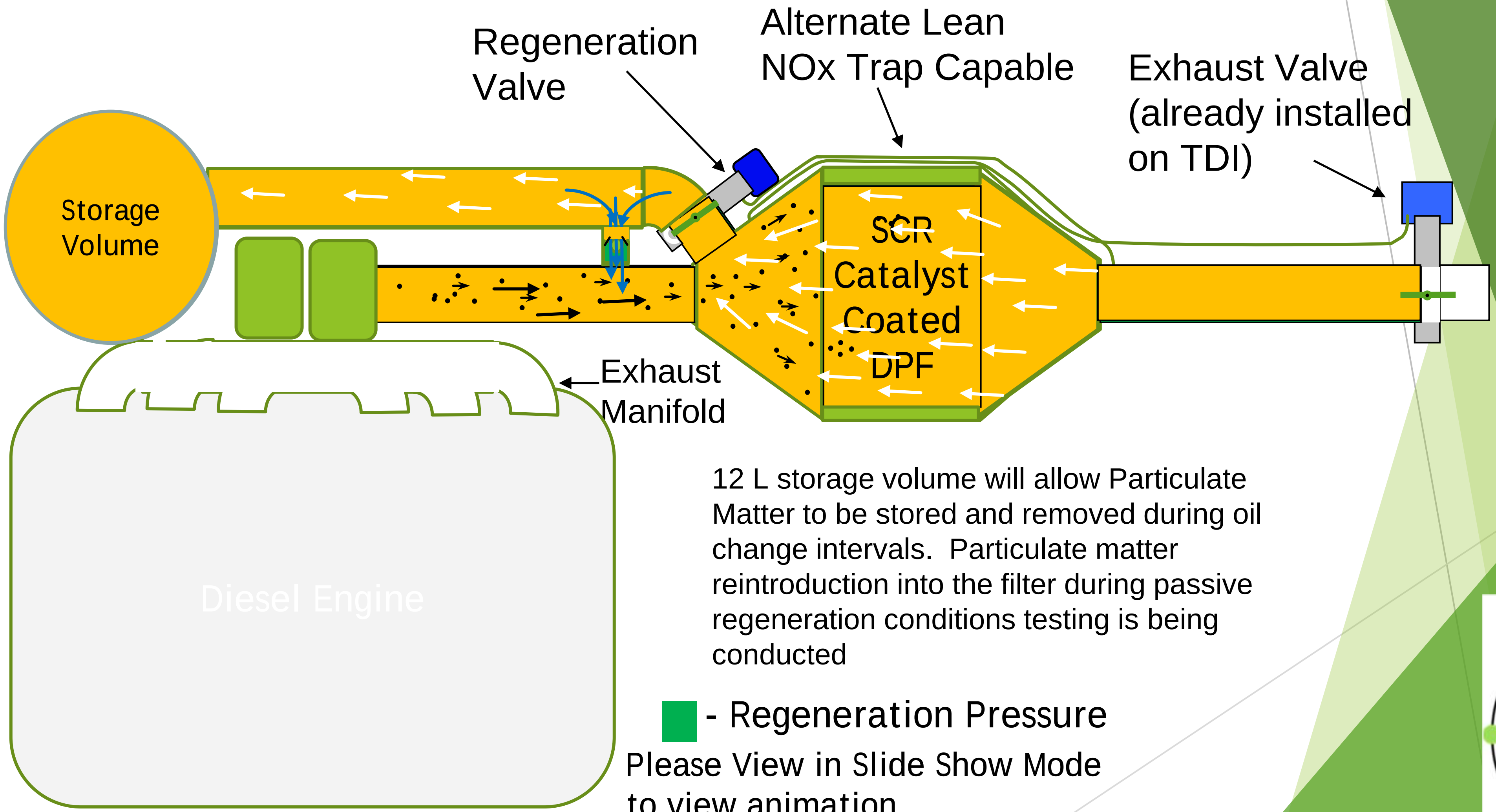
2. Pressurizing to Regeneration Set Point

3. Removing Particulate by Back Flushing Filter



Agglomerated Particles Removed from Filter

Cool Particulate Regeneration™, CPR™ How it works



12 L storage volume will allow Particulate Matter to be stored and removed during oil change intervals. Particulate matter reintroduction into the filter during passive regeneration conditions testing is being conducted

- Regeneration Pressure

Please View in Slide Show Mode to view animation

DOC – Diesel Oxidation Catalyst DPF – Diesel Particulate Filter LNT – Lean NOx Trap

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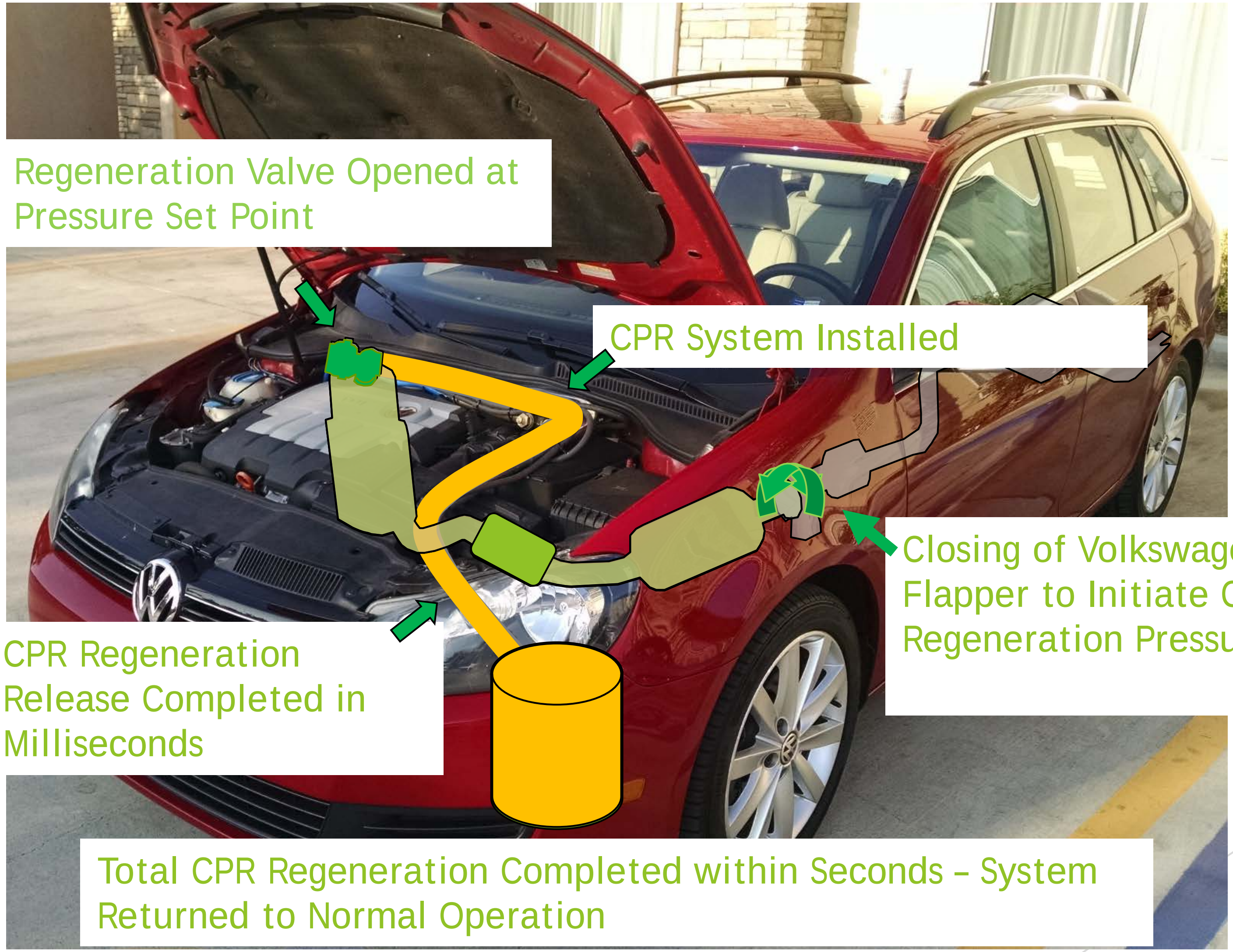
CPR Demonstration Vehicle



Modified Jetta Hardware

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Cost Reduction Enables Next Generation

Emerging Market Diesel Engine

Hybridization of the Diesel in Developed Markets for CO_2

CPR

Too Costly
Poor Real World Emissions

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EU LDVs Diesel Emissions Cost Ever Increasing

- Diesel Engine Costs Allowing Gasoline and Electric Vehicle traction in the market place
- CPR DPF $337
- DPF/SCR Combined ~$306
- Mechanical/Low Press Common Rail ~$337
- EGR Removal

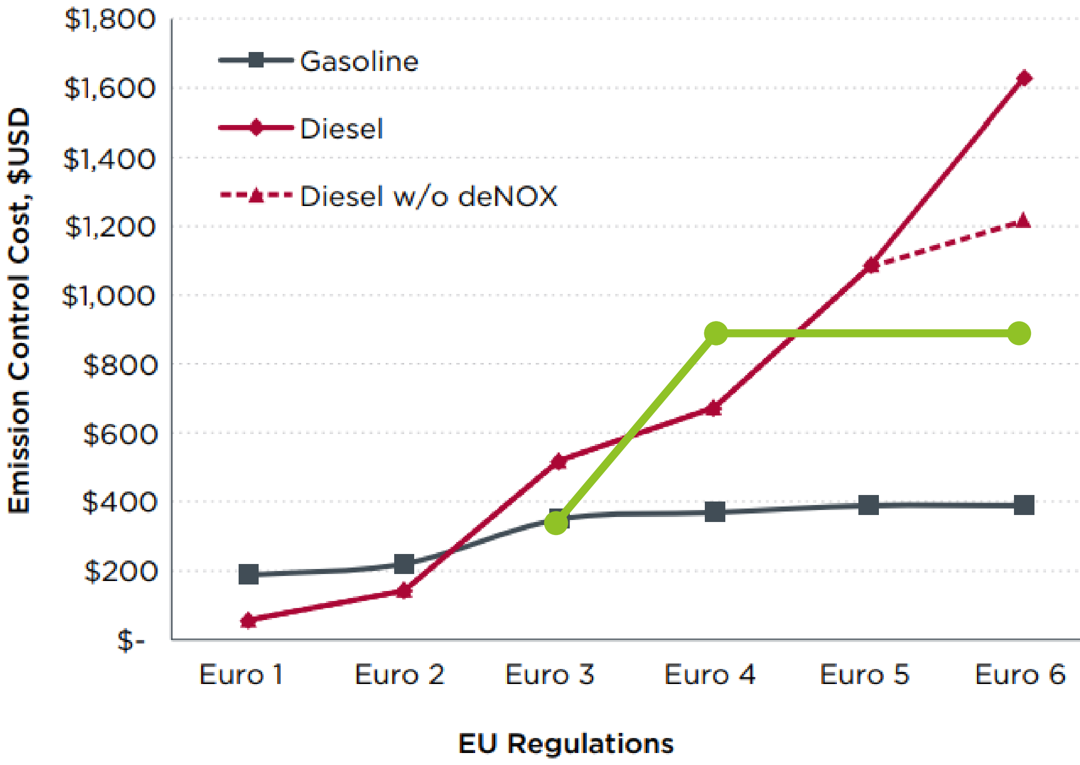

Figure ES-2 Estimated cumulative emission control technology cost for vehicles assuming a 2.0 L engine

Table ES-1 Incremental costs for LDVs meeting European standards (2010 dollars)

ENGINE TYPE	VEHICLE CLASS	EURO 1 (BASELINE)	EURO 1 TO EURO 2	EURO 2 TO EURO 3	EURO 3 TO EURO 4	EURO 4 TO EURO 5	EURO 5 TO EURO 6	NO CONTROL TO EURO 6
Gasoline	4 cylinders Vd= 1.5 L	$142	$63	$122	$25	$10	--	$362
Gasoline	4 cylinders Vd = 2.5 L	$232	$3	$137	$15	$30	--	$417
Diesel	4 cylinders Vd = 1.5 L	$56	$84	$337	$145	$306	$471	$1,399
Diesel	4 cylinders Vd = 2.5 L	$56	$89	$419	$164	$508	$626	$1,862

Emerging Market Main Engine
Developed Country Hybrid Diesel

Table 5. In-cylinder control and OBD costs.

Technology	Cost
Fuel system, common rail or extra with respect to unit injector systems	$750 + 10% for each successive standard
VGT (extra cost with respect to turbocharger)	$370
EGR system	$439
EGR intercooler	$108 ($85–130)
Full OBD	$425 ($350–$500)

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Computational Fluid Dynamics (CFD) Analysis of CPR on the Volkswagen Jetta TDI

What is Florida Polytechnic University?

- Established in 2014 and regionally accredited in 2017, Florida Polytechnic University is a science, technology, engineering, and mathematics (STEM) focused university.
- Florida Polytechnic University has a IBM Supercomputer which was utilized in unison with Converge Science CFD to complete this project.

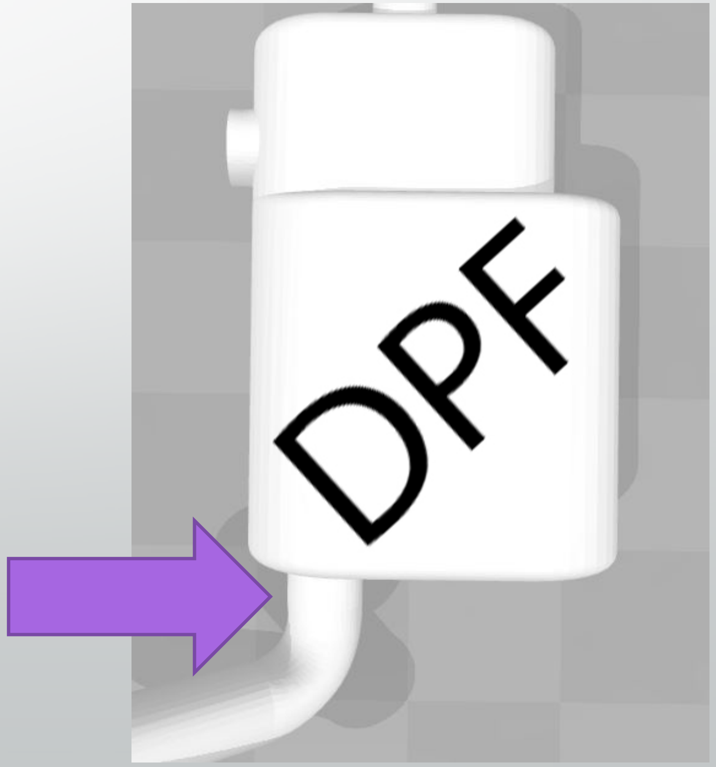
FLORIDA POLYTECHNIC UNIVERSITY

Background

- The success of GCD's marketing demonstrations put the project on hold until May of 2018. GCD's success, in the Indian market, shifted the focus to low speed operation
- Limited testing, under Indian low load, demonstrated a build up of backpressure.
- CFD analysis of the Jetta's CPR began in the summer of 2018 to gain a better understanding of CPR regeneration.
- The CFD analysis revealed that the regenerations were suffering from several flow issues.

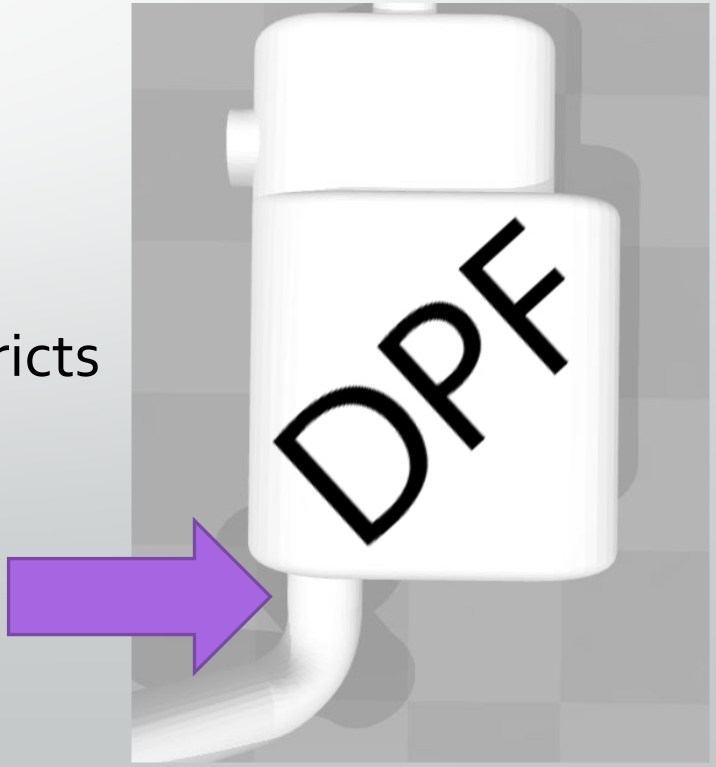
Flow Challenges

- Design modifications were limited by packaging constraints
- The off center engine exhaust outlet creates a bias to one side of the filter during reverse flow.



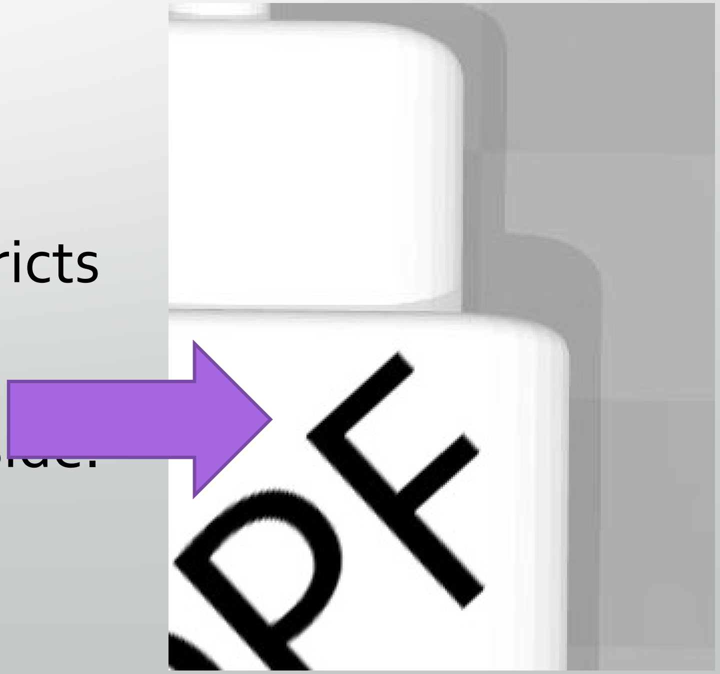
Flow Challenges

- Design modifications were limited by packaging constraints
- The off center engine exhaust outlet creates a bias to one side of the filter during reverse flow.
- The bottom of DPF is close to the exhaust which restricts the flow to the right creating a left flow bias.



Flow Challenges

- Design modifications were limited by packaging constraints
- The off center engine exhaust outlet creates a bias to one side of the filter during reverse flow.
- The bottom of DPF is close to the exhaust which restricts the flow to the right creating a left flow bias.
- Additionally his lip further restricts flow on the right side.



Our Solutions

- Thus, given the previously stated design challenges, simply attaching a CPR system to the Jetta does not achieve our development goal.
- The CFD simulations suggest that certain parts of the filter receive less flow than others, reducing the effectiveness of regeneration.
- We propose a 20% reduction of filter volume and a slight design modification to allow for more uniform flow.

Our Solutions (cont.)

Before

After

Lip length reduced by 13 MM

Filter length reduced by 46 MM

Our Solutions (cont.)

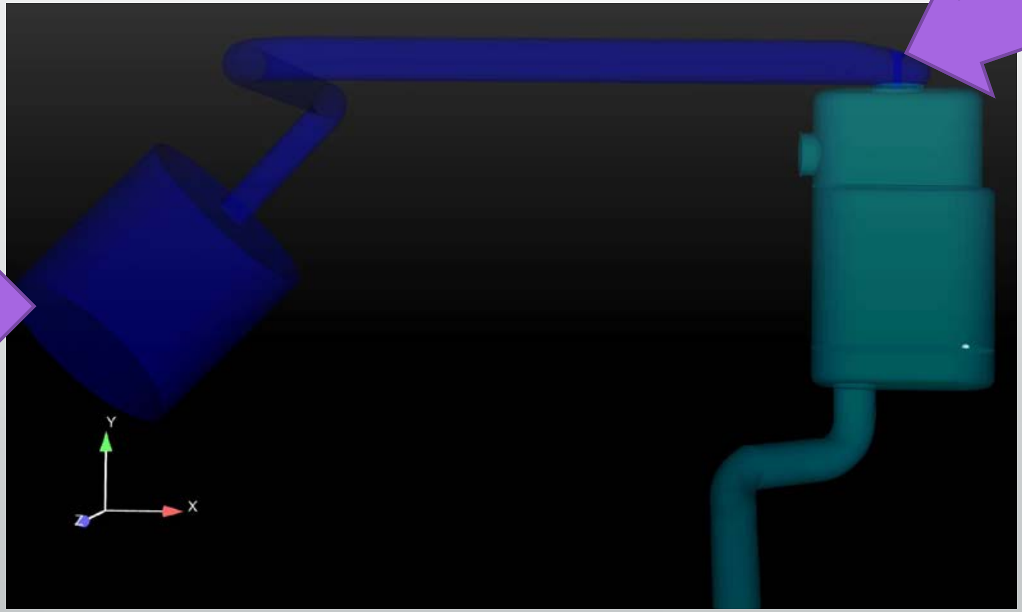
- With this new filter design modeled and simulated, we've addressed two solutions that represent two opposites sides of a spectrum. These two being with no vacuum and with a vacuum. However many possible solutions exist within these two bounds.
- Solution 1: Simply increase the regeneration pressure.
- Solution 2: Pull a vacuum, in the storage tank, to keep regeneration pressures low.

Solution 1

(no vacuum)

- A 17 liter storage tank and a 66 mm Poppet valve were mounted to the top of the oxidation catalyst.

66 mm Poppet valve

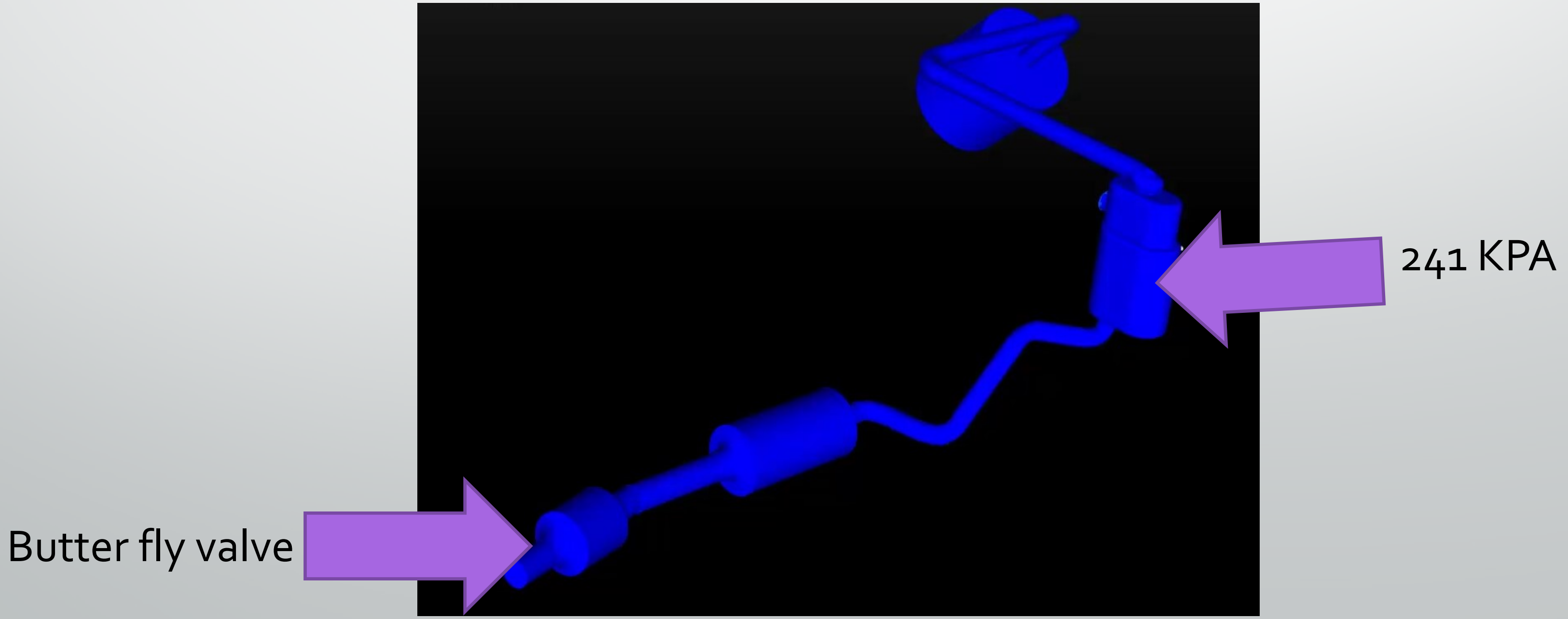


17 liter tank at ambient pressure.

Solution 1

(no vacuum)

- Then, the butterfly valve, already installed for EGR, was closed to pressurize the system (not including the 17 liter tank) to 240 kPa gauge.



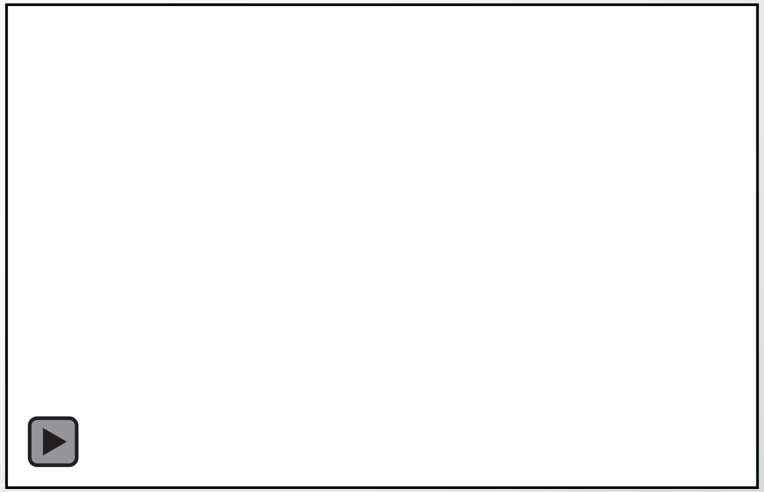
No Vacuum Results

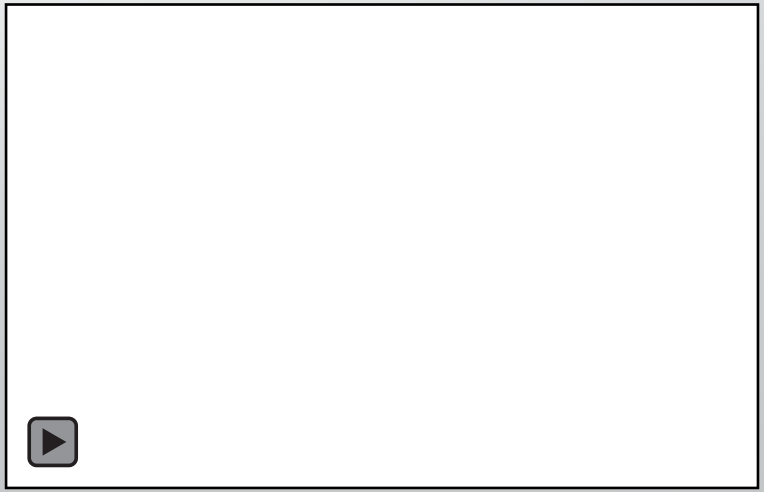
No Vacuum Results

No Vacuum Results

Solution 1 (no vacuum) Conclusion

- The particle traces demonstrate a successful regeneration in 1.26 s.
- The system takes exactly 1.16 s to build up pressure.
- The system takes 0.1 s to complete the regeneration.





Solution 1 (no vacuum) Conclusion

Advantages:

- Very simple
- Low cost
- Effective

Disadvantages:

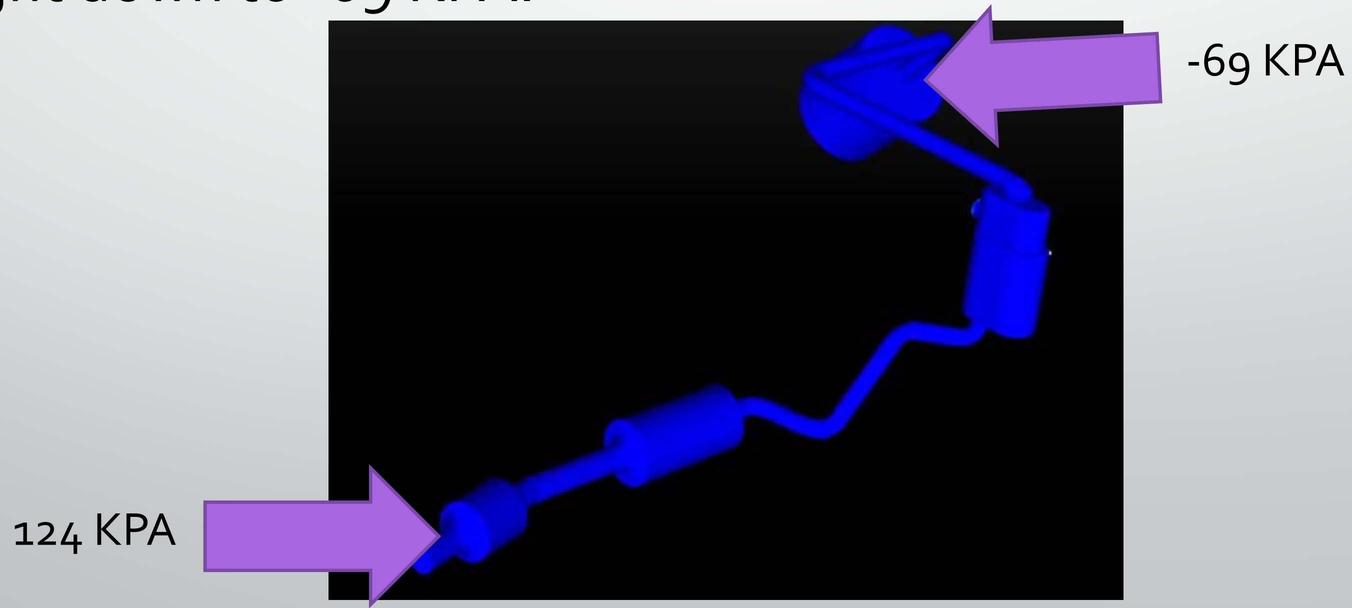
- Requires higher regeneration pressure

We envision this solution being used on everyday cars and large vehicles

Solution 2

(vacuum)

- The design is identical, the system was pressurized (not including the 17 litre tank) to 124 KPA. Then, the pressure in the 17 litre tank and the Poppet value was brought down to -69 KPA.



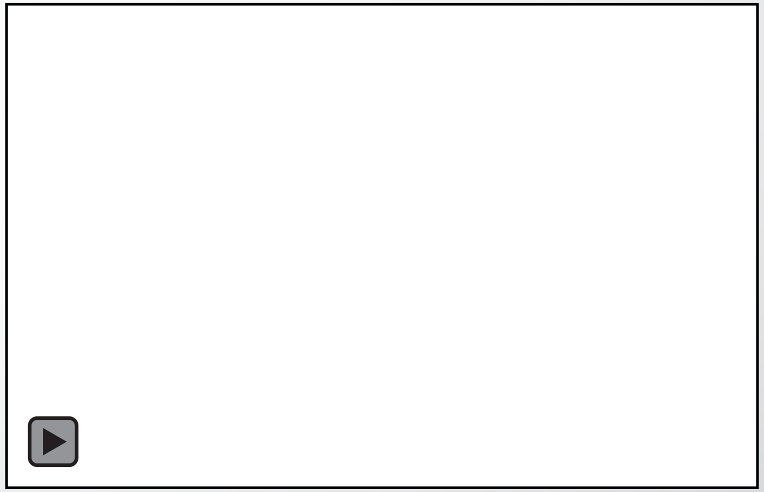
Vacuum Results

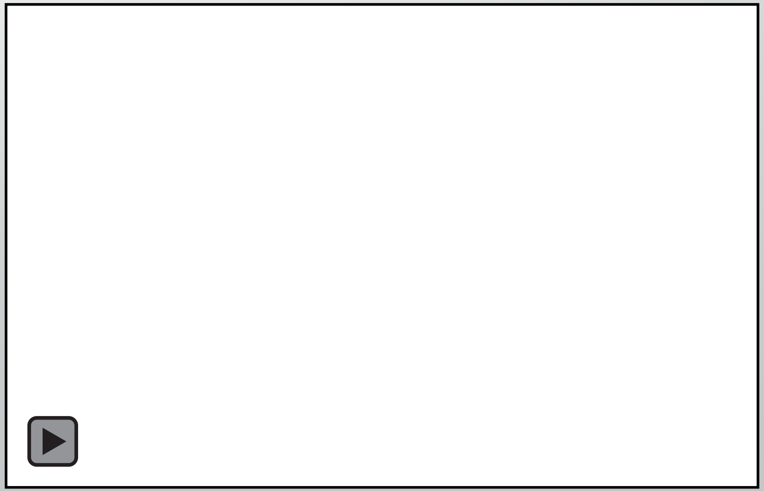
Vacuum Results

Vacuum Results

Solution 2 (vacuum) Conclusion

- The flow is mostly uniform and the particle traces demonstrate a successful regeneration in 0.5 s.
- The system takes 0.4 s to build up pressure.
- The system takes 0.1 s to complete the regeneration.





Solution 2 (vacuum) Conclusion

Advantages:

- Better distribution of flow
- Faster regeneration

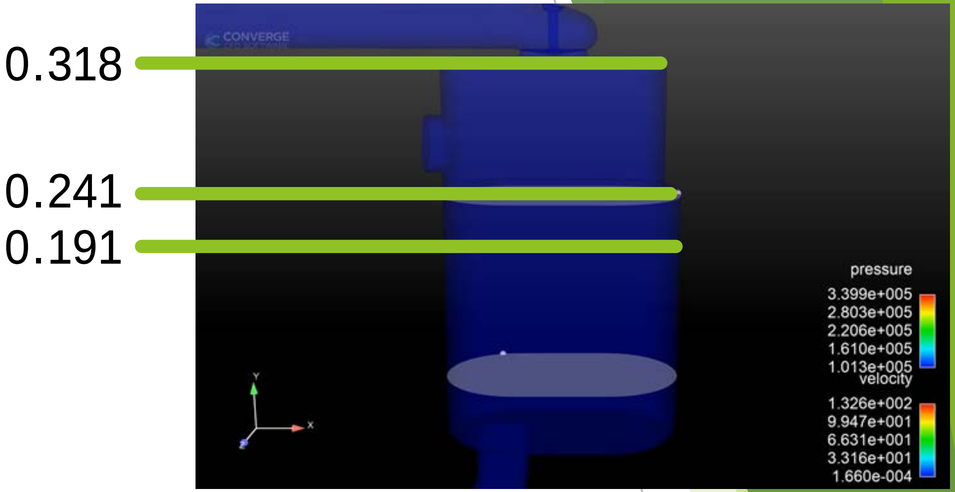
Disadvantages:

- More complex
- More expensive

We envision this solution being used on luxury cars where efficiency is important and cost is not as much of an issue.

Final Thoughts On CFD

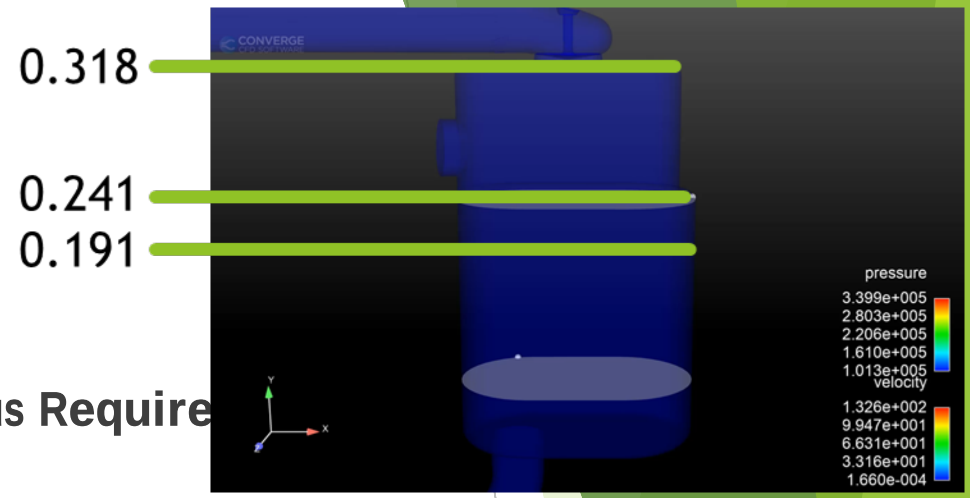
- We overcame the challenges and with CFD we were able to demonstrate it is possible to implement CPR in the Volkswagen Jetta TDI.
- These solutions were also capable of no passive regeneration conditions with a minor design change of the filter.
- The CPR regeneration is quick and efficient requiring no thermal active regeneration.



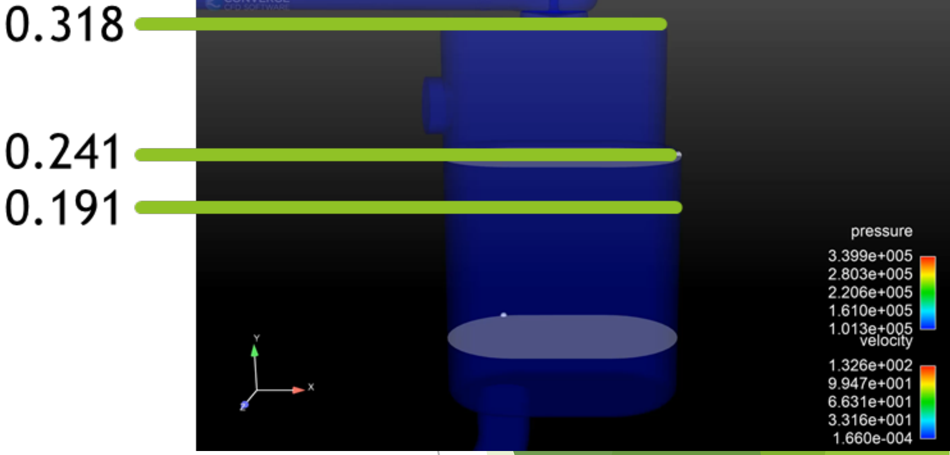
Cool Particulate Regeneration Unsteady 1D Code

Quickly Research and Develop new CPR system demonstrations

CPR 1D Modeling Tests



Test #	RegenP kPa	Valve mm	Tank l	RevDist kPa	Delta P l	Annulus Require
Test 1	240	46	10.2	0.164	17.15	Y
Test 2	340	46	10.2	0.22	33.4	Y
Test 3	340	46	15.4	0.269	58	Y
Test 4	240	66	15.4	0.1843	24	Y
Test 5	340	66	15.4	0.269	58	?
Test 6	340	66				



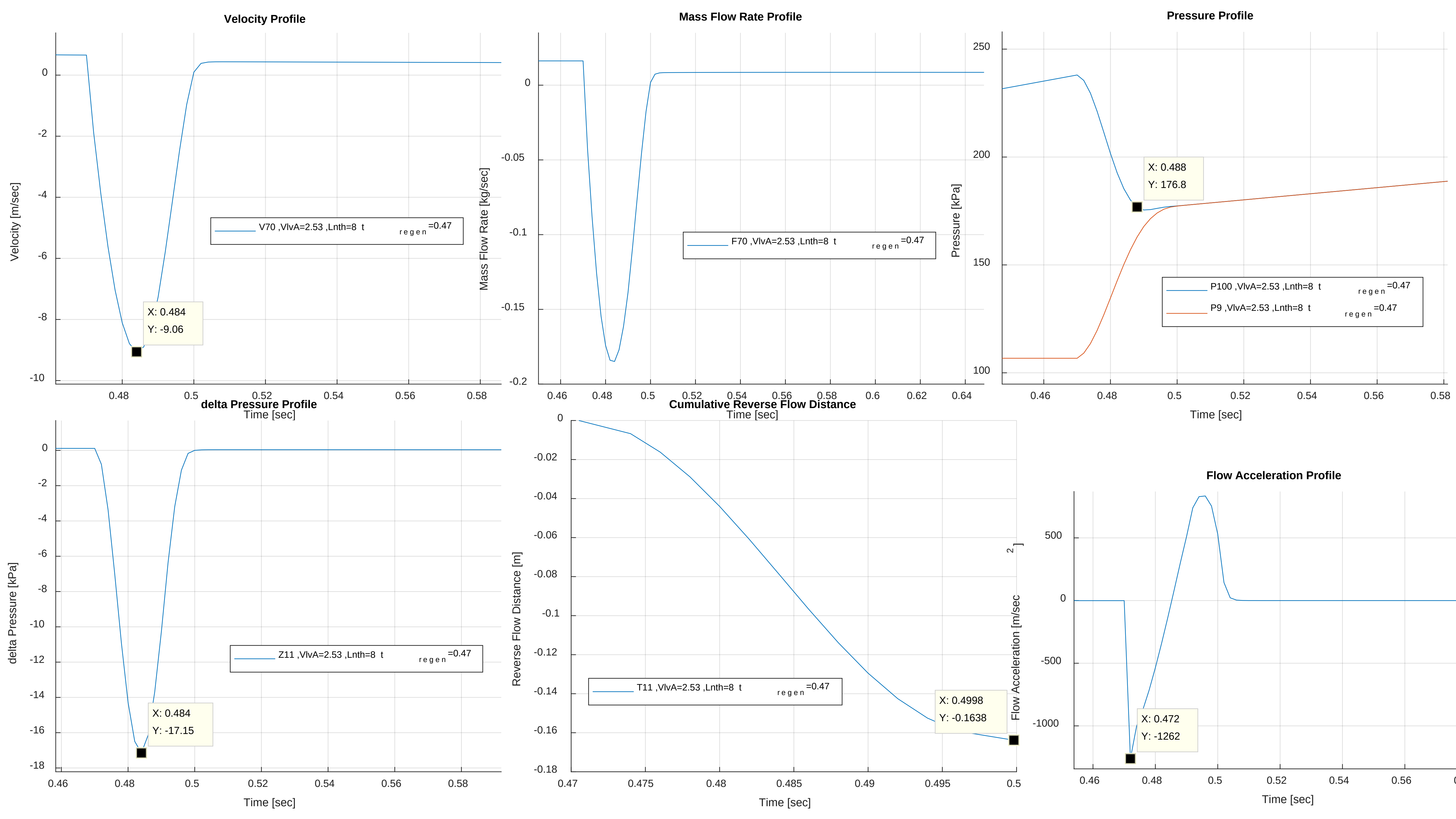
Test 1 Baseline Arrangement 240kPa (20psi) 10.2l (2.75gal) Holding 46mm Regen Valve

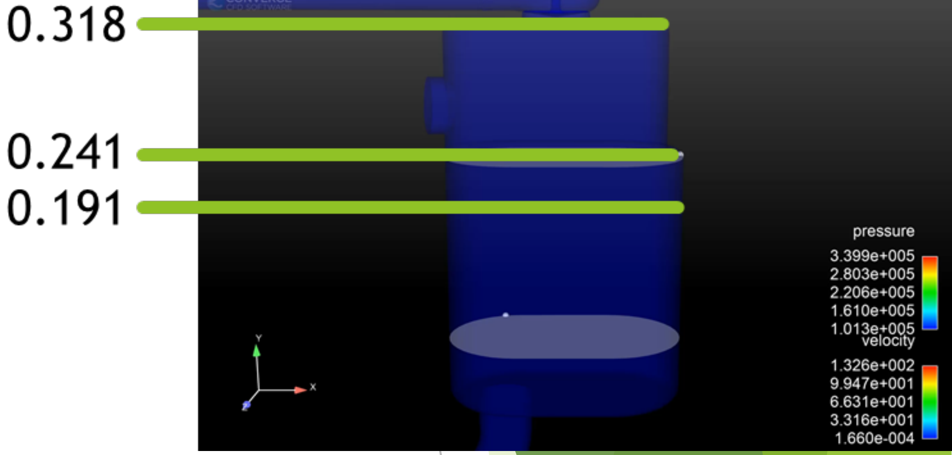
Base Holding Tank Size (10L)

Regeneration through an Annulus Design

Annulus Design or Outlet between DOC and DPF required for low Loads

- 0.164 m reverse flow distance
- 17.2kPa Delta P pressure
- 9 m/s reverse flow velocity
- 86% reversed flowed out of the filter

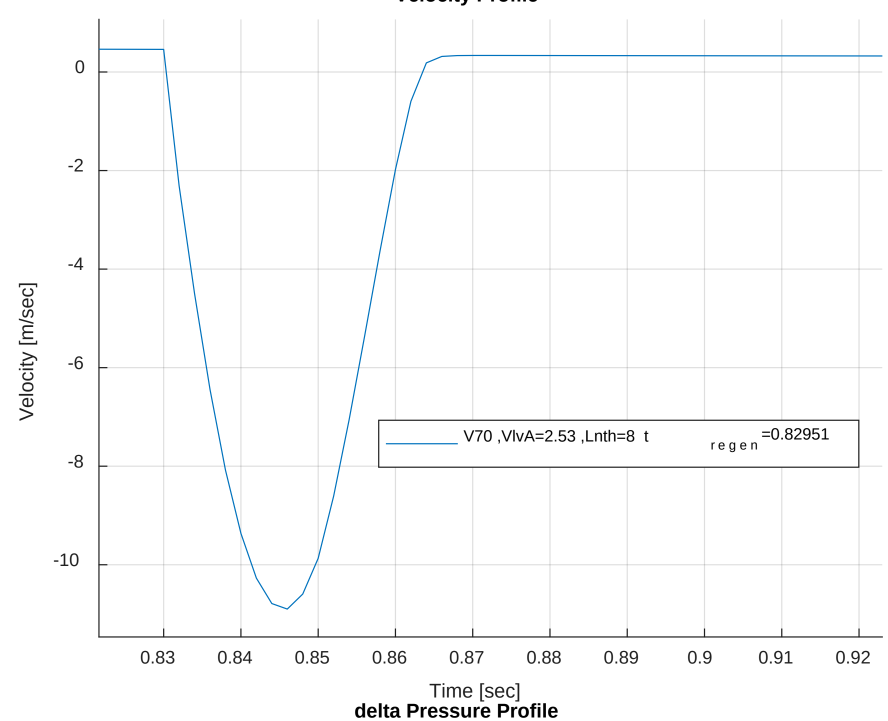

Velocity Profile
Velocity [m/sec]
V70 ,VlvA=2.53 ,Lnth=8 t regen =0.47
X: 0.484
Y: -9.06
Time [sec]
Mass Flow Rate Profile
Mass Flow Rate [kg/sec]
F70 ,VlvA=2.53 ,Lnth=8 t regen =0.47
Time [sec]
Pressure Profile
Pressure [kPa]
X: 0.488
Y: 176.8
P100 ,VlvA=2.53 ,Lnth=8 t regen =0.47
P9 ,VlvA=2.53 ,Lnth=8 t regen =0.47
Time [sec]
delta Pressure Profile
delta Pressure [kPa]
Z11 ,VlvA=2.53 ,Lnth=8 t regen =0.47
X: 0.484
Y: -17.15
Time [sec]
Cumulative Reverse Flow Distance
Reverse Flow Distance [m]
T11 ,VlvA=2.53 ,Lnth=8 t regen =0.47
X: 0.4998
Y: -0.1638
Time [sec]
Flow Acceleration Profile
Flow Acceleration [m/sec 2]
X: 0.472
Y: -1262
Time [sec]

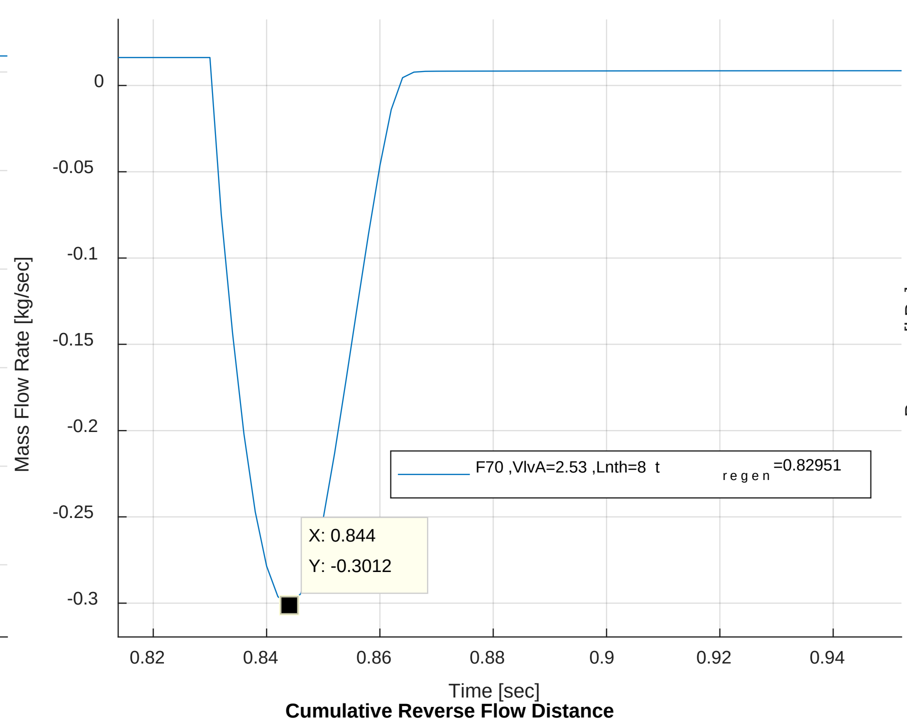


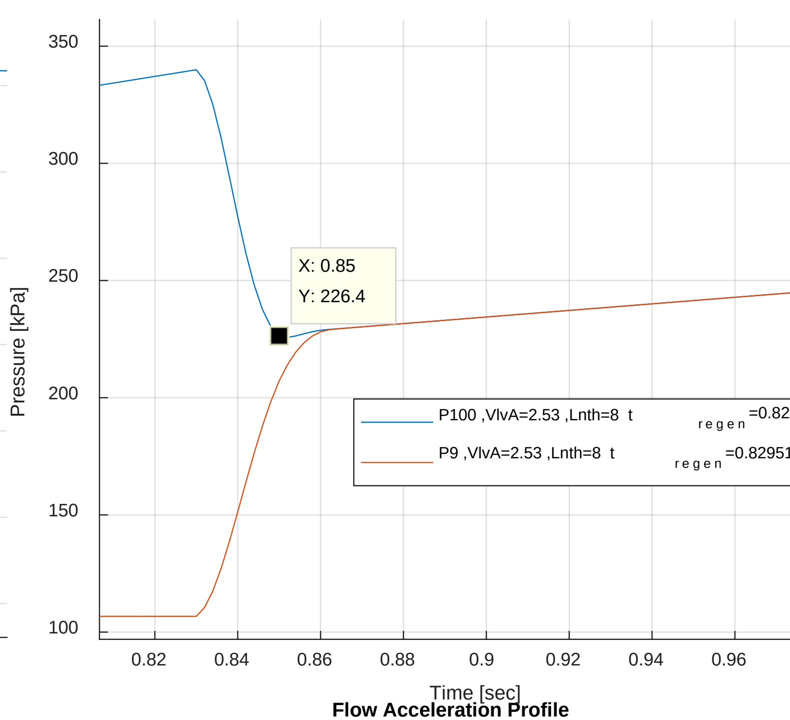
Test 2 Baseline Arrangement with Increased Pressure
340kPa (35psi) 10.2l (2.75gal) Holding

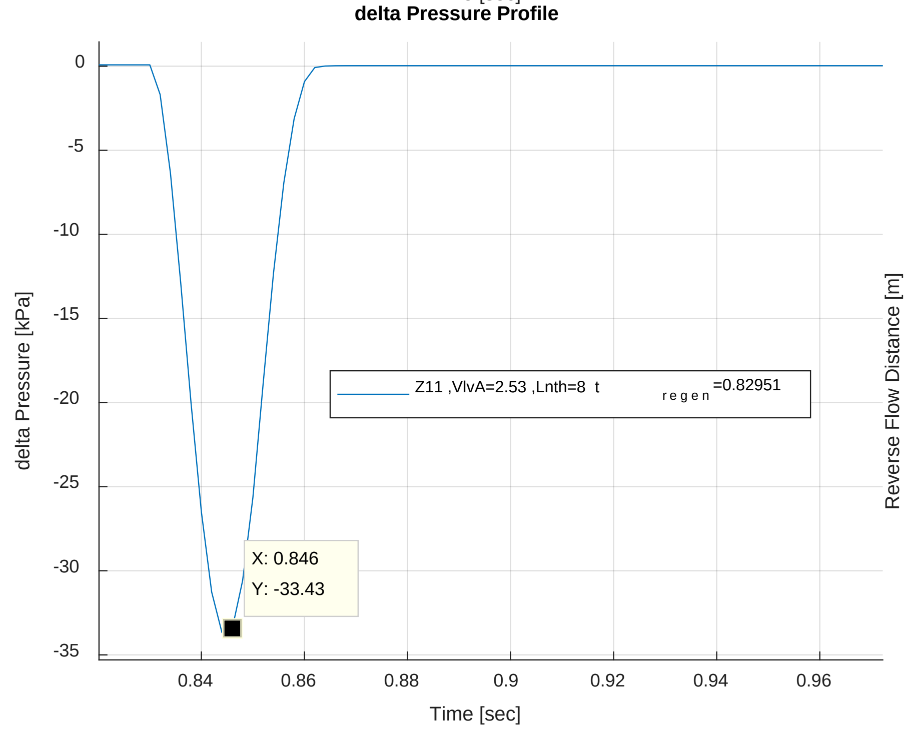
Base Holding Tank Size (10L)

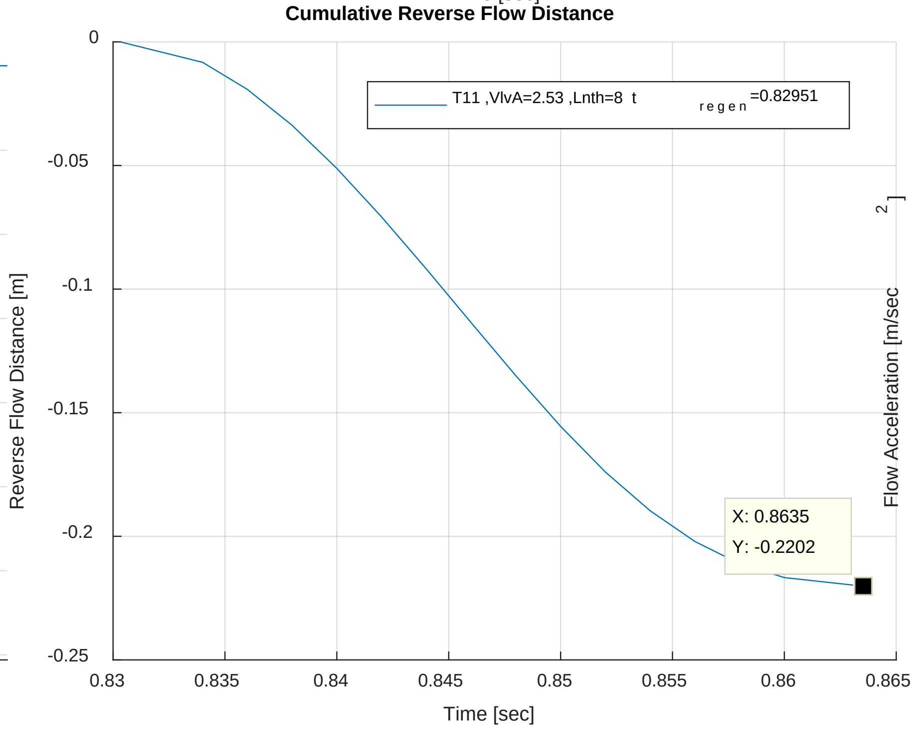
Regeneration through an Annulus Design

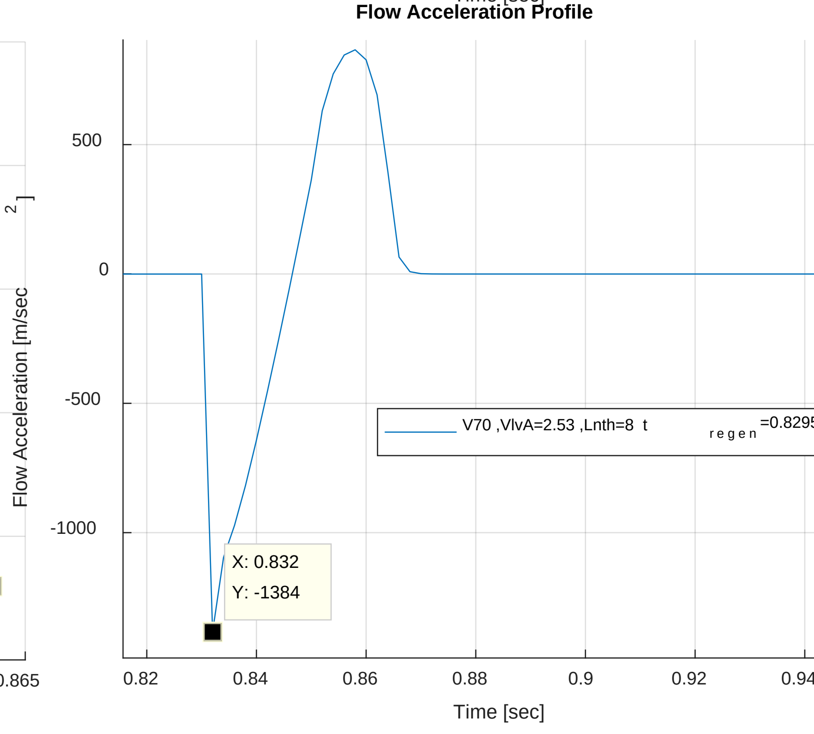

Velocity Profile
Velocity [m/sec]
0
-2
-4
-6
-8
-10
0.83
0.84
0.85
0.86
0.87
0.88
0.89
0.9
0.91
0.92
Time [sec]
V70 ,VlvA=2.53 ,Lnth=8 t regen =0.82951

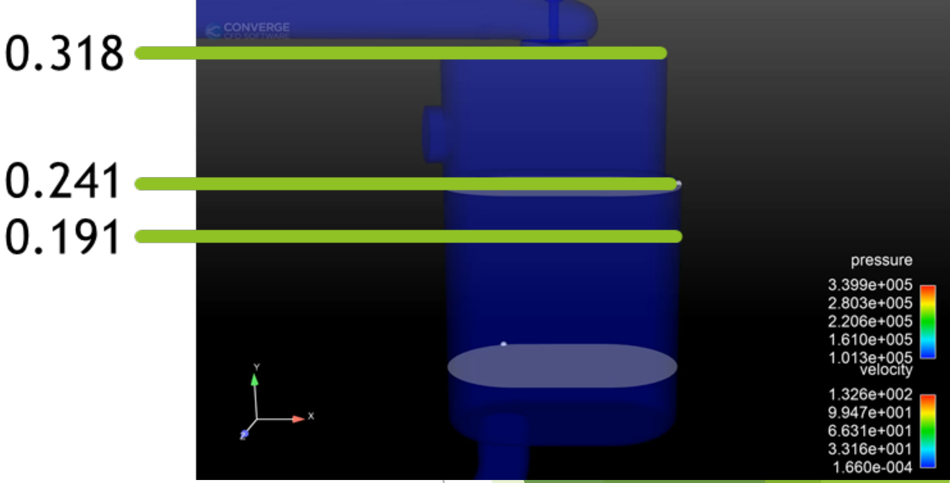

Mass Flow Rate [kg/sec]
0
-0.05
-0.1
-0.15
-0.2
-0.25
-0.3
0.82
0.84
0.86
0.88
0.9
0.92
0.94
Time [sec]
F70 ,VlvA=2.53 ,Lnth=8 t regen =0.82951
X: 0.844
Y: -0.3012


Pressure [kPa]
350
300
250
200
150
100
0.82
0.84
0.86
0.88
0.9
0.92
0.94
0.96
Time [sec]
X: 0.85
Y: 226.4
P100 ,VlvA=2.53 ,Lnth=8 t regen =0.82
P9 ,VlvA=2.53 ,Lnth=8 t regen =0.82951


delta Pressure Profile
delta Pressure [kPa]
0
-5
-10
-15
-20
-25
-30
-35
0.84
0.86
0.88
0.9
0.92
0.94
0.96
Time [sec]
Z11 ,VlvA=2.53 ,Lnth=8 t regen =0.82951
X: 0.846
Y: -33.43


Cumulative Reverse Flow Distance
Reverse Flow Distance [m]
0
-0.05
-0.1
-0.15
-0.2
-0.25
0.83
0.835
0.84
0.845
0.85
0.855
0.86
0.865
Time [sec]
T11 ,VlvA=2.53 ,Lnth=8 t regen =0.82951
X: 0.8635
Y: -0.2202

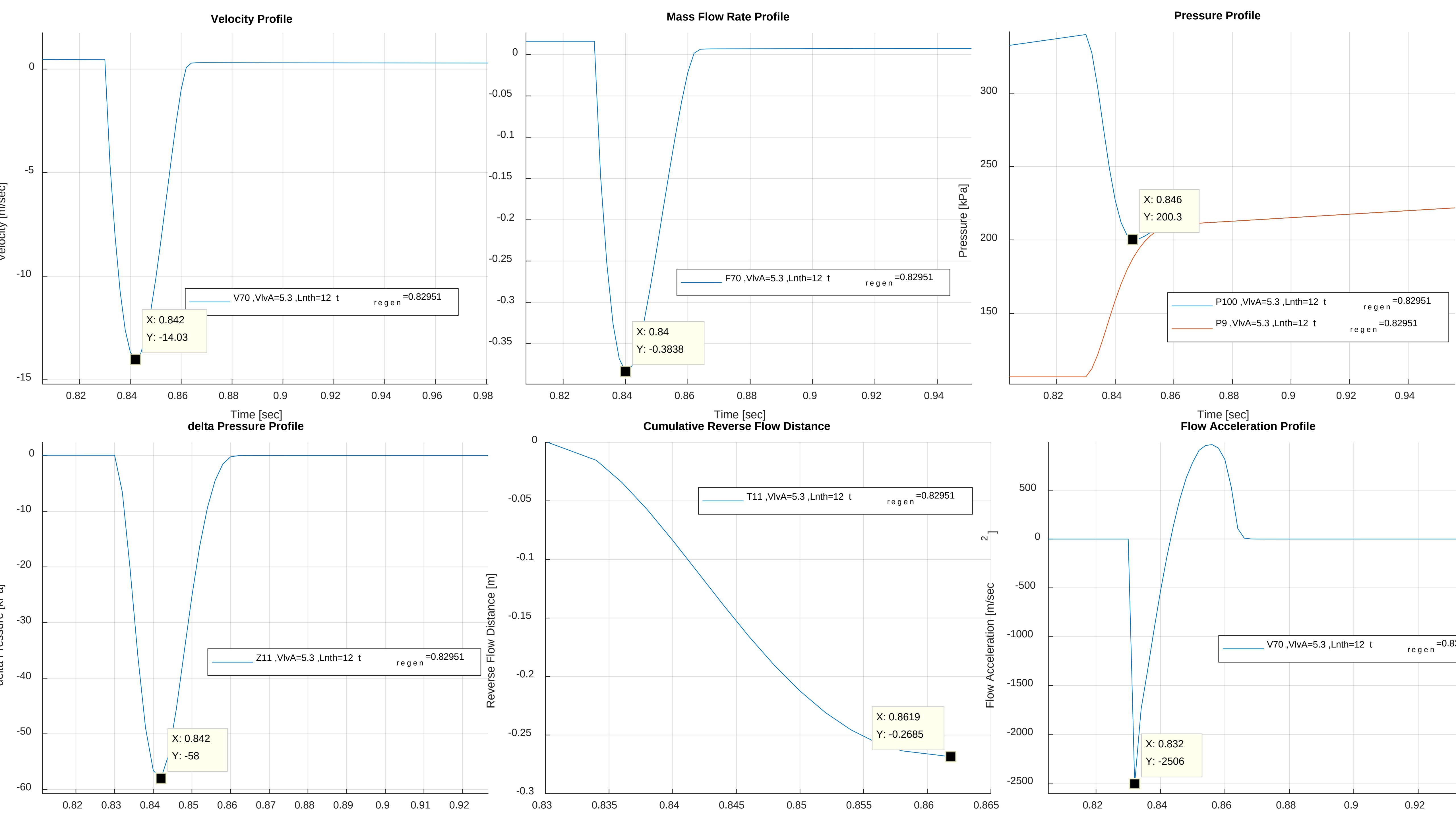

Flow Acceleration Profile
Flow Acceleration [m/sec 2]
500
0
-500
-1000
0.82
0.84
0.86
0.88
0.9
0.92
0.94
Time [sec]
V70 ,VlvA=2.53 ,Lnth=8 t regen =0.8295
X: 0.832
Y: -1384

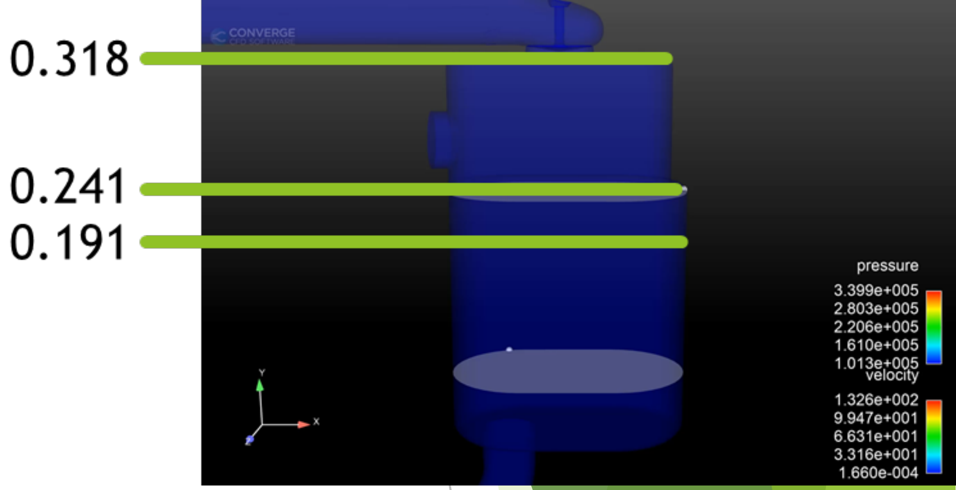


Test 3 340kPa (35psi) 15.4l (4gal) Holding

Base Holding Tank Size (10L)

Regeneration through an Annulus Design

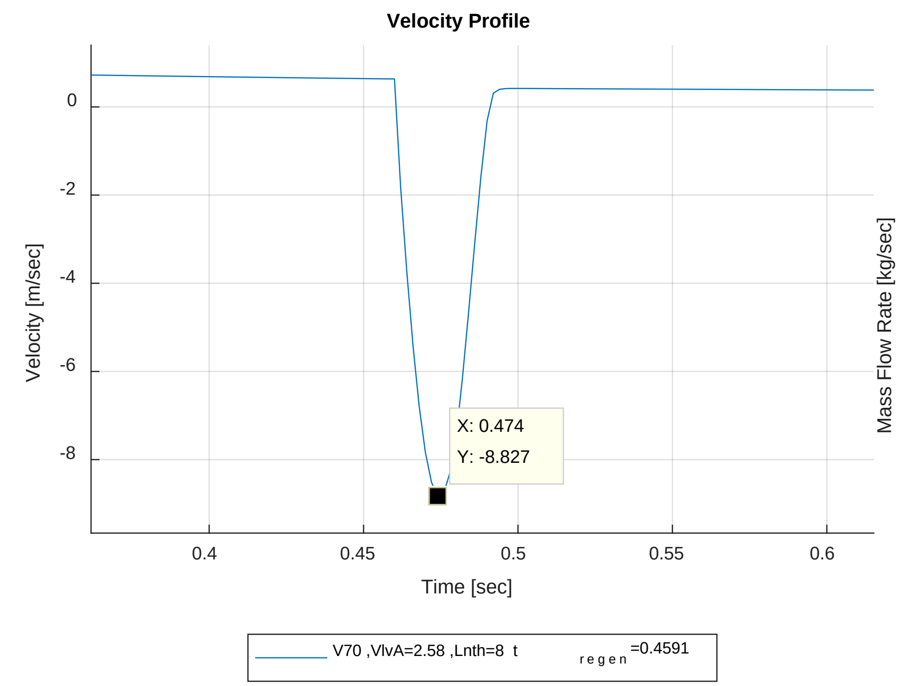

Velocity Profile
Velocity [m/sec]
Time [sec]
V70 ,VlvA=5.3 ,Lnth=12 t regen =0.82951
X: 0.842
Y: -14.03
Mass Flow Rate Profile
Time [sec]
F70 ,VlvA=5.3 ,Lnth=12 t regen =0.82951
X: 0.84
Y: -0.3838
Pressure Profile
Pressure [kPa]
Time [sec]
P100 ,VlvA=5.3 ,Lnth=12 t regen =0.82951
P9 ,VlvA=5.3 ,Lnth=12 t regen =0.82951
X: 0.846
Y: 200.3
delta Pressure Profile
Z11 ,VlvA=5.3 ,Lnth=12 t regen =0.82951
X: 0.842
Y: -58
Cumulative Reverse Flow Distance
Reverse Flow Distance [m]
T11 ,VlvA=5.3 ,Lnth=12 t regen =0.82951
X: 0.8619
Y: -0.2685
Flow Acceleration Profile
Flow Acceleration [m/sec 2]
V70 ,VlvA=5.3 ,Lnth=12 t regen
X: 0.832
Y: -2506

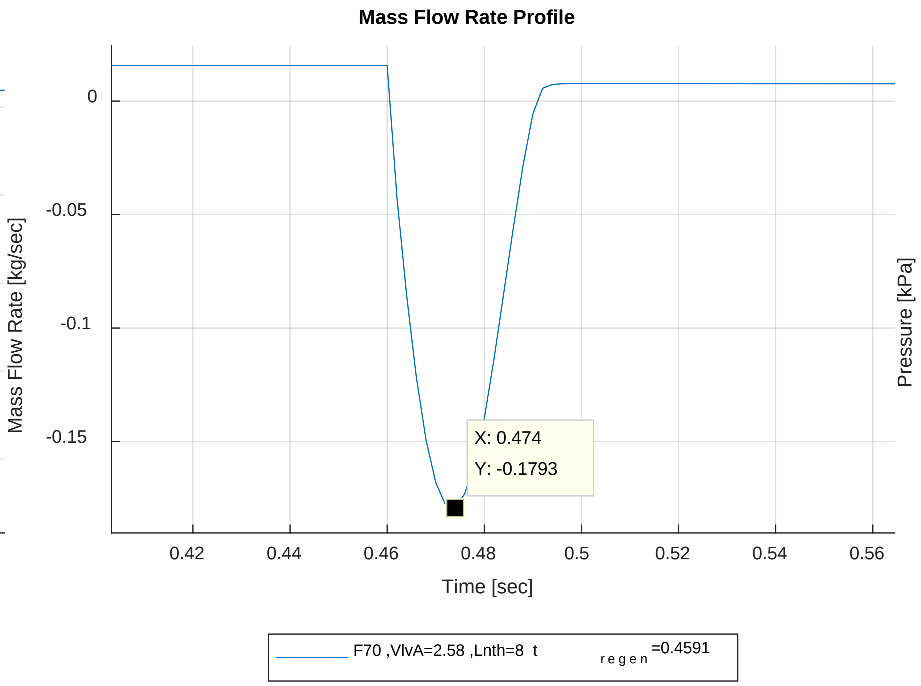


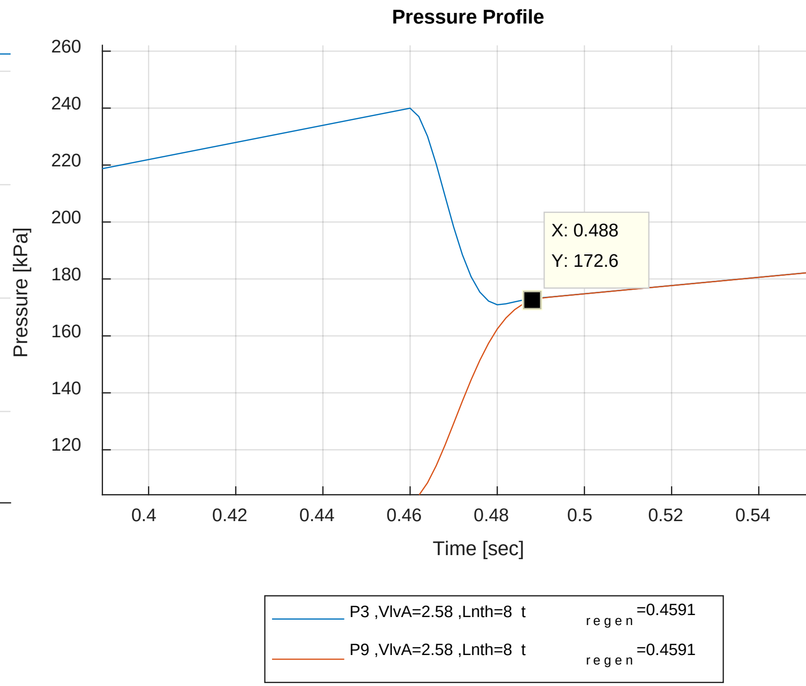
Test 4 240kPa (20psi) 10l Holding

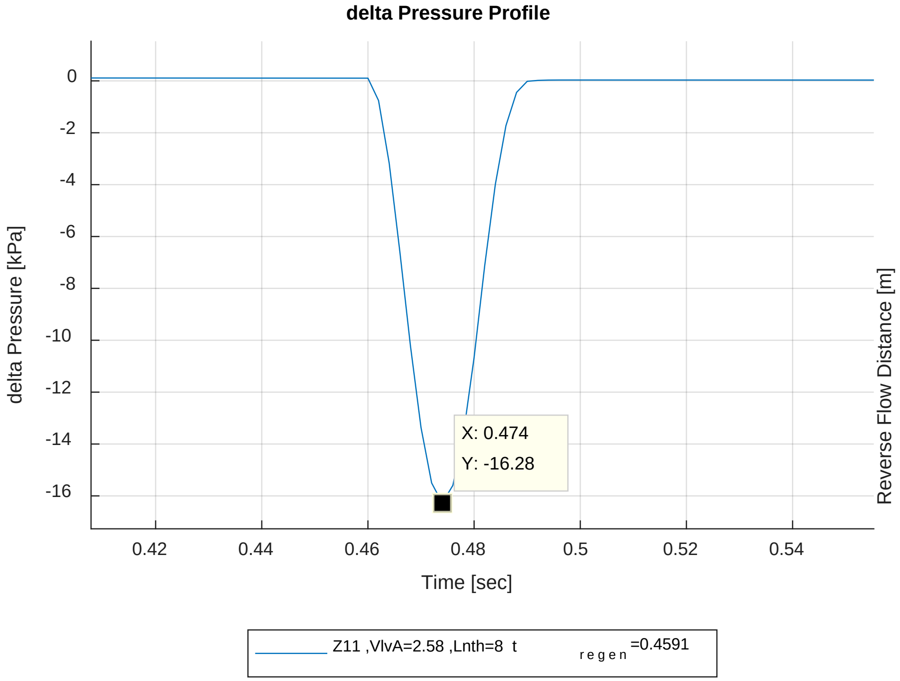
Base Holding Tank Size (10L)

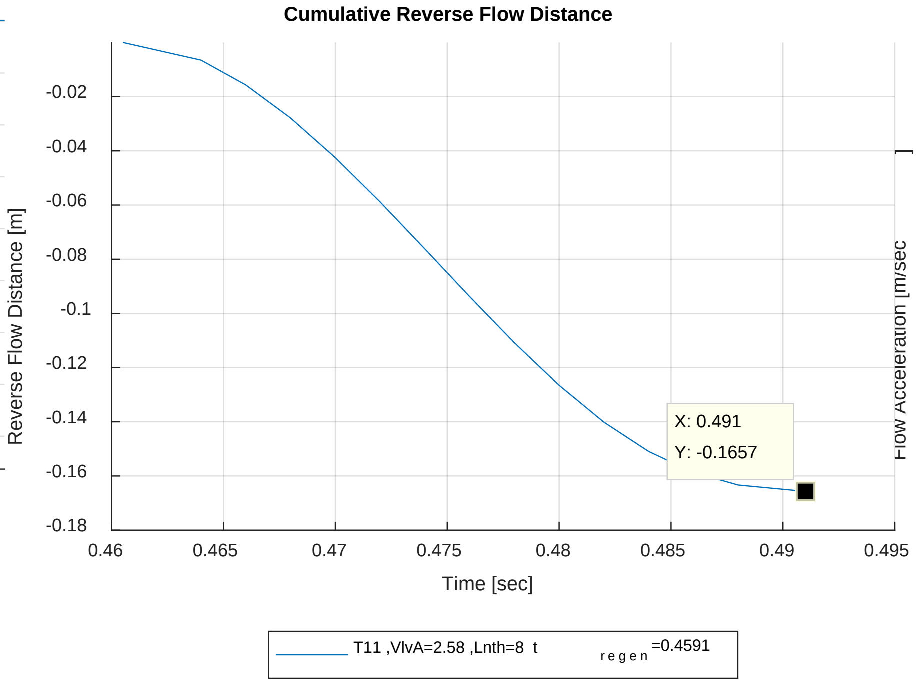
Regeneration through an Annulus Design

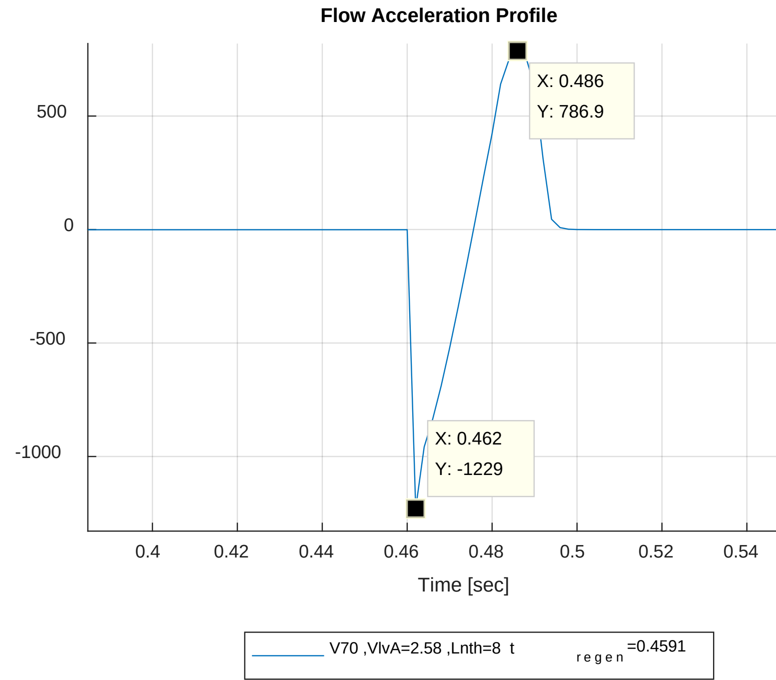

Velocity Profile
Velocity [m/sec]
0
-2
-4
-6
-8
X: 0.474
Y: -8.827
0.4
0.45
0.5
0.55
0.6
Time [sec]
V70 ,VlvA=2.58 ,Lnth=8 t regen =0.4591

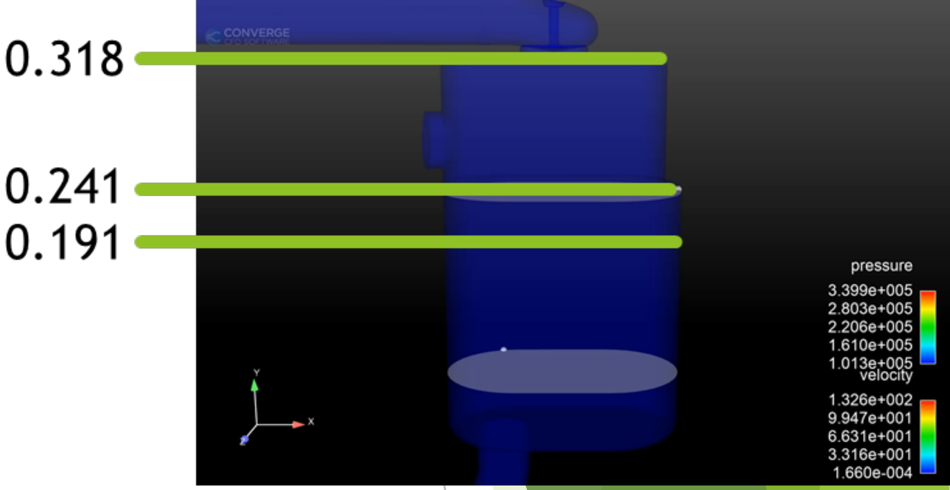

Mass Flow Rate Profile
Mass Flow Rate [kg/sec]
0
-0.05
-0.1
-0.15
X: 0.474
Y: -0.1793
0.42
0.44
0.46
0.48
0.5
0.52
0.54
0.56
Time [sec]
F70 ,VlvA=2.58 ,Lnth=8 t regen =0.4591


Pressure Profile
Pressure [kPa]
260
240
220
200
180
160
140
120
X: 0.488
Y: 172.6
0.4
0.42
0.44
0.46
0.48
0.5
0.52
0.54
Time [sec]
P3 ,VlvA=2.58 ,Lnth=8 t regen =0.4591
P9 ,VlvA=2.58 ,Lnth=8 t regen =0.4591


delta Pressure Profile
delta Pressure [kPa]
0
-2
-4
-6
-8
-10
-12
-14
-16
X: 0.474
Y: -16.28
0.42
0.44
0.46
0.48
0.5
0.52
0.54
Time [sec]
Z11 ,VlvA=2.58 ,Lnth=8 t regen =0.4591

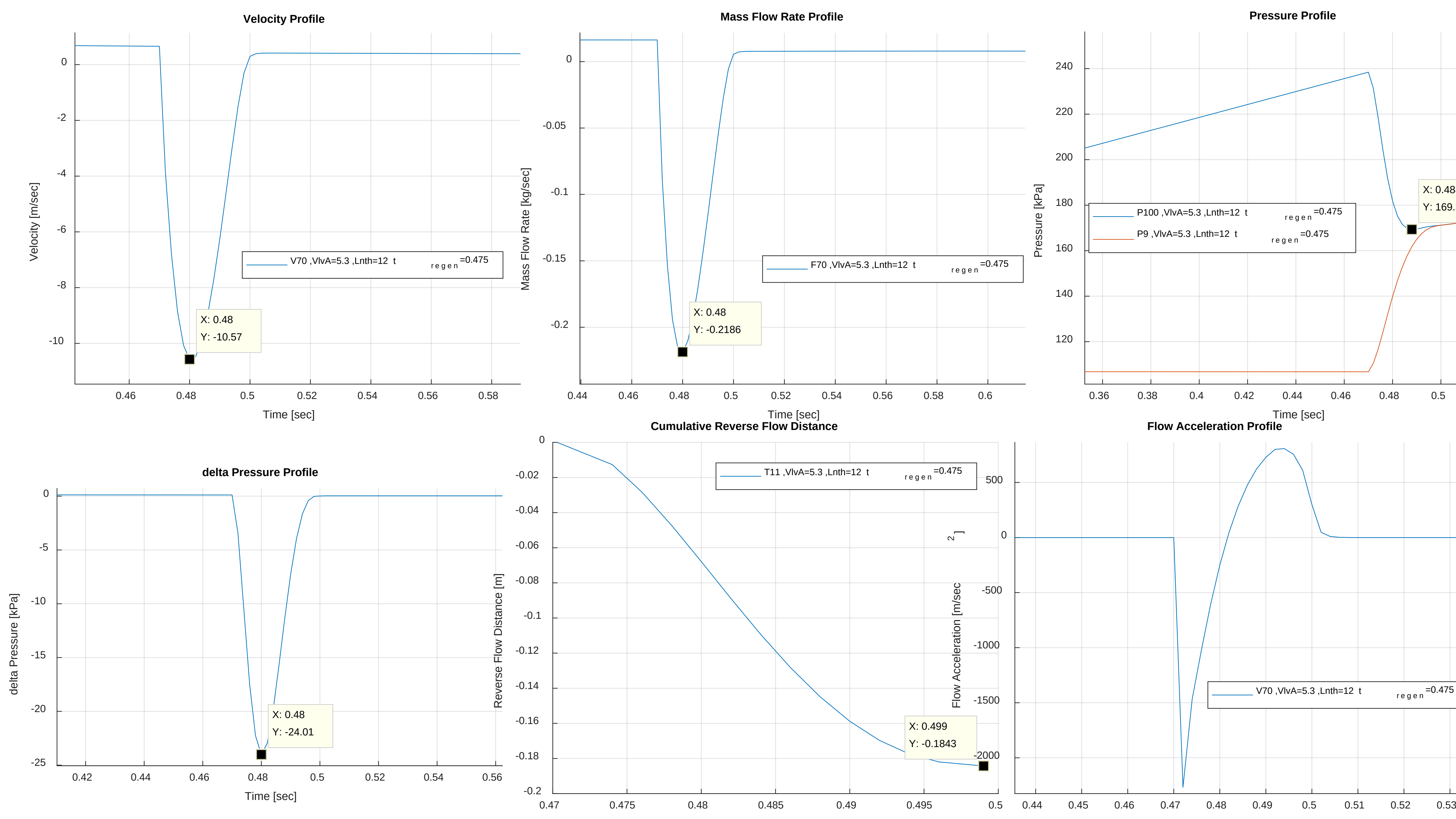

Cumulative Reverse Flow Distance
Reverse Flow Distance [m]
-0.02
-0.04
-0.06
-0.08
-0.1
-0.12
-0.14
-0.16
-0.18
X: 0.491
Y: -0.1657
0.46
0.465
0.47
0.475
0.48
0.485
0.49
0.495
Time [sec]
T11 ,VlvA=2.58 ,Lnth=8 t regen =0.4591


Flow Acceleration Profile
Flow Acceleration [m/sec
500
0
-500
-1000
X: 0.486
Y: 786.9
X: 0.462
Y: -1229
0.4
0.42
0.44
0.46
0.48
0.5
0.52
0.54
Time [sec]
V70 ,VlvA=2.58 ,Lnth=8 t regen =0.4591



Test 5 240kPa (20psi) 15.4l Holding

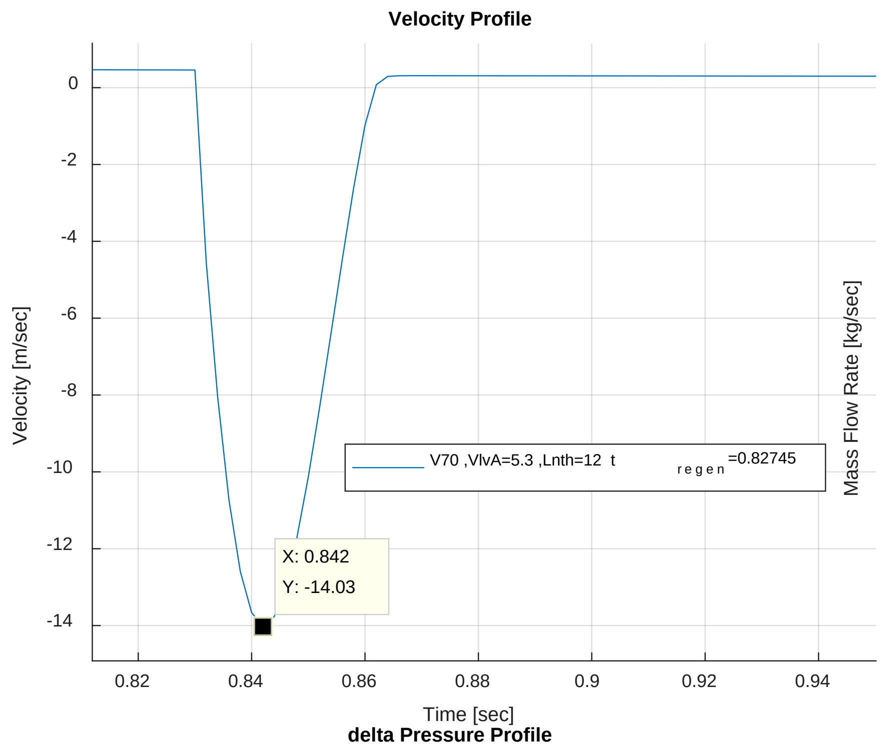
Base Holding Tank Size 15.4L (4 gal)

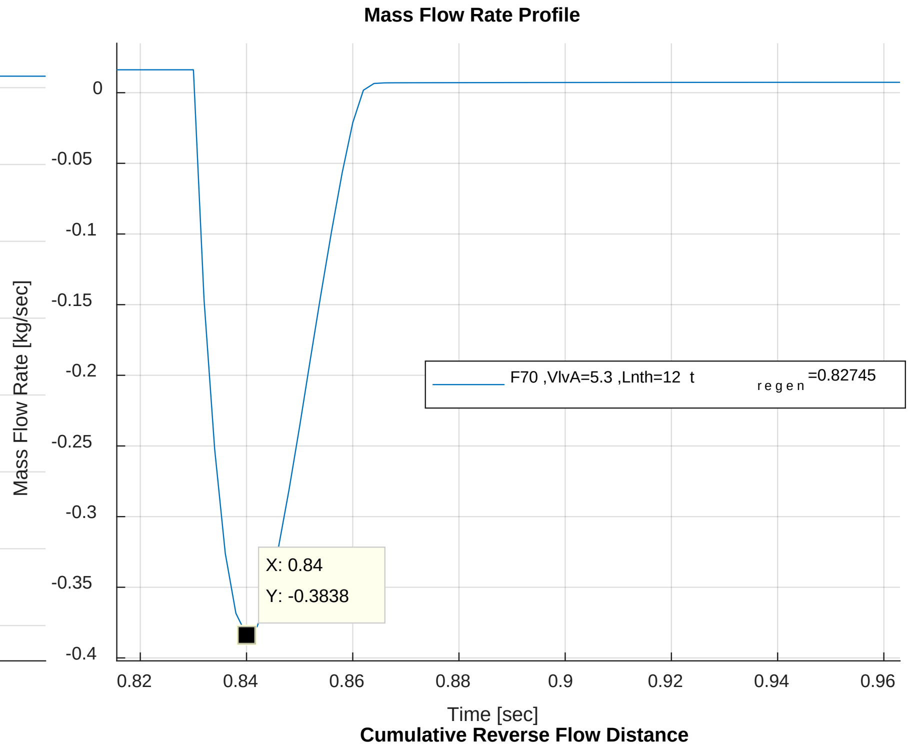

Velocity Profile
Velocity [m/sec]
Time [sec]
V70 ,VlvA=5.3 ,Lnth=12 t regen =0.475
X: 0.48
Y: -10.57
Mass Flow Rate Profile
Mass Flow Rate [kg/sec]
Time [sec]
F70 ,VlvA=5.3 ,Lnth=12 t regen =0.475
X: 0.48
Y: -0.2186
Pressure Profile
Pressure [kPa]
Time [sec]
P100 ,VlvA=5.3 ,Lnth=12 t regen =0.475
P9 ,VlvA=5.3 ,Lnth=12 t regen =0.475
delta Pressure Profile
delta Pressure [kPa]
Time [sec]
X: 0.48
Y: -24.01
Cumulative Reverse Flow Distance
Reverse Flow Distance [m]
T11 ,VlvA=5.3 ,Lnth=12 t regen =0.475
X: 0.499
Y: -0.1843
Flow Acceleration Profile
Flow Acceleration [m/sec 2]
V70 ,VlvA=5.3 ,Lnth=12 t regen =0.475

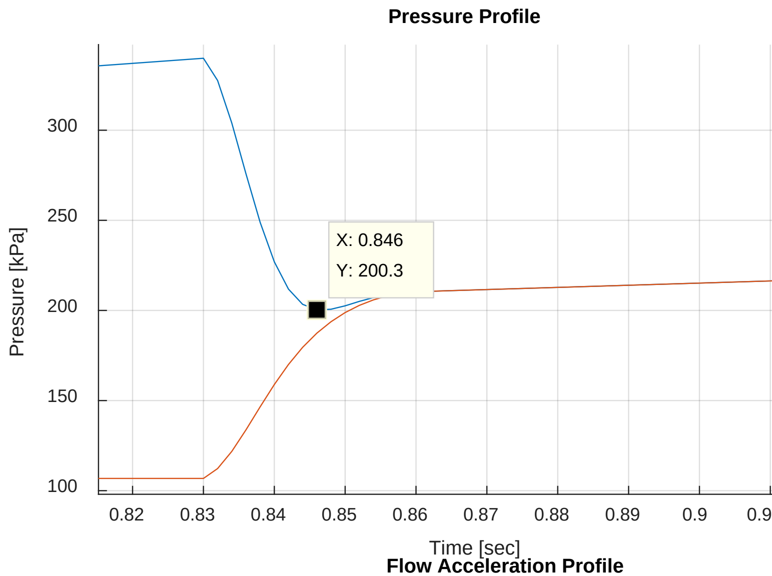
Baseline Test 6 340kPa (35psi) Regen Pres

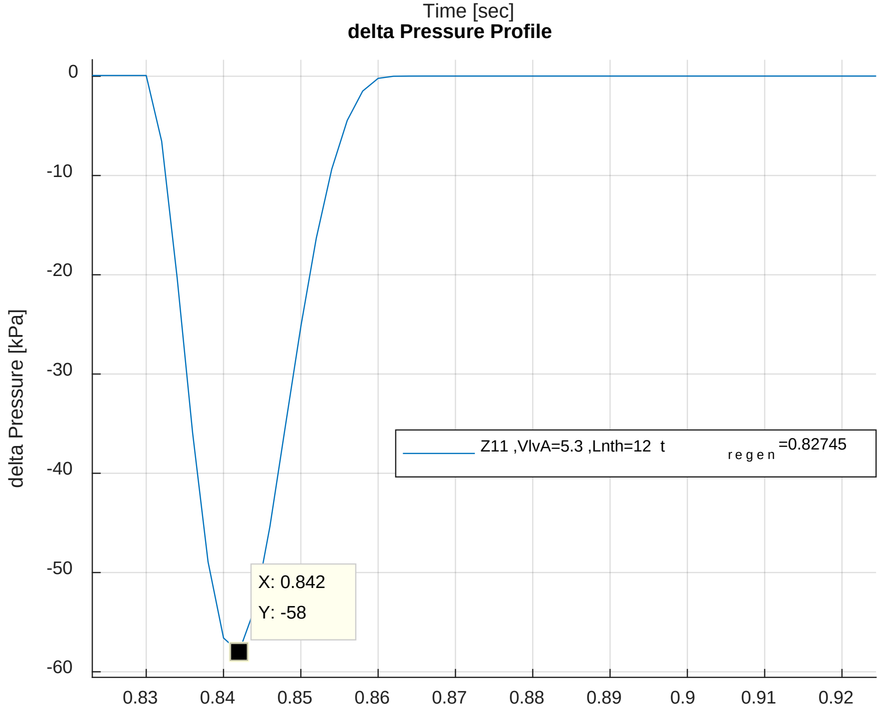
66mm Regeneration Valve Diameter

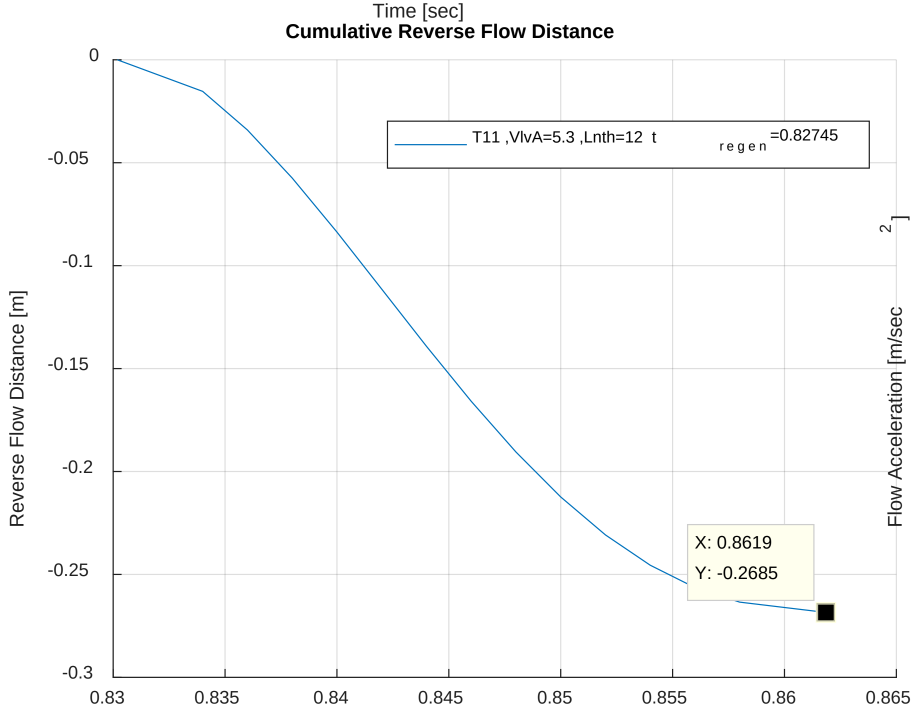
15.4 (4 gal) Holding Tank

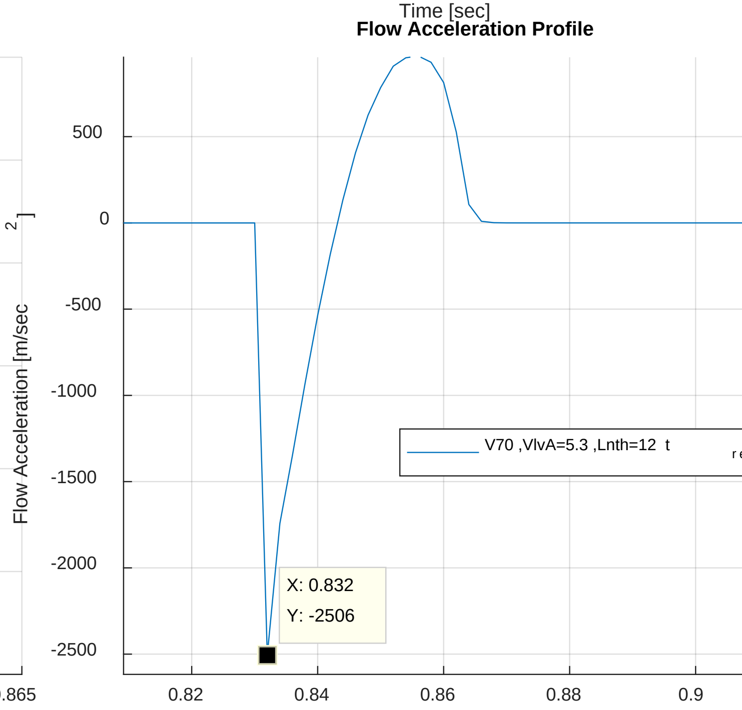

Velocity Profile
Velocity [m/sec]
Time [sec]
V70 ,VlvA=5.3 ,Lnth=12 t regen =0.82745
X: 0.842
Y: -14.03


Mass Flow Rate Profile
Mass Flow Rate [kg/sec]
Time [sec]
F70 ,VlvA=5.3 ,Lnth=12 t regen =0.82745
X: 0.84
Y: -0.3838


Pressure Profile
Pressure [kPa]
Time [sec]
X: 0.846
Y: 200.3


delta Pressure Profile
delta Pressure [kPa]
Z11 ,VlvA=5.3 ,Lnth=12 t regen =0.82745
X: 0.842
Y: -58

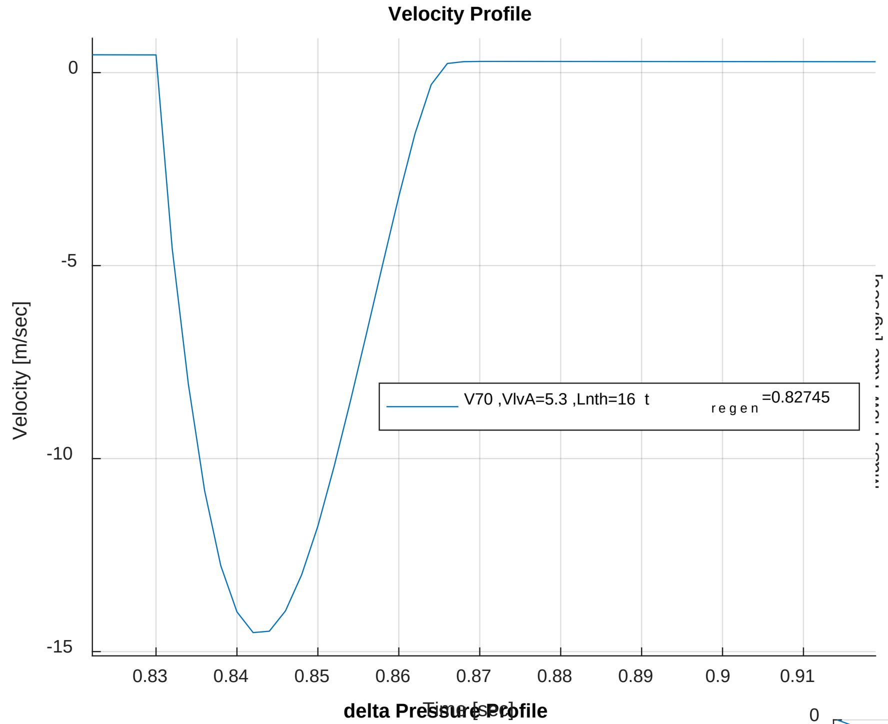

Cumulative Reverse Flow Distance
Reverse Flow Distance [m]
T11 ,VlvA=5.3 ,Lnth=12 t regen =0.82745
X: 0.8619
Y: -0.2685

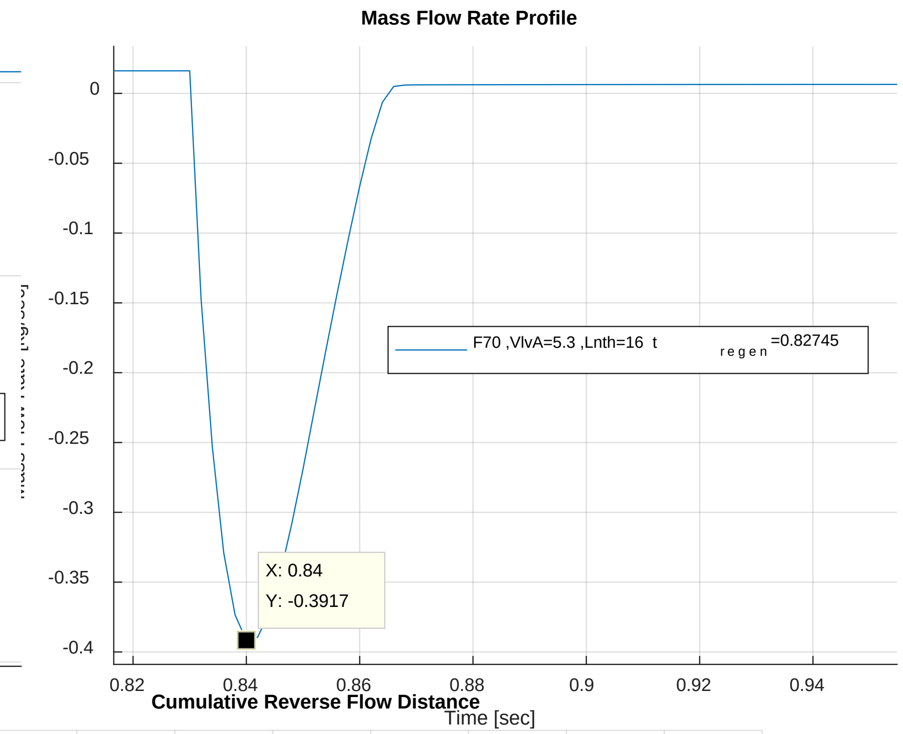

Flow Acceleration Profile
Flow Acceleration [m/sec 2]
V70 ,VlvA=5.3 ,Lnth=12 t
X: 0.832
Y: -2506

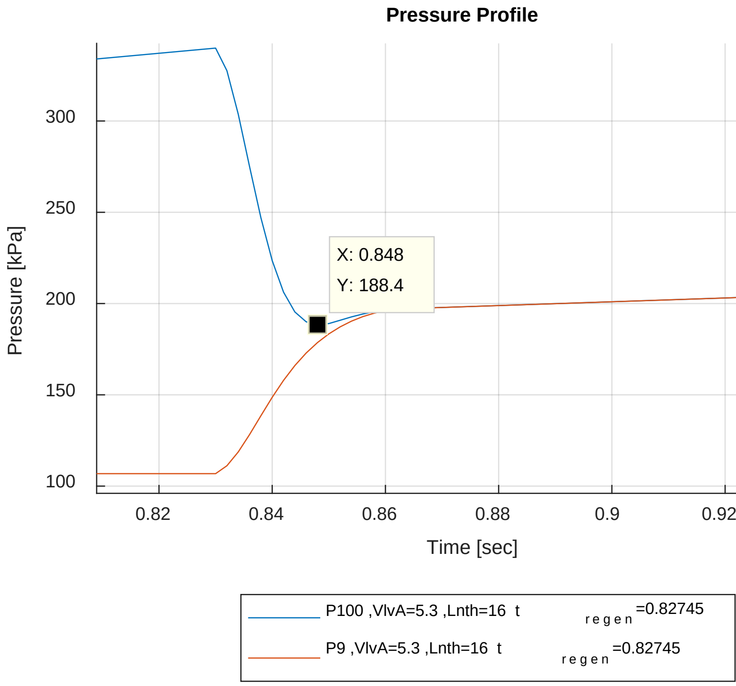
Baseline 340kPa (35psi) Regen Pres

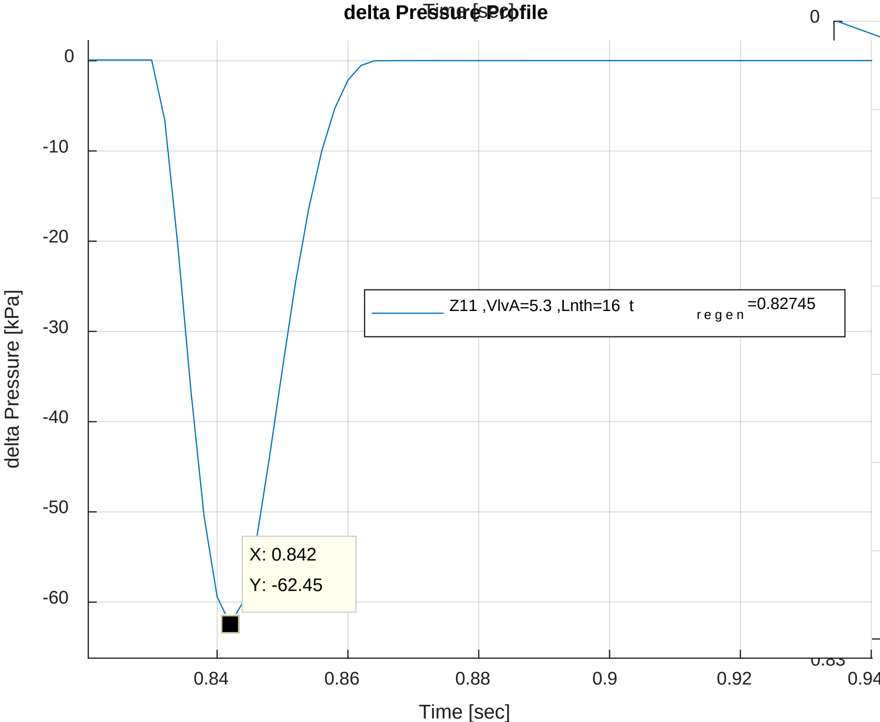
66mm Regeneration Valve Diameter

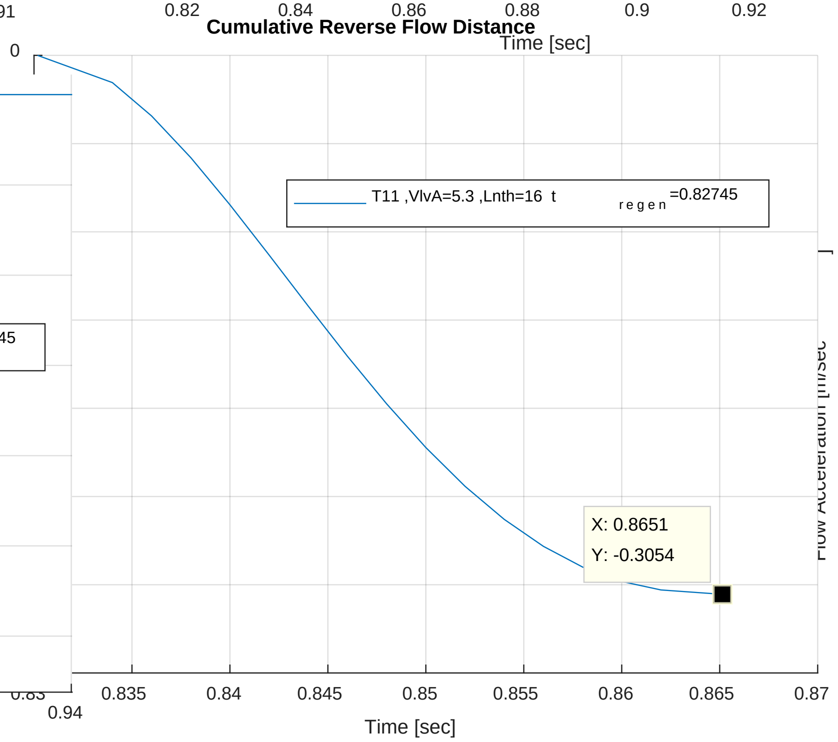
20.6 (5.5gal) Holding Tank

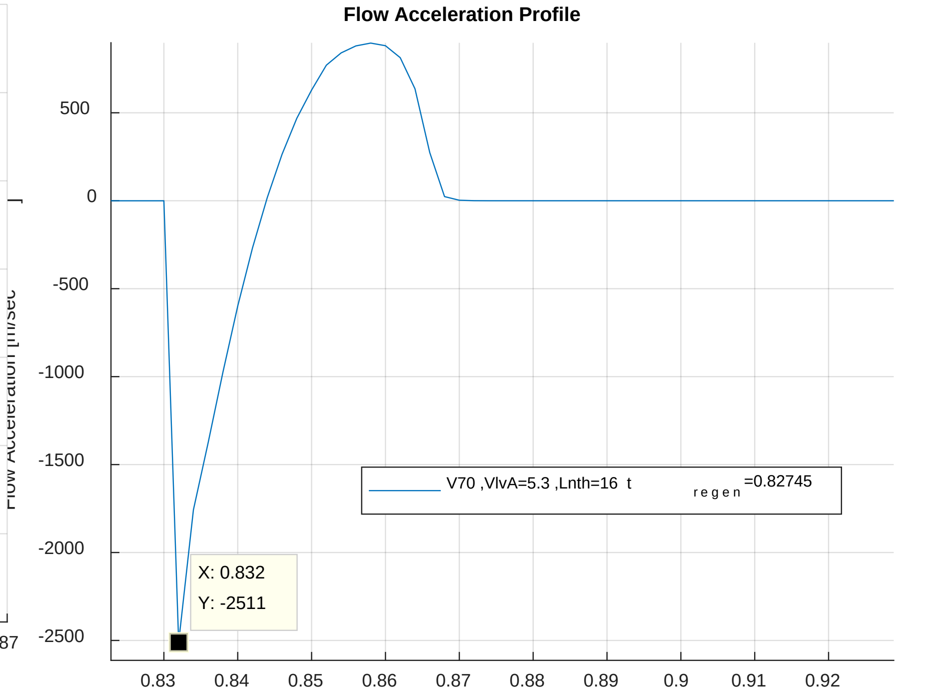

Velocity Profile
Velocity [m/sec]
V70 ,VlvA=5.3 ,Lnth=16 t regen =0.82745
0
-5
-10
-15
0.83
0.84
0.85
0.86
0.87
0.88
0.89
0.9
0.91


Mass Flow Rate Profile
F70 ,VlvA=5.3 ,Lnth=16 t regen =0.82745
X: 0.84
Y: -0.3917
Time [sec]
0
-0.05
-0.1
-0.15
-0.2
-0.25
-0.3
-0.35
-0.4
0.82
0.84
0.86
0.88
0.9
0.92
0.94


Pressure Profile
Pressure [kPa]
X: 0.848
Y: 188.4
Time [sec]
P100 ,VlvA=5.3 ,Lnth=16 t regen =0.82745
P9 ,VlvA=5.3 ,Lnth=16 t regen =0.82745
300
250
200
150
100
0.82
0.84
0.86
0.88
0.9
0.92


delta Pressure Profile
delta Pressure [kPa]
Z11 ,VlvA=5.3 ,Lnth=16 t regen =0.82745
X: 0.842
Y: -62.45
Time [sec]
0
-10
-20
-30
-40
-50
-60
0.84
0.86
0.88
0.9
0.92
0.94

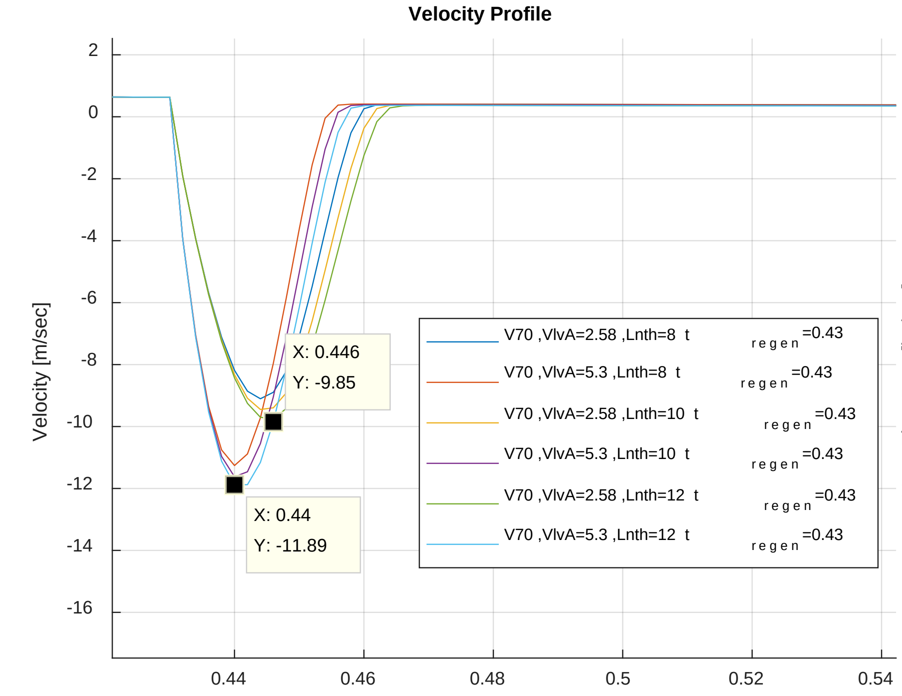

Cumulative Reverse Flow Distance
T11 ,VlvA=5.3 ,Lnth=16 t regen =0.82745
X: 0.8651
Y: -0.3054
Time [sec]
0
0.835
0.84
0.845
0.85
0.855
0.86
0.865
0.87

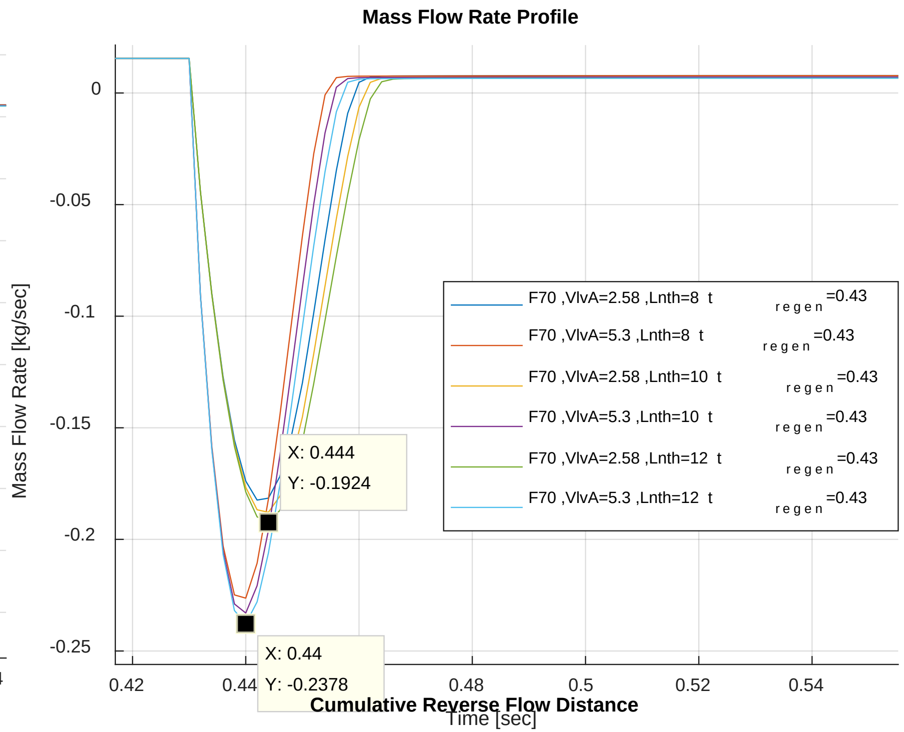

Flow Acceleration Profile
V70 ,VlvA=5.3 ,Lnth=16 t regen =0.82745
X: 0.832
Y: -2511
500
0
-500
-1000
-1500
-2000
-2500
0.83
0.84
0.85
0.86
0.87
0.88
0.89
0.9
0.91
0.92

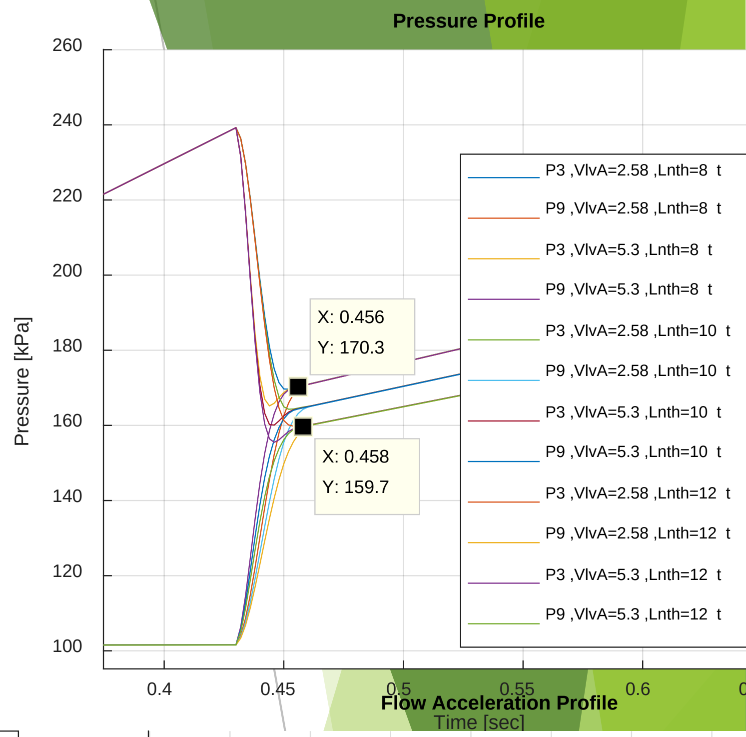
Baseline 140kPa (20psi) Regen Pres

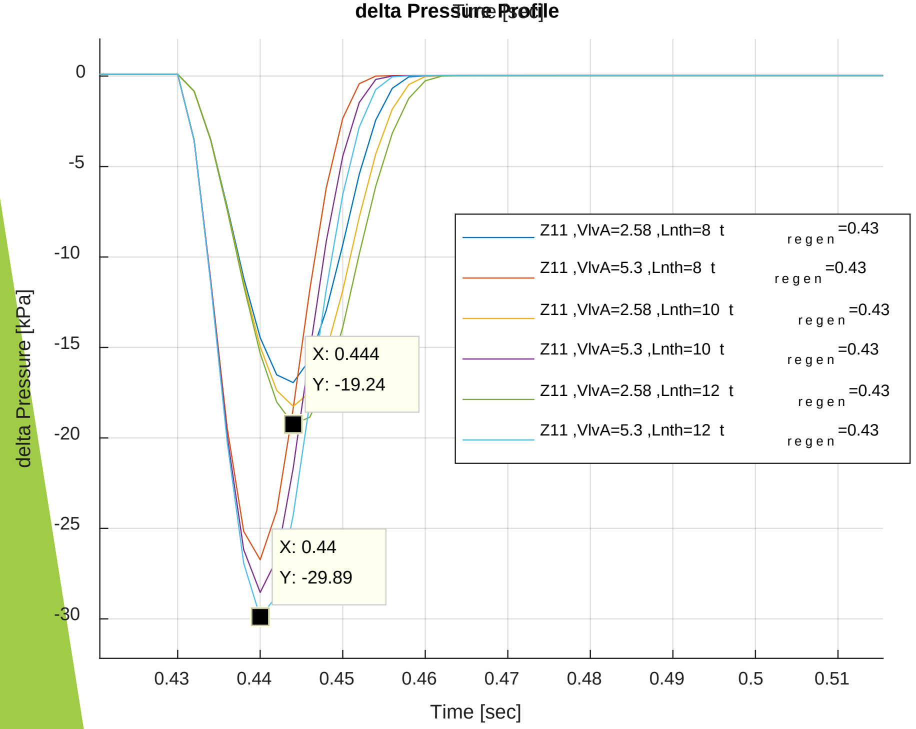
46 & 66mm Regeneration Valve Diameters

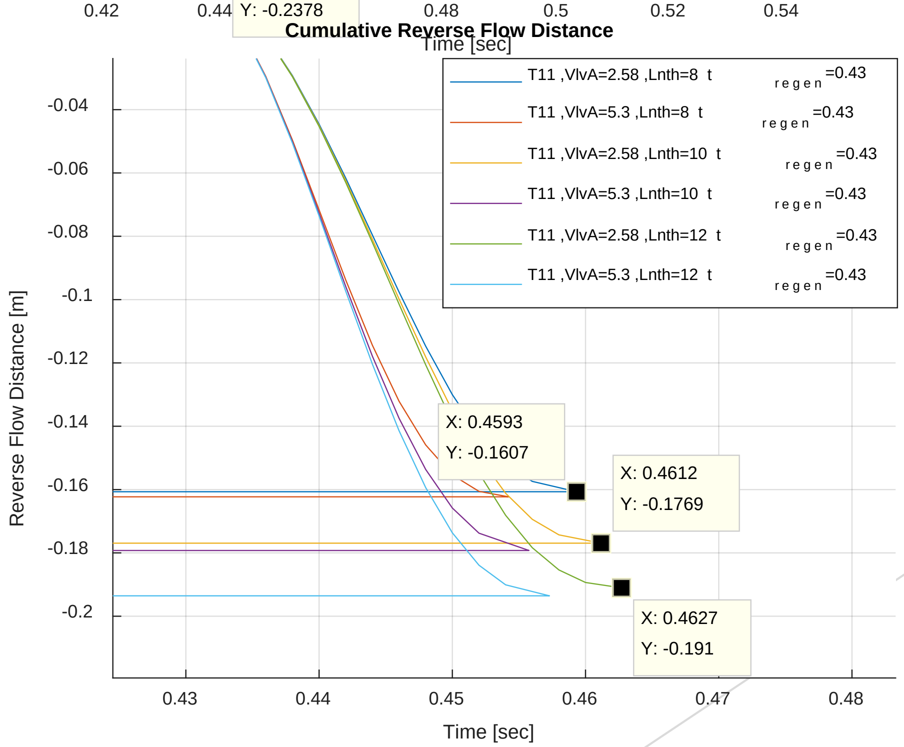
10.3L, 12.8, 15.4 (2.75, 3.4, & 4 gal) Holding Tank

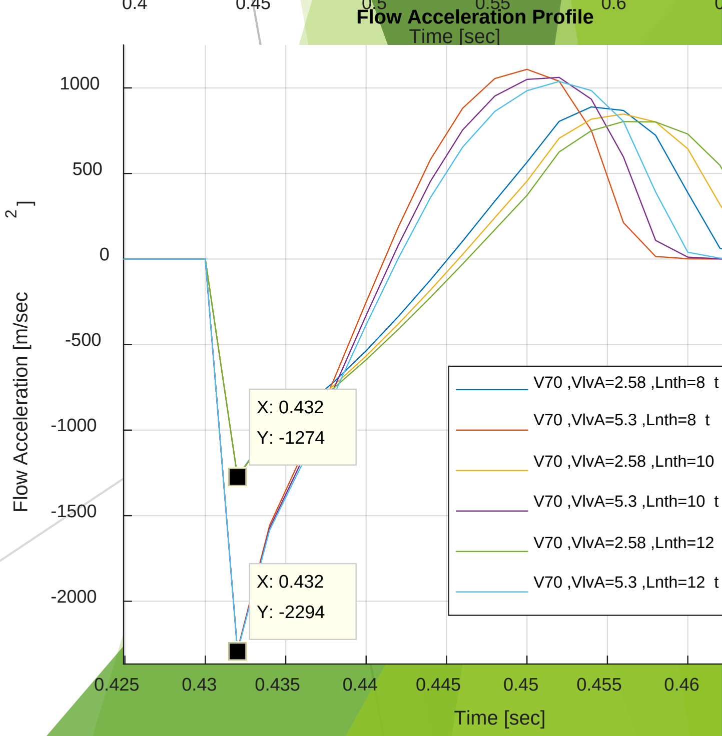

Velocity Profile
Velocity [m/sec]
Time [sec]
X: 0.446
Y: -9.85
X: 0.44
Y: -11.89
V70 ,VlvA=2.58 ,Lnth=8 t regen =0.43
V70 ,VlvA=5.3 ,Lnth=8 t regen =0.43
V70 ,VlvA=2.58 ,Lnth=10 t regen =0.43
V70 ,VlvA=5.3 ,Lnth=10 t regen =0.43
V70 ,VlvA=2.58 ,Lnth=12 t regen =0.43
V70 ,VlvA=5.3 ,Lnth=12 t regen =0.43

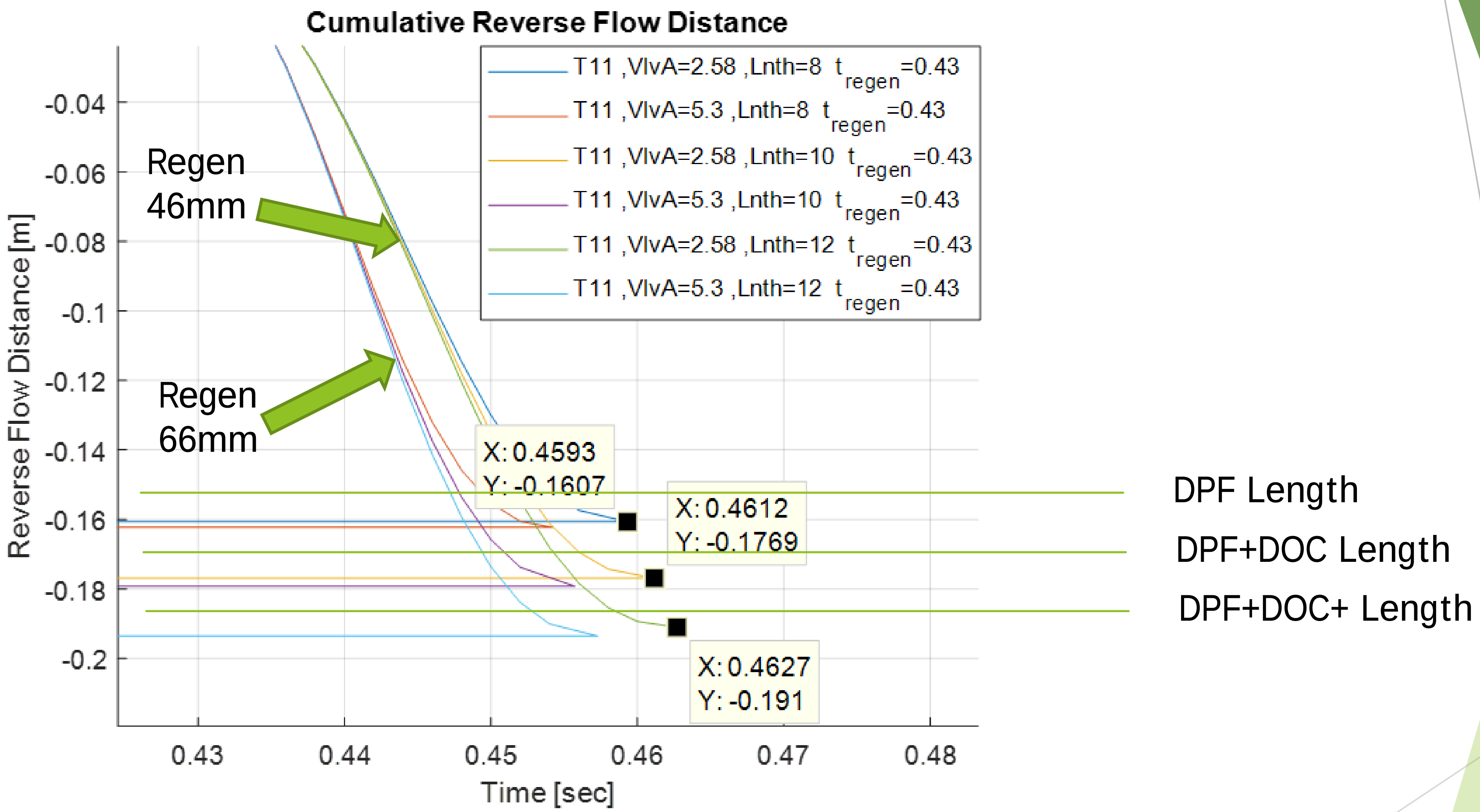

Mass Flow Rate Profile
Mass Flow Rate [kg/sec]
Time [sec]
X: 0.444
Y: -0.1924
X: 0.44
Y: -0.2378
F70 ,VlvA=2.58 ,Lnth=8 t regen =0.43
F70 ,VlvA=5.3 ,Lnth=8 t regen =0.43
F70 ,VlvA=2.58 ,Lnth=10 t regen =0.43
F70 ,VlvA=5.3 ,Lnth=10 t regen =0.43
F70 ,VlvA=2.58 ,Lnth=12 t regen =0.43
F70 ,VlvA=5.3 ,Lnth=12 t regen =0.43


Pressure Profile
Pressure [kPa]
Time [sec]
X: 0.456
Y: 170.3
X: 0.458
Y: 159.7
P3 ,VlvA=2.58 ,Lnth=8 t
P9 ,VlvA=2.58 ,Lnth=8 t
P3 ,VlvA=5.3 ,Lnth=8 t
P9 ,VlvA=5.3 ,Lnth=8 t
P3 ,VlvA=2.58 ,Lnth=10 t
P9 ,VlvA=2.58 ,Lnth=10 t
P3 ,VlvA=5.3 ,Lnth=10 t
P9 ,VlvA=5.3 ,Lnth=10 t
P3 ,VlvA=2.58 ,Lnth=12 t
P9 ,VlvA=2.58 ,Lnth=12 t
P3 ,VlvA=5.3 ,Lnth=12 t
P9 ,VlvA=5.3 ,Lnth=12 t


delta Pressure Profile
delta Pressure [kPa]
Time [sec]
X: 0.444
Y: -19.24
X: 0.44
Y: -29.89
Z11 ,VlvA=2.58 ,Lnth=8 t regen =0.43
Z11 ,VlvA=5.3 ,Lnth=8 t regen =0.43
Z11 ,VlvA=2.58 ,Lnth=10 t regen =0.43
Z11 ,VlvA=5.3 ,Lnth=10 t regen =0.43
Z11 ,VlvA=2.58 ,Lnth=12 t regen =0.43
Z11 ,VlvA=5.3 ,Lnth=12 t regen =0.43


Cumulative Reverse Flow Distance
Reverse Flow Distance [m]
Time [sec]
X: 0.4593
Y: -0.1607
X: 0.4612
Y: -0.1769
X: 0.4627
Y: -0.191
T11 ,VlvA=2.58 ,Lnth=8 t regen =0.43
T11 ,VlvA=5.3 ,Lnth=8 t regen =0.43
T11 ,VlvA=2.58 ,Lnth=10 t regen =0.43
T11 ,VlvA=5.3 ,Lnth=10 t regen =0.43
T11 ,VlvA=2.58 ,Lnth=12 t regen =0.43
T11 ,VlvA=5.3 ,Lnth=12 t regen =0.43


Flow Acceleration Profile
Flow Acceleration [m/sec 2]
Time [sec]
X: 0.432
Y: -1274
X: 0.432
Y: -2294
V70 ,VlvA=2.58 ,Lnth=8 t
V70 ,VlvA=5.3 ,Lnth=8 t
V70 ,VlvA=2.58 ,Lnth=10
V70 ,VlvA=5.3 ,Lnth=10 t
V70 ,VlvA=2.58 ,Lnth=12
V70 ,VlvA=5.3 ,Lnth=12 t



Lnth=8 – 10.3l (2.7gal) Tank

Lnth=10 – 15l (3.4 gal) Tank

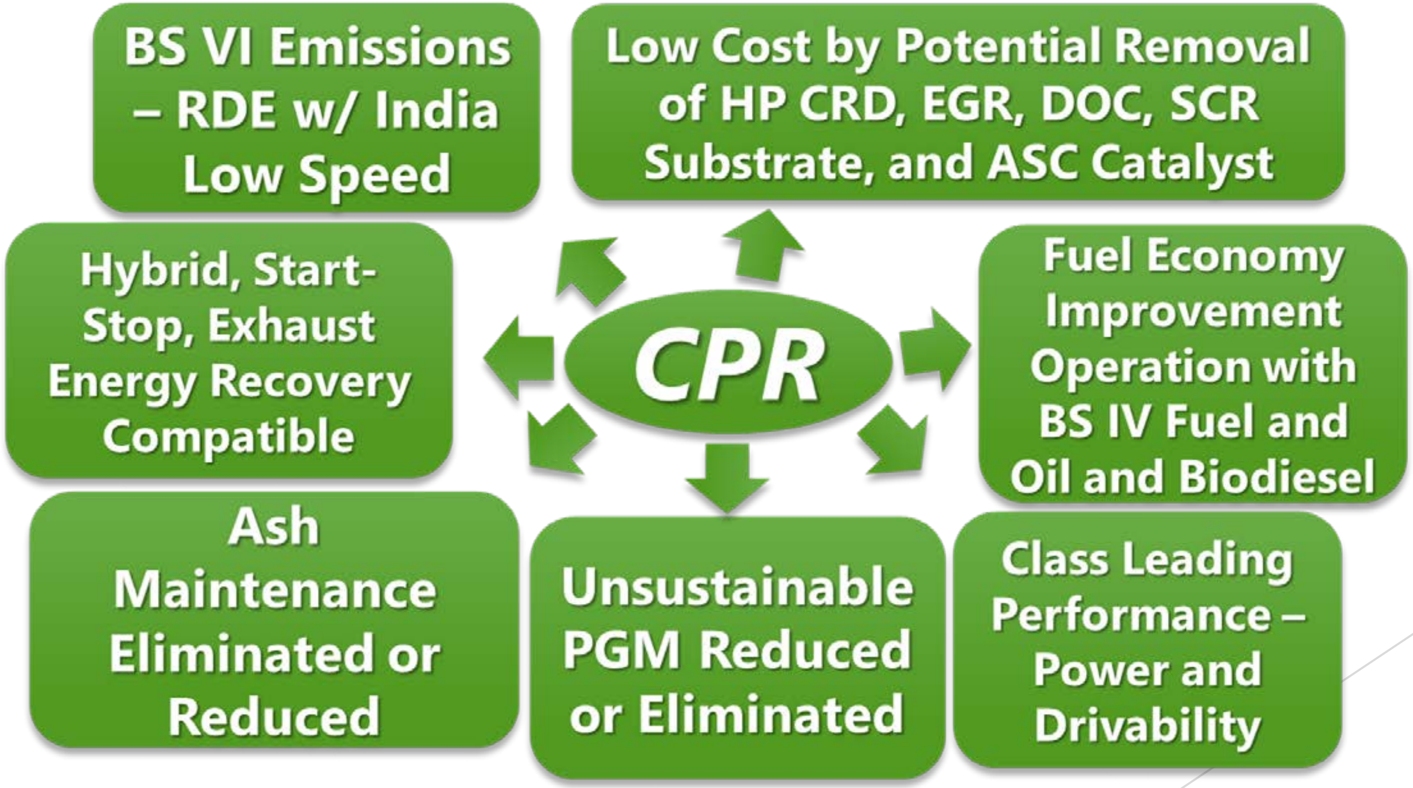
Lnth=12 – 15l (4gal) Tank

Conclusions

- **Retrofitting of millions of Volkswagen Jetta TDI and similar vehicles is possible**
  - **Power, Response, Emissions, and Efficiency can be achieved**
- **3D Modeling Demonstrating Flow Concerns**
- **1D Modeling Demonstrating Need for Reduced Translation Distance**

India Bharat VI Emissions
Opportunity for Ford Motor Company

- India is a double digit growth market for Ford. It is a cost driven market requiring simple maintenance.
- Thermal Regeneration Expected to be Challenged by Low Speeds and Start/Stop Operation of India
- Success in India Replicated in Europe and US Diesel Hybrids



Please Contact for Additional Information

Contact Information:

Brett M. Bailey

President and CEO

IVHCO

Mobile 239-284-9992

Email: brett.bailey@ivhco.com

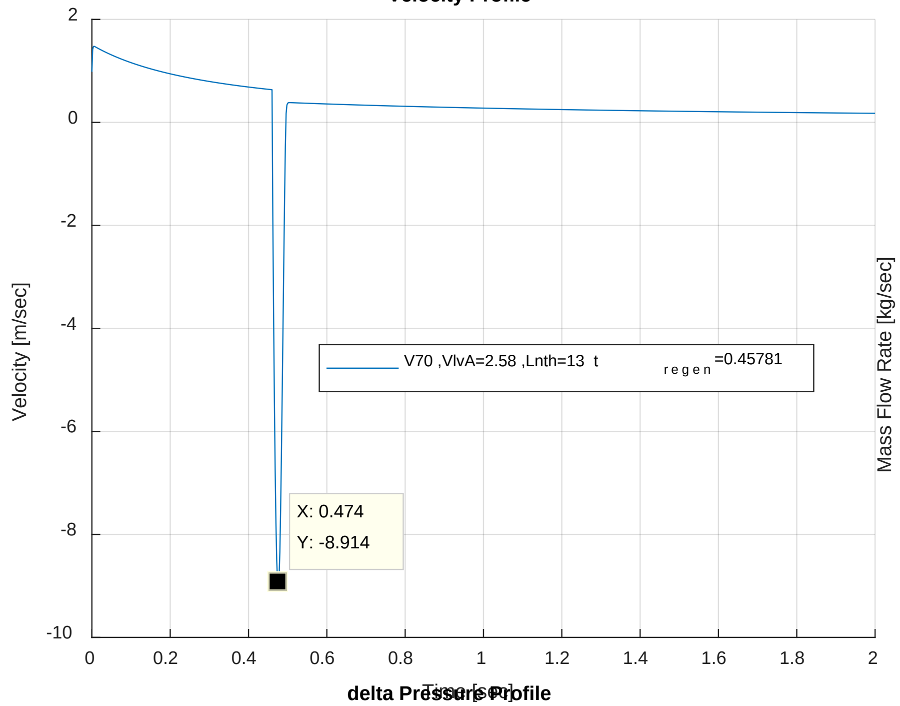
Web: www.ivhco.com

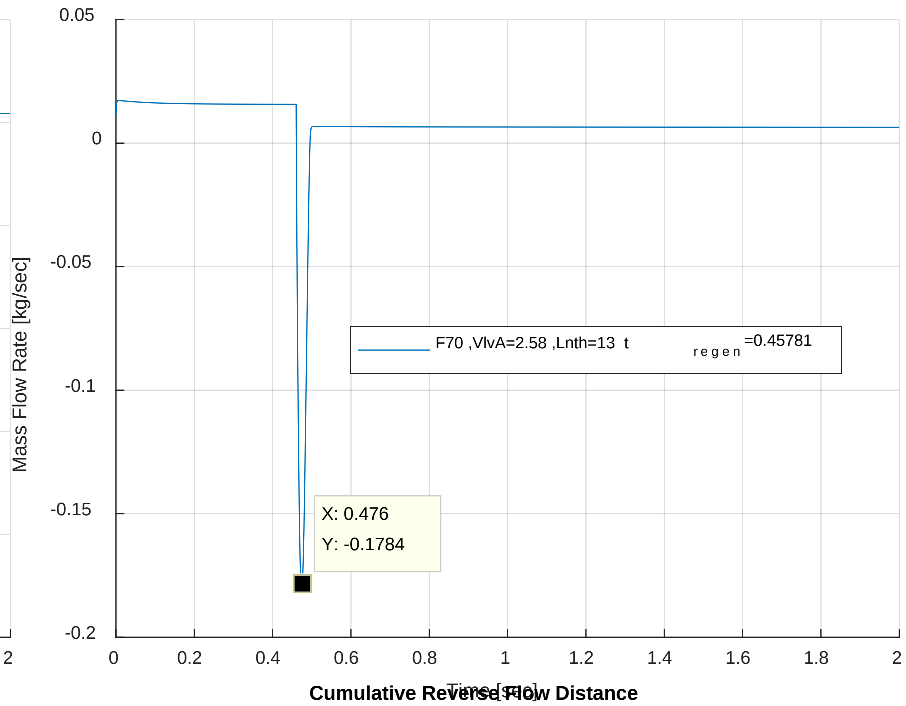
240kPa Slightly Oversized Settling Tank

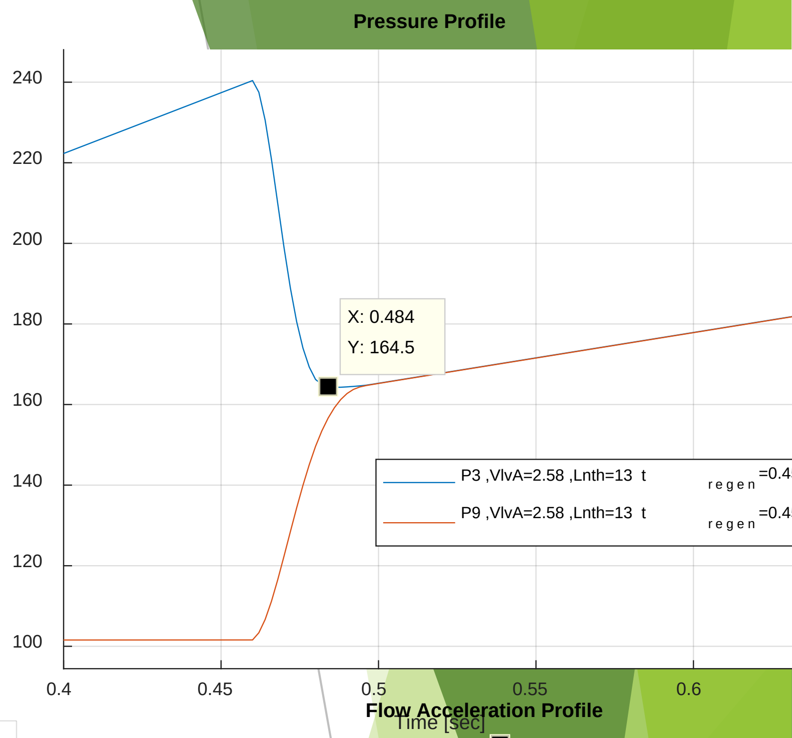
Baseline without Vacuum

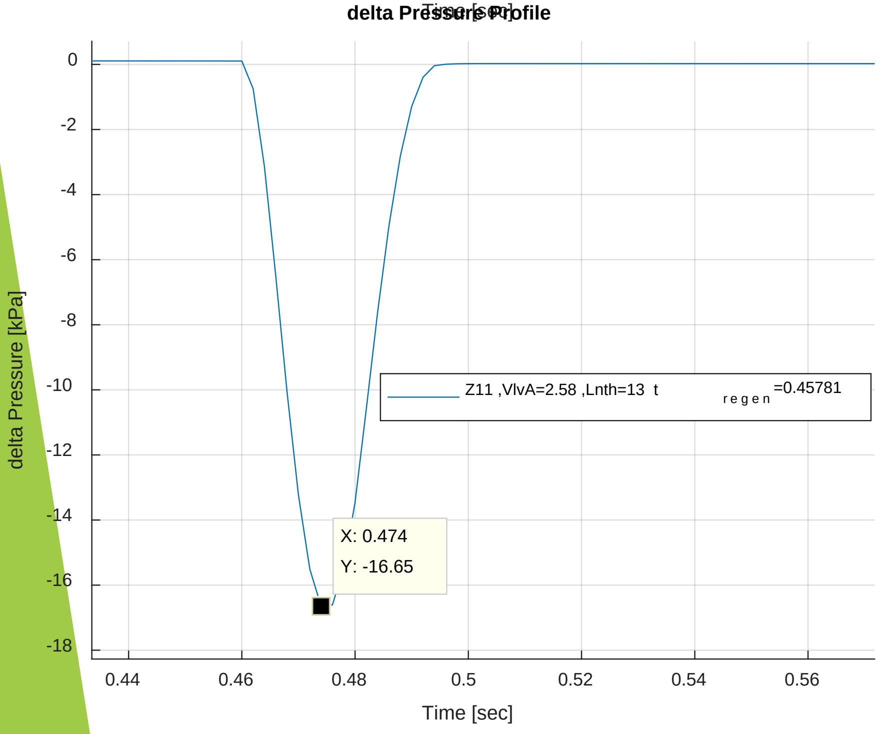
17 L (4.5 Gal) Tank

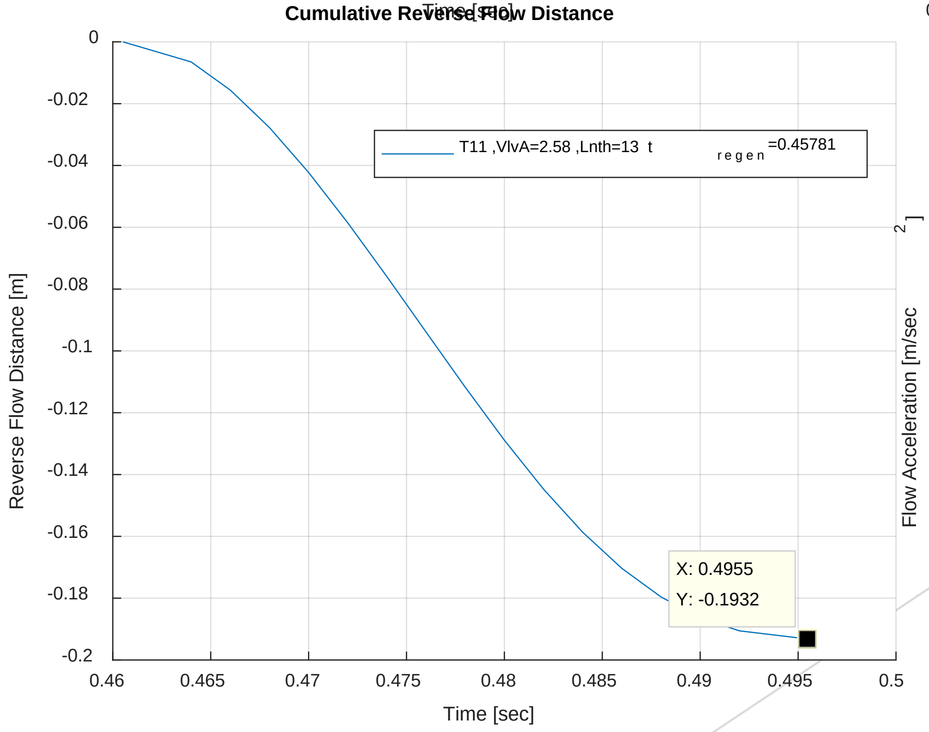
46mm Valve

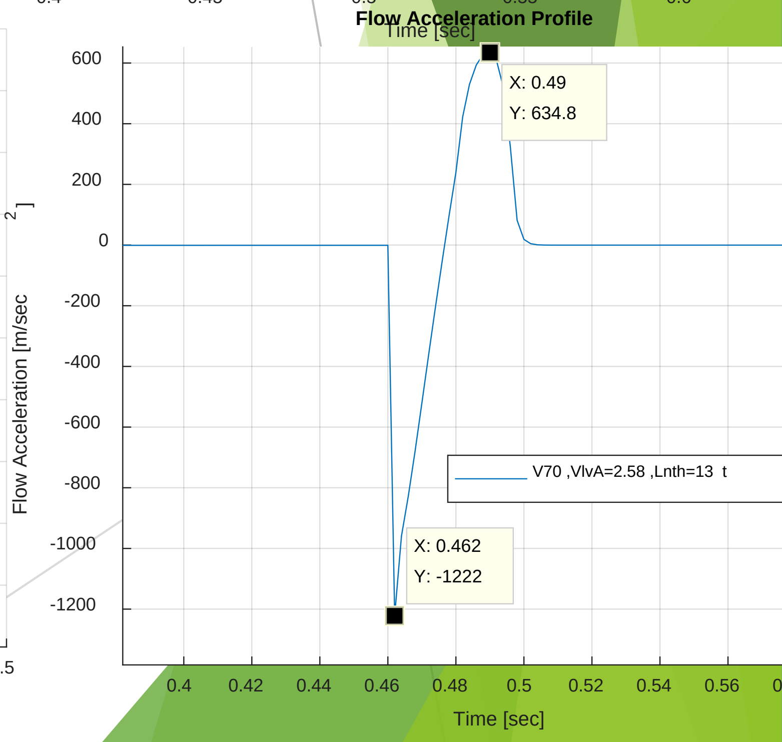

Velocity [m/sec]
Time [sec]
V70 ,VlvA=2.58 ,Lnth=13 t regen =0.45781
X: 0.474
Y: -8.914


Mass Flow Rate [kg/sec]
Time [sec]
F70 ,VlvA=2.58 ,Lnth=13 t regen =0.45781
X: 0.476
Y: -0.1784


Pressure Profile
Time [sec]
X: 0.484
Y: 164.5
P3 ,VlvA=2.58 ,Lnth=13 t regen
P9 ,VlvA=2.58 ,Lnth=13 t regen


delta Pressure Profile
delta Pressure [kPa]
Time [sec]
Z11 ,VlvA=2.58 ,Lnth=13 t regen =0.45781
X: 0.474
Y: -16.65


Cumulative Reverse Flow Distance
Reverse Flow Distance [m]
Time [sec]
T11 ,VlvA=2.58 ,Lnth=13 t regen =0.45781
X: 0.4955
Y: -0.1932


Flow Acceleration Profile
Flow Acceleration [m/sec 2]
Time [sec]
X: 0.49
Y: 634.8
V70 ,VlvA=2.58 ,Lnth=13 t
X: 0.462
Y: -1222

Demonstration of Acceptable EU Retrofit 240kPa Slightly Oversized Settling Tank Plugging of Filter and CPR Adaptability

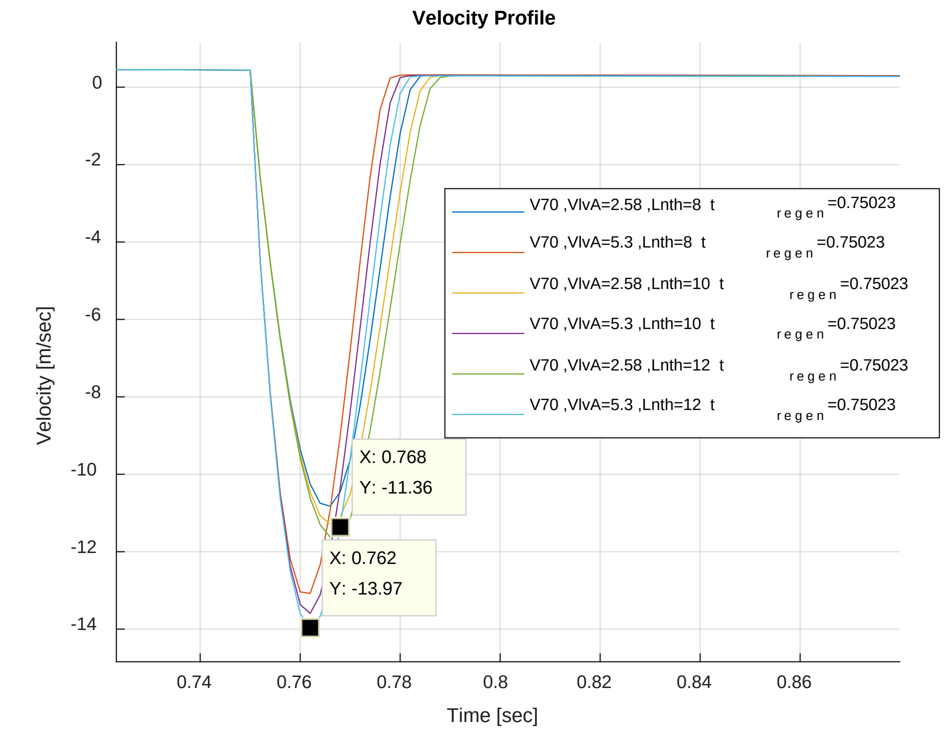
17 L (4.5 Gal) Tank

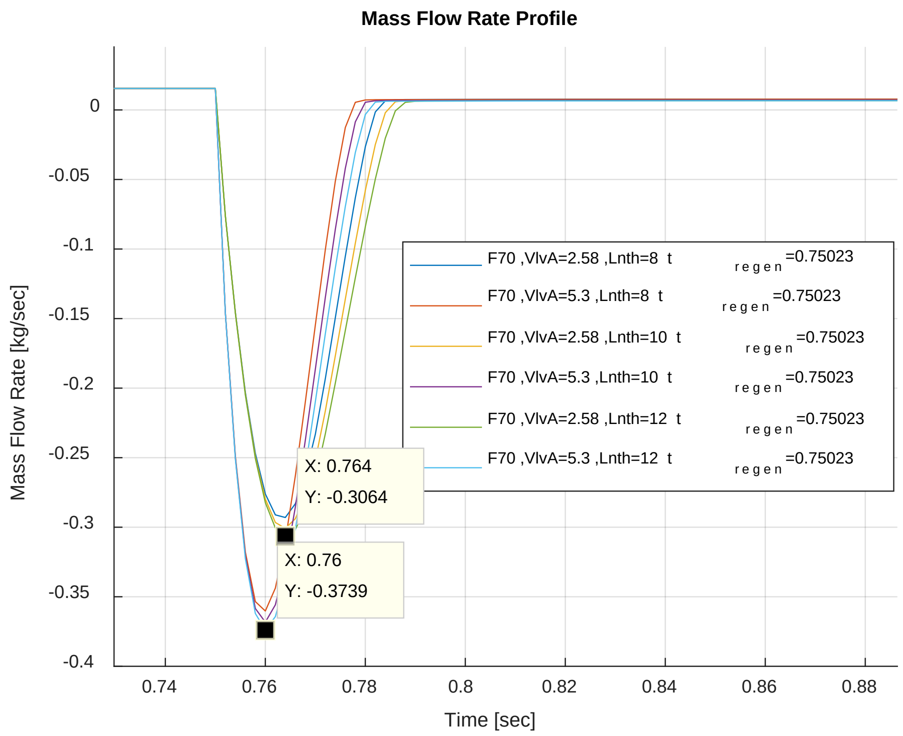
46mm Valve

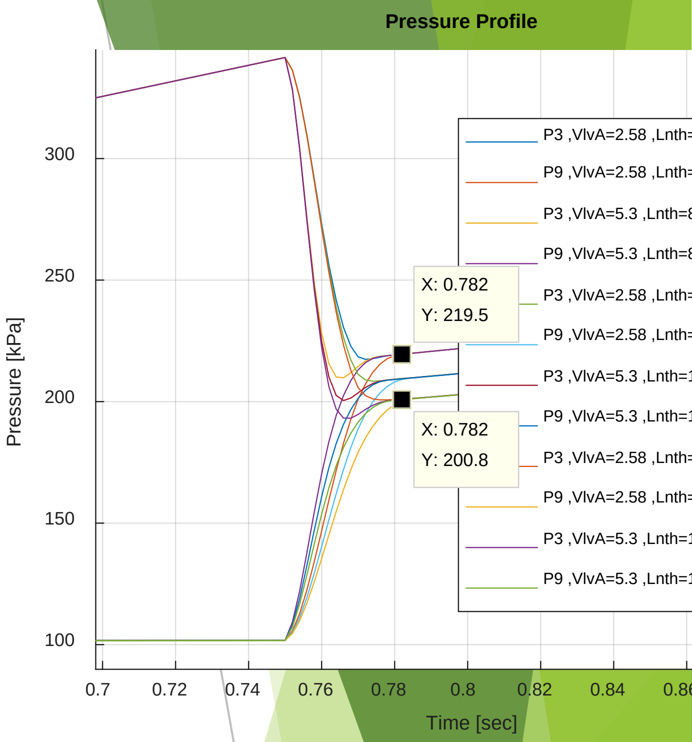
250kPa (35psi) Regen Pres

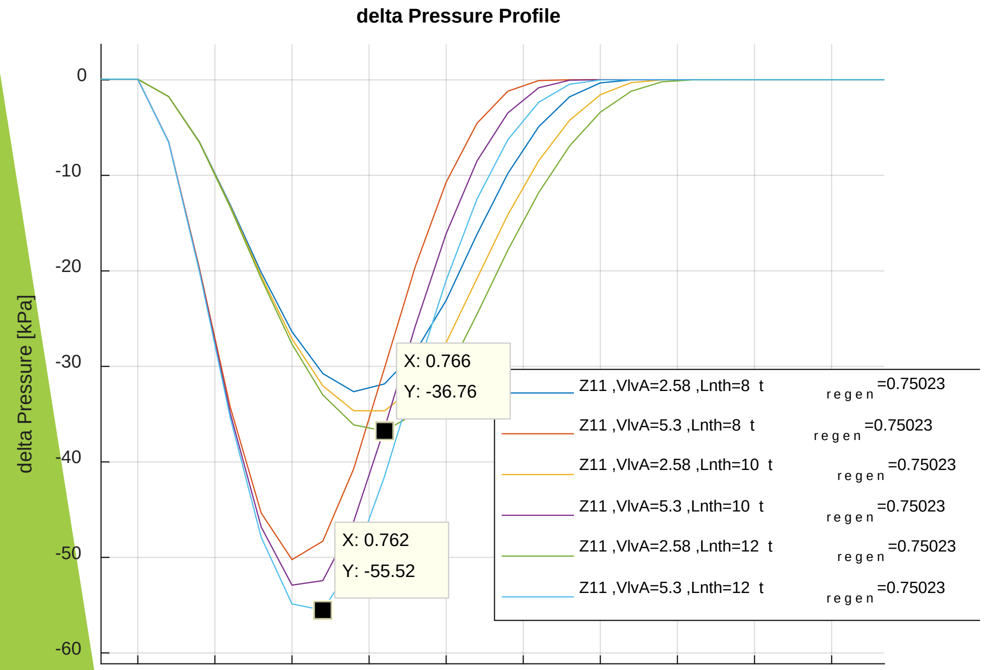
46 & 66mm Regeneration Valve Diameters

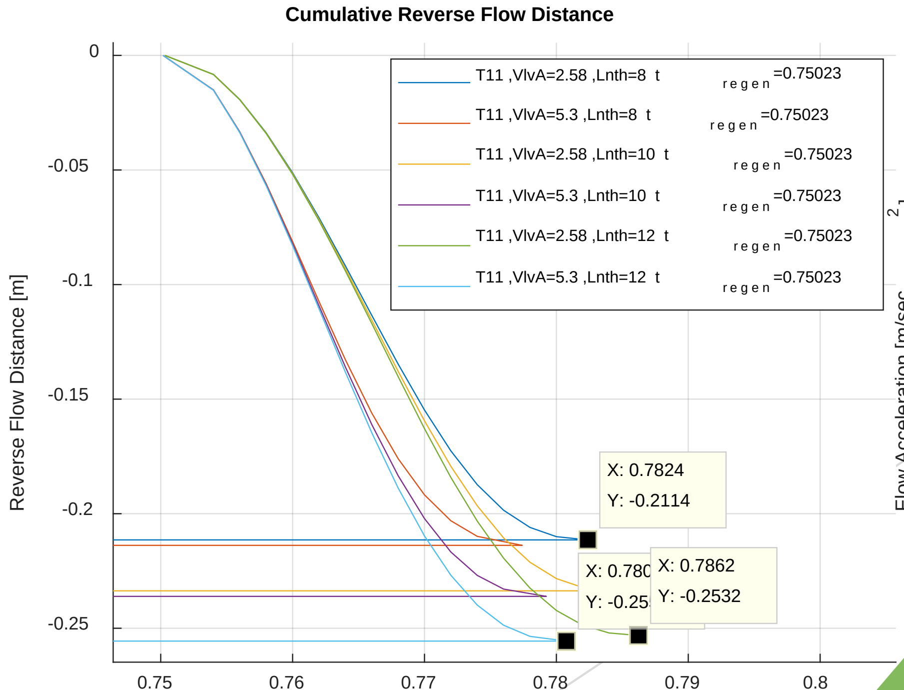
10.3L, 12.8, 15.4 (2.75, 3.4, & 4 gal) Holding Tank

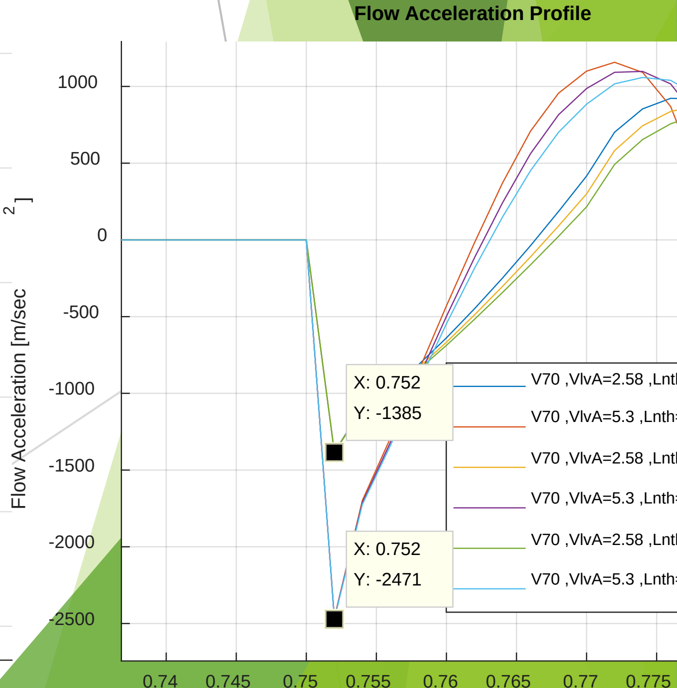

Velocity Profile
Velocity [m/sec]
Time [sec]
V70 ,VlvA=2.58 ,Lnth=8 t regen =0.75023
V70 ,VlvA=5.3 ,Lnth=8 t regen =0.75023
V70 ,VlvA=2.58 ,Lnth=10 t regen =0.75023
V70 ,VlvA=5.3 ,Lnth=10 t regen =0.75023
V70 ,VlvA=2.58 ,Lnth=12 t regen =0.75023
V70 ,VlvA=5.3 ,Lnth=12 t regen =0.75023
X: 0.768
Y: -11.36
X: 0.762
Y: -13.97


Mass Flow Rate Profile
Mass Flow Rate [kg/sec]
Time [sec]
F70 ,VlvA=2.58 ,Lnth=8 t regen =0.75023
F70 ,VlvA=5.3 ,Lnth=8 t regen =0.75023
F70 ,VlvA=2.58 ,Lnth=10 t regen =0.75023
F70 ,VlvA=5.3 ,Lnth=10 t regen =0.75023
F70 ,VlvA=2.58 ,Lnth=12 t regen =0.75023
F70 ,VlvA=5.3 ,Lnth=12 t regen =0.75023
X: 0.764
Y: -0.3064
X: 0.76
Y: -0.3739


Pressure Profile
Pressure [kPa]
Time [sec]
P3 ,VlvA=2.58 ,Lnth=
P9 ,VlvA=2.58 ,Lnth=
P3 ,VlvA=5.3 ,Lnth=8
P9 ,VlvA=5.3 ,Lnth=8
P3 ,VlvA=2.58 ,Lnth=
P9 ,VlvA=2.58 ,Lnth=
P3 ,VlvA=5.3 ,Lnth=1
P9 ,VlvA=5.3 ,Lnth=1
P3 ,VlvA=2.58 ,Lnth=
P9 ,VlvA=2.58 ,Lnth=
P3 ,VlvA=5.3 ,Lnth=1
P9 ,VlvA=5.3 ,Lnth=1
X: 0.782
Y: 219.5
X: 0.782
Y: 200.8


delta Pressure Profile
delta Pressure [kPa]
Z11 ,VlvA=2.58 ,Lnth=8 t regen =0.75023
Z11 ,VlvA=5.3 ,Lnth=8 t regen =0.75023
Z11 ,VlvA=2.58 ,Lnth=10 t regen =0.75023
Z11 ,VlvA=5.3 ,Lnth=10 t regen =0.75023
Z11 ,VlvA=2.58 ,Lnth=12 t regen =0.75023
Z11 ,VlvA=5.3 ,Lnth=12 t regen =0.75023
X: 0.766
Y: -36.76
X: 0.762
Y: -55.52

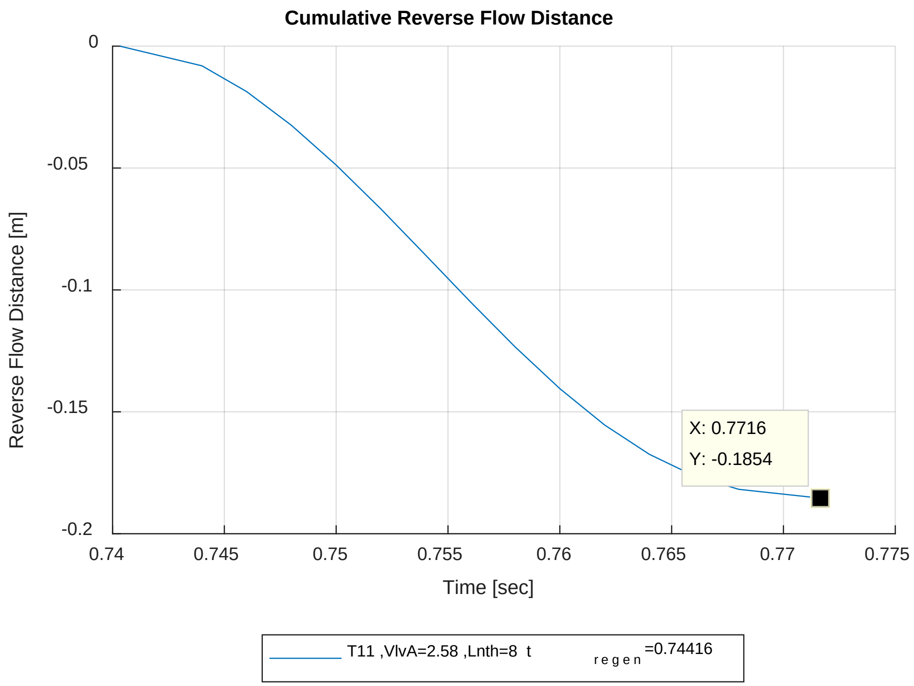

Cumulative Reverse Flow Distance
Reverse Flow Distance [m]
T11 ,VlvA=2.58 ,Lnth=8 t regen =0.75023
T11 ,VlvA=5.3 ,Lnth=8 t regen =0.75023
T11 ,VlvA=2.58 ,Lnth=10 t regen =0.75023
T11 ,VlvA=5.3 ,Lnth=10 t regen =0.75023
T11 ,VlvA=2.58 ,Lnth=12 t regen =0.75023
T11 ,VlvA=5.3 ,Lnth=12 t regen =0.75023
X: 0.7824
Y: -0.2114
X: 0.7862
Y: -0.2532

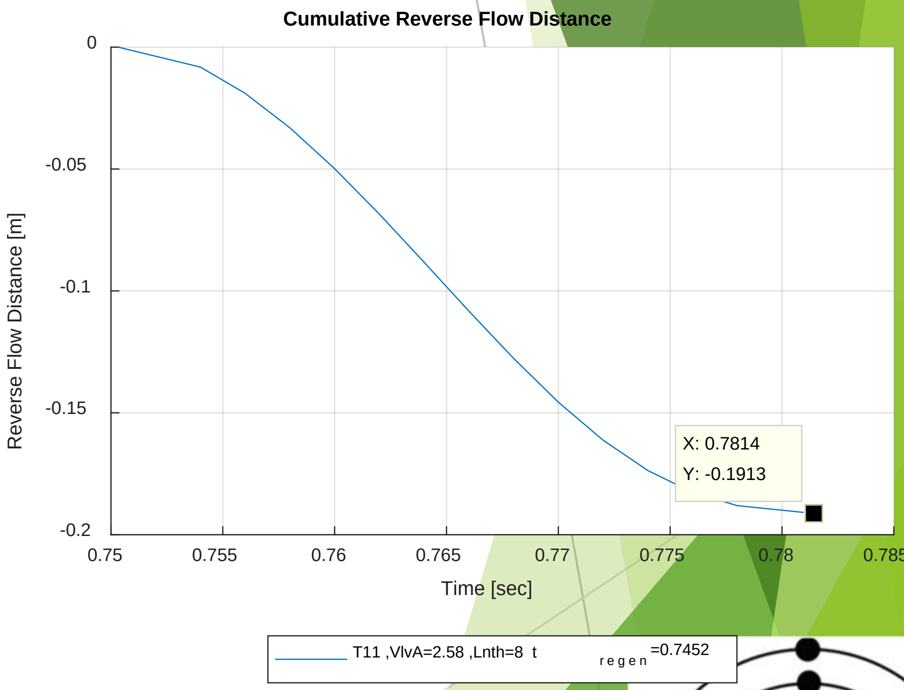

Flow Acceleration Profile
Flow Acceleration [m/sec 2]
V70 ,VlvA=2.58 ,Lnt
V70 ,VlvA=5.3 ,Lnth
V70 ,VlvA=2.58 ,Lnt
V70 ,VlvA=5.3 ,Lnth
V70 ,VlvA=2.58 ,Lnt
V70 ,VlvA=5.3 ,Lnth
X: 0.752
Y: -1385
X: 0.752
Y: -2471

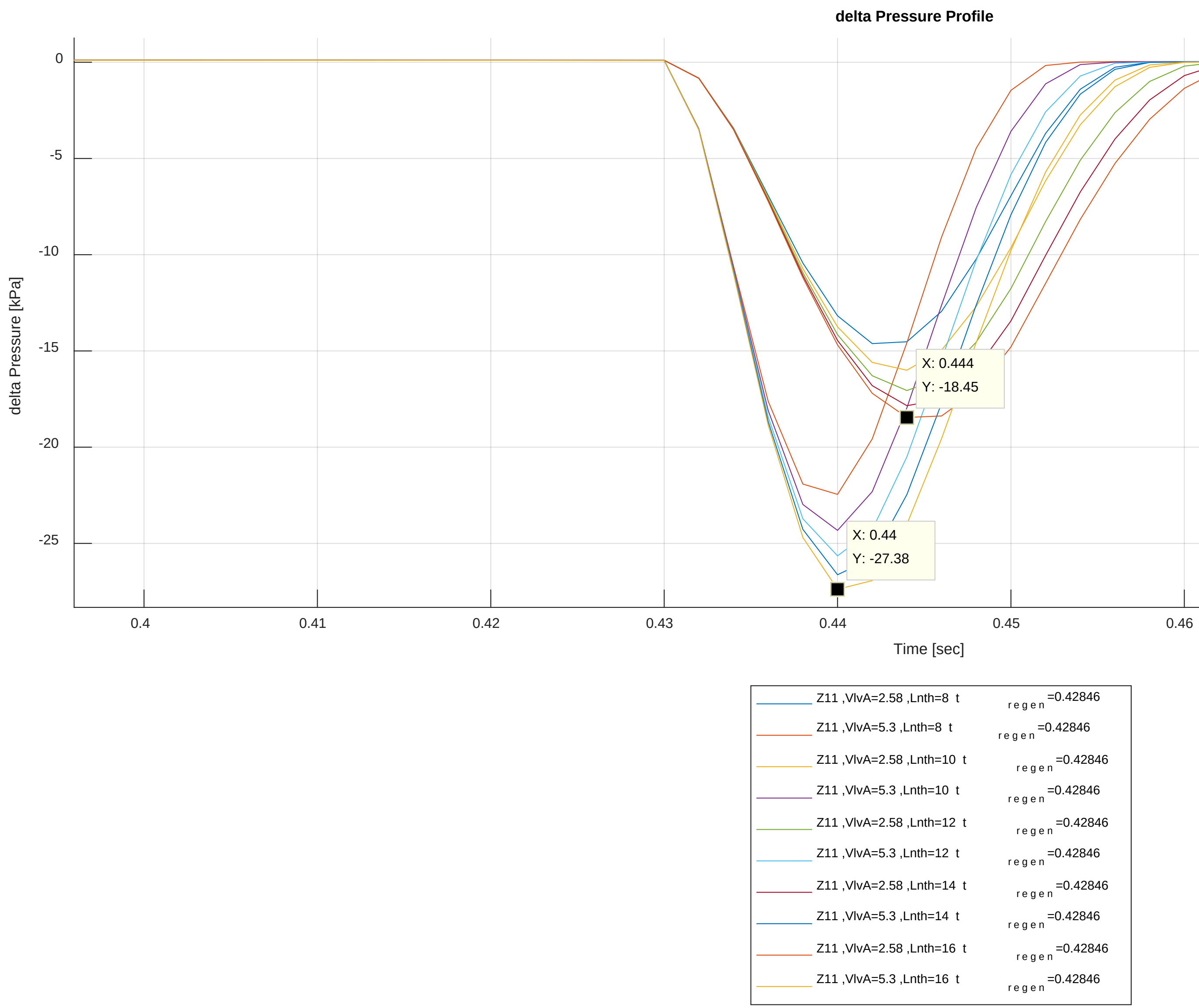
250kPa (35psi) Regen Pres

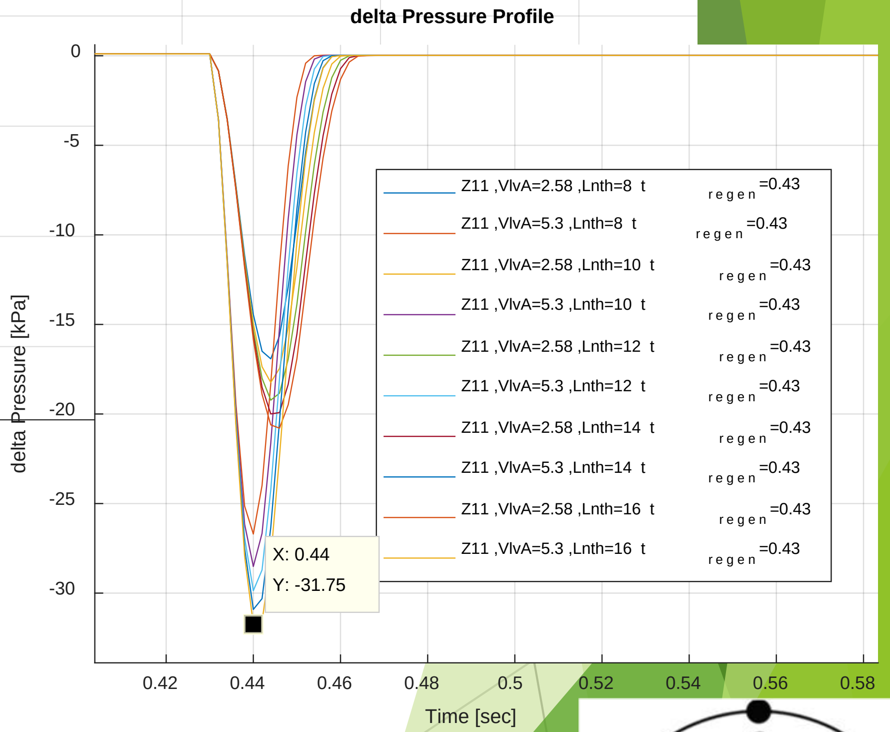
46 & 66mm Regeneration Valve Diameters

10.3L, 12.8, 15.4 (2.75, 3.4, & 4 gal) Holding Tank

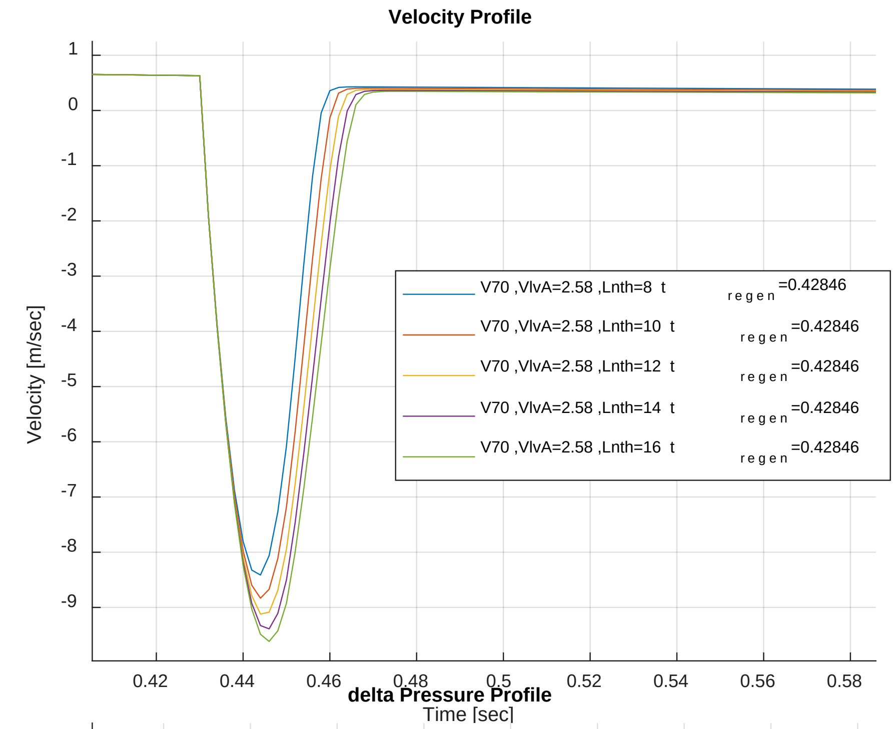

Cumulative Reverse Flow Distance
Reverse Flow Distance [m]
Time [sec]
X: 0.7716
Y: -0.1854
0
-0.05
-0.1
-0.15
-0.2
0.74
0.745
0.75
0.755
0.76
0.765
0.77
0.775
T11 ,VlvA=2.58 ,Lnth=8 t regen =0.74416

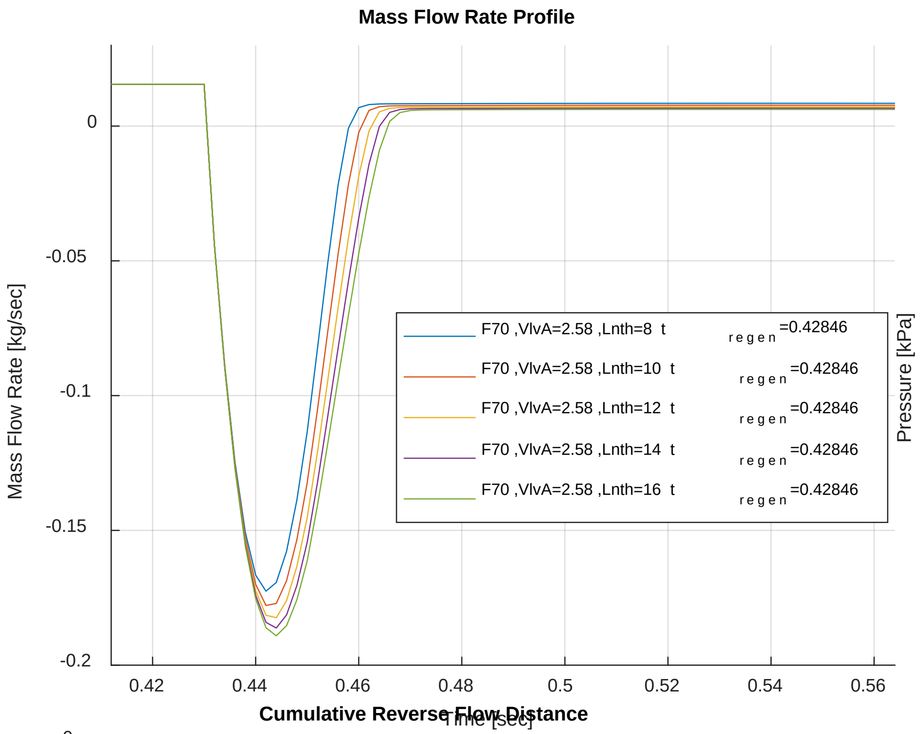

Cumulative Reverse Flow Distance
Reverse Flow Distance [m]
Time [sec]
X: 0.7814
Y: -0.1913
0
-0.05
-0.1
-0.15
-0.2
0.75
0.755
0.76
0.765
0.77
0.775
0.78
0.785
T11 ,VlvA=2.58 ,Lnth=8 t regen =0.7452

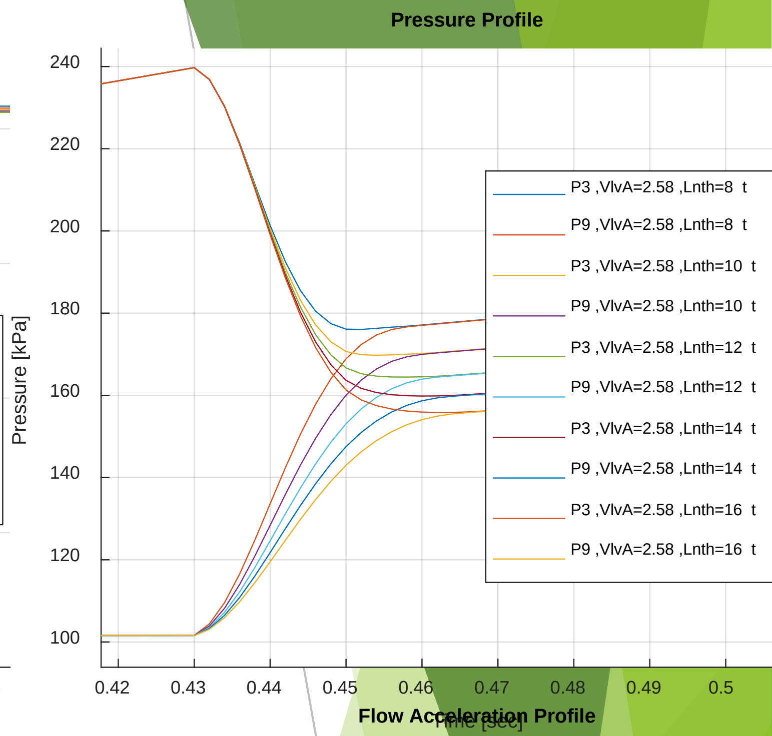


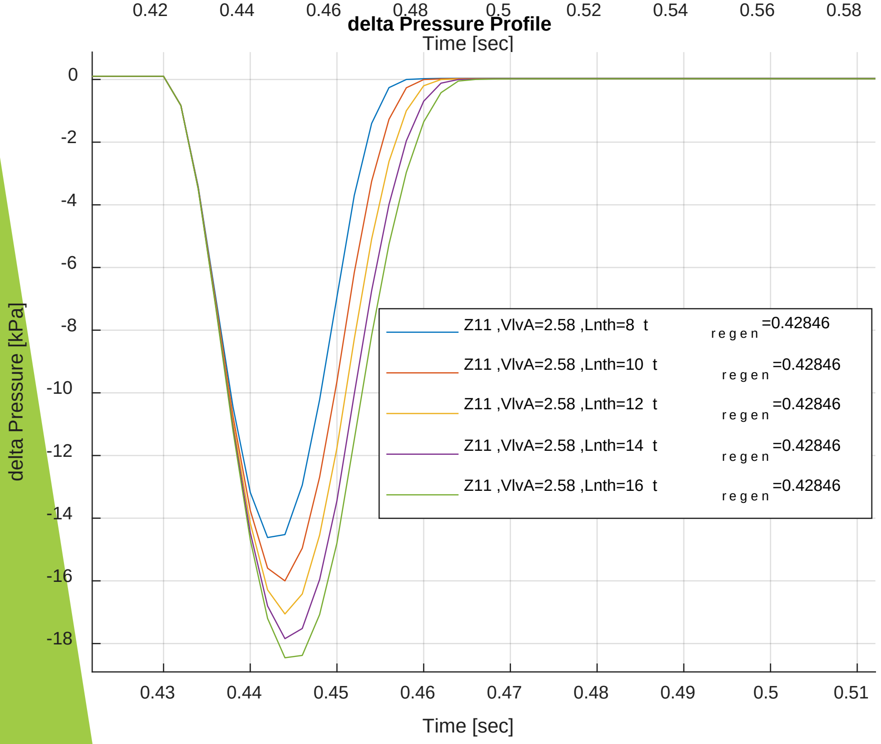


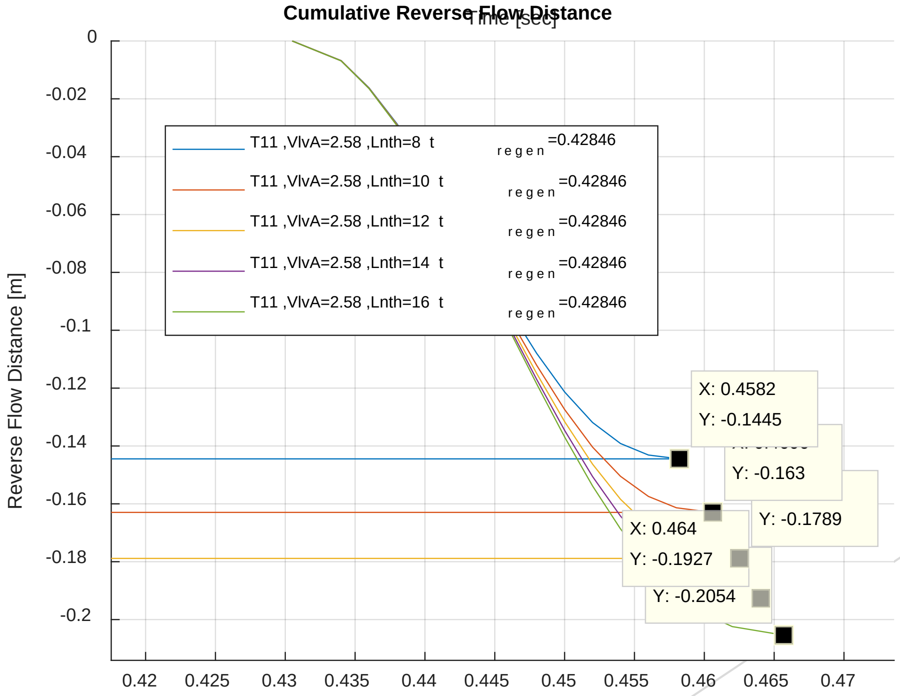
GLOBAL CLEAN DIESEL

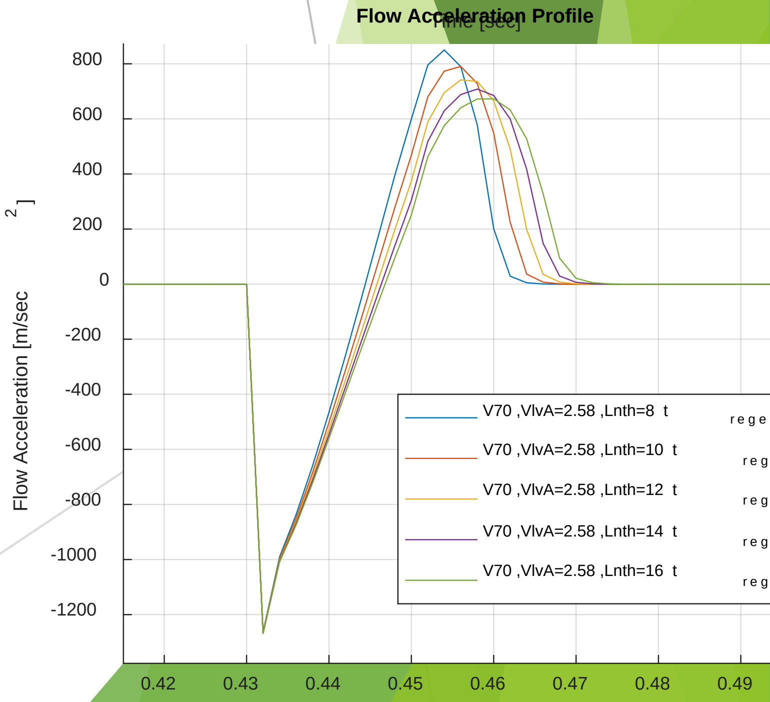

Velocity Profile
Velocity [m/sec]
Time [sec]
V70 ,VlvA=2.58 ,Lnth=8 t regen =0.42846
V70 ,VlvA=2.58 ,Lnth=10 t regen =0.42846
V70 ,VlvA=2.58 ,Lnth=12 t regen =0.42846
V70 ,VlvA=2.58 ,Lnth=14 t regen =0.42846
V70 ,VlvA=2.58 ,Lnth=16 t regen =0.42846


Mass Flow Rate Profile
Mass Flow Rate [kg/sec]
Time [sec]
F70 ,VlvA=2.58 ,Lnth=8 t regen =0.42846
F70 ,VlvA=2.58 ,Lnth=10 t regen =0.42846
F70 ,VlvA=2.58 ,Lnth=12 t regen =0.42846
F70 ,VlvA=2.58 ,Lnth=14 t regen =0.42846
F70 ,VlvA=2.58 ,Lnth=16 t regen =0.42846


Pressure Profile
Pressure [kPa]
P3 ,VlvA=2.58 ,Lnth=8 t
P9 ,VlvA=2.58 ,Lnth=8 t
P3 ,VlvA=2.58 ,Lnth=10 t
P9 ,VlvA=2.58 ,Lnth=10 t
P3 ,VlvA=2.58 ,Lnth=12 t
P9 ,VlvA=2.58 ,Lnth=12 t
P3 ,VlvA=2.58 ,Lnth=14 t
P9 ,VlvA=2.58 ,Lnth=14 t
P3 ,VlvA=2.58 ,Lnth=16 t
P9 ,VlvA=2.58 ,Lnth=16 t


delta Pressure Profile
delta Pressure [kPa]
Time [sec]
Z11 ,VlvA=2.58 ,Lnth=8 t regen =0.42846
Z11 ,VlvA=2.58 ,Lnth=10 t regen =0.42846
Z11 ,VlvA=2.58 ,Lnth=12 t regen =0.42846
Z11 ,VlvA=2.58 ,Lnth=14 t regen =0.42846
Z11 ,VlvA=2.58 ,Lnth=16 t regen =0.42846

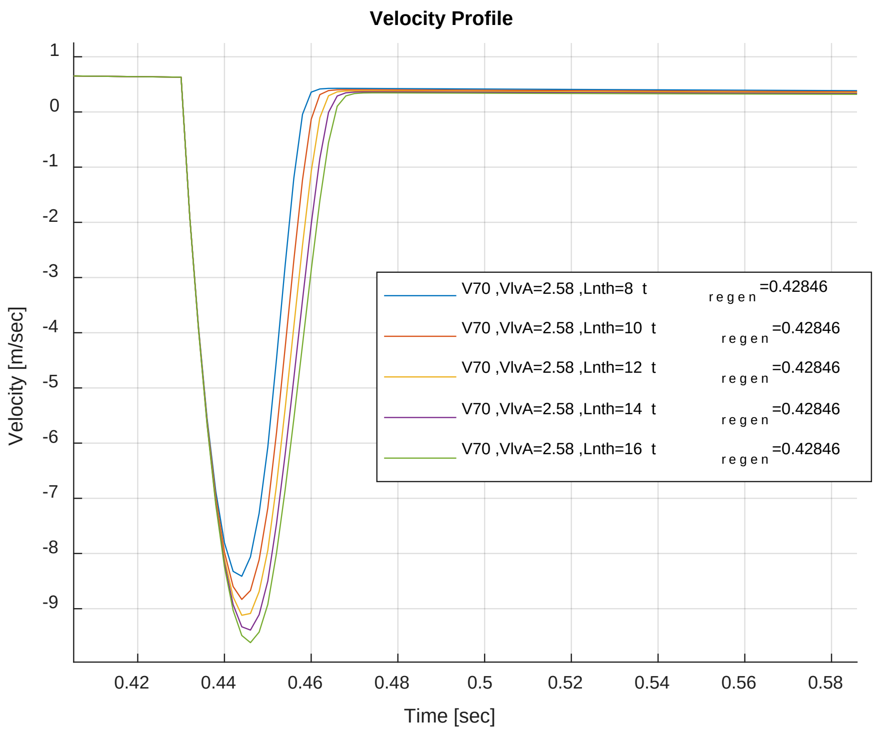

Cumulative Reverse Flow Distance
Reverse Flow Distance [m]
T11 ,VlvA=2.58 ,Lnth=8 t regen =0.42846
T11 ,VlvA=2.58 ,Lnth=10 t regen =0.42846
T11 ,VlvA=2.58 ,Lnth=12 t regen =0.42846
T11 ,VlvA=2.58 ,Lnth=14 t regen =0.42846
T11 ,VlvA=2.58 ,Lnth=16 t regen =0.42846
X: 0.4582
Y: -0.1445
Y: -0.163
Y: -0.1789
X: 0.464
Y: -0.1927
Y: -0.2054

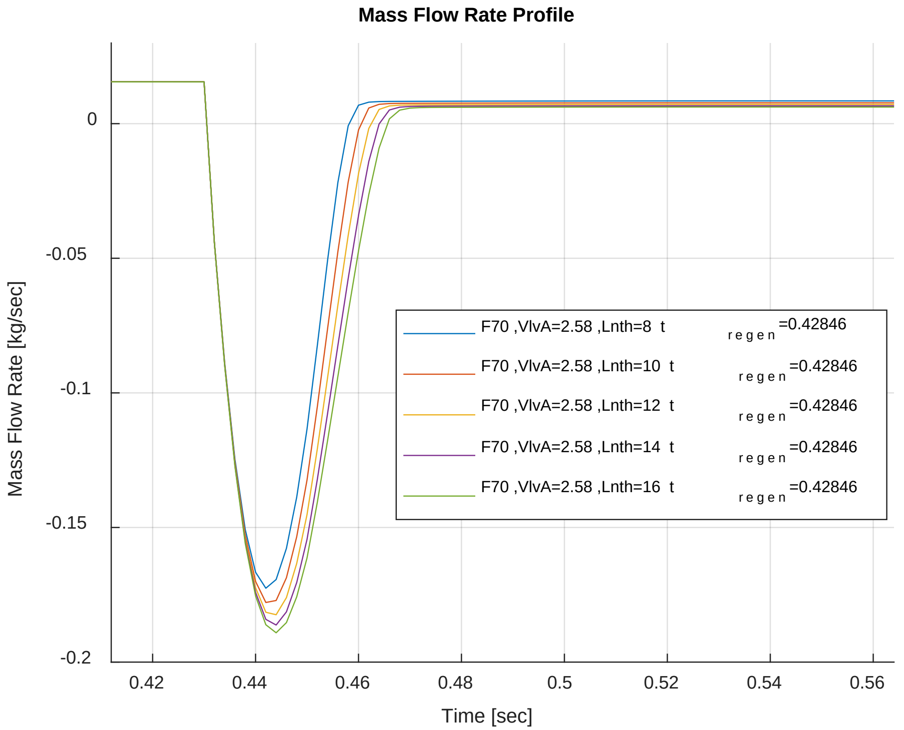

Flow Acceleration Profile
Flow Acceleration [m/sec 2]
V70 ,VlvA=2.58 ,Lnth=8 t
V70 ,VlvA=2.58 ,Lnth=10 t
V70 ,VlvA=2.58 ,Lnth=12 t
V70 ,VlvA=2.58 ,Lnth=14 t
V70 ,VlvA=2.58 ,Lnth=16 t

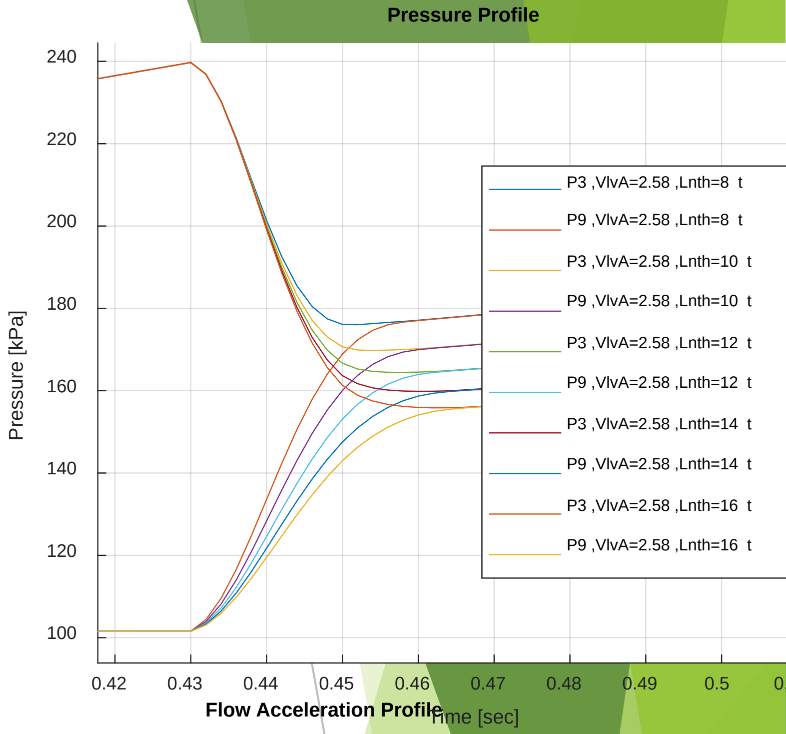
240kPa Regen Press

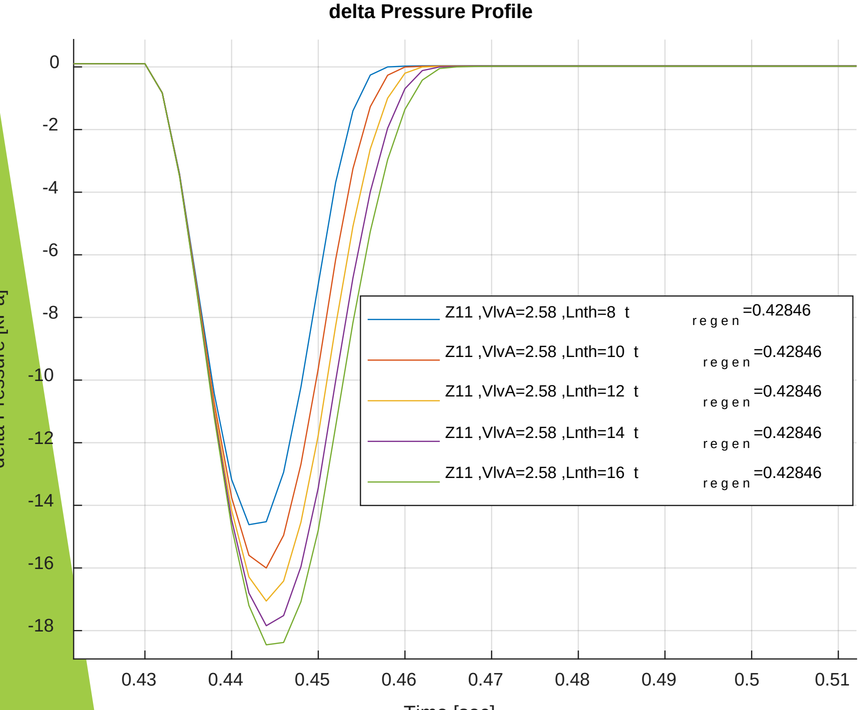
46mm Regen Valve Dia

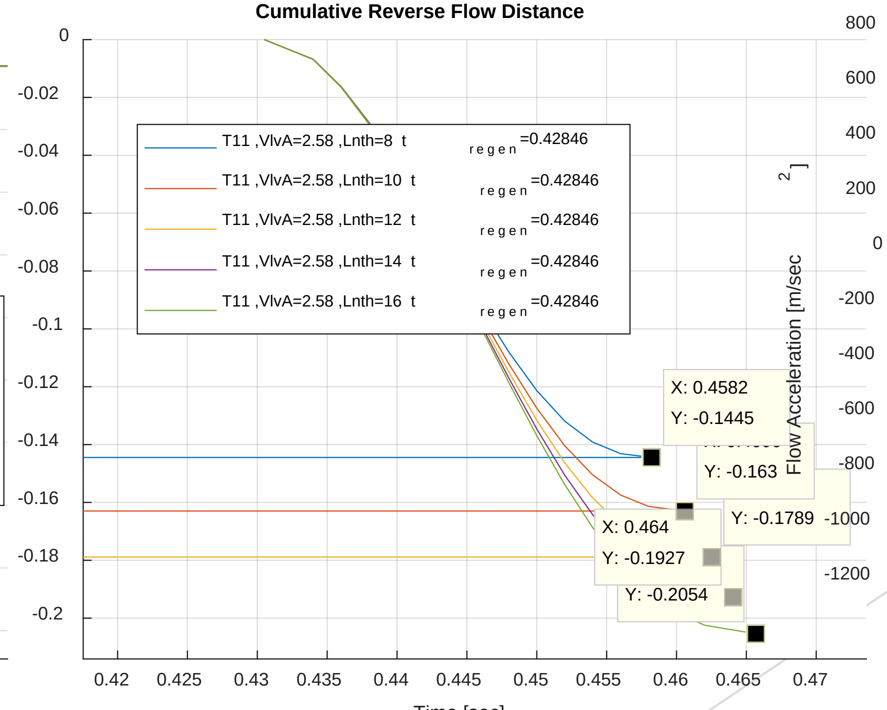
Parametric Study of Settling tank Size

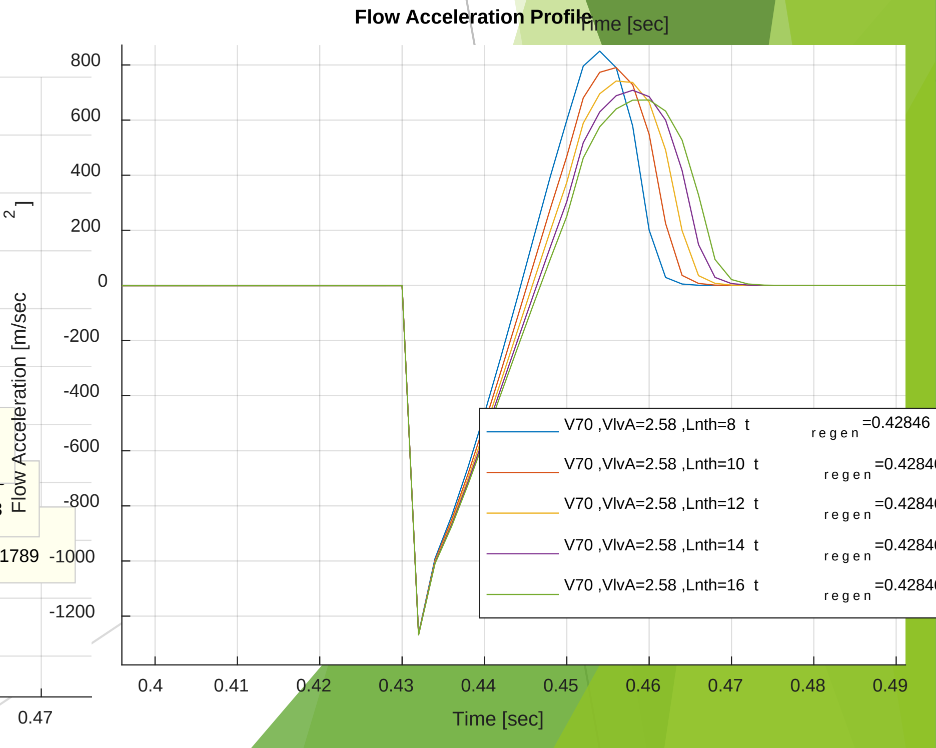

Velocity Profile
Velocity [m/sec]
Time [sec]
V70 ,VlvA=2.58 ,Lnth=8 t regen =0.42846
V70 ,VlvA=2.58 ,Lnth=10 t regen =0.42846
V70 ,VlvA=2.58 ,Lnth=12 t regen =0.42846
V70 ,VlvA=2.58 ,Lnth=14 t regen =0.42846
V70 ,VlvA=2.58 ,Lnth=16 t regen =0.42846


Mass Flow Rate Profile
Mass Flow Rate [kg/sec]
Time [sec]
F70 ,VlvA=2.58 ,Lnth=8 t regen =0.42846
F70 ,VlvA=2.58 ,Lnth=10 t regen =0.42846
F70 ,VlvA=2.58 ,Lnth=12 t regen =0.42846
F70 ,VlvA=2.58 ,Lnth=14 t regen =0.42846
F70 ,VlvA=2.58 ,Lnth=16 t regen =0.42846

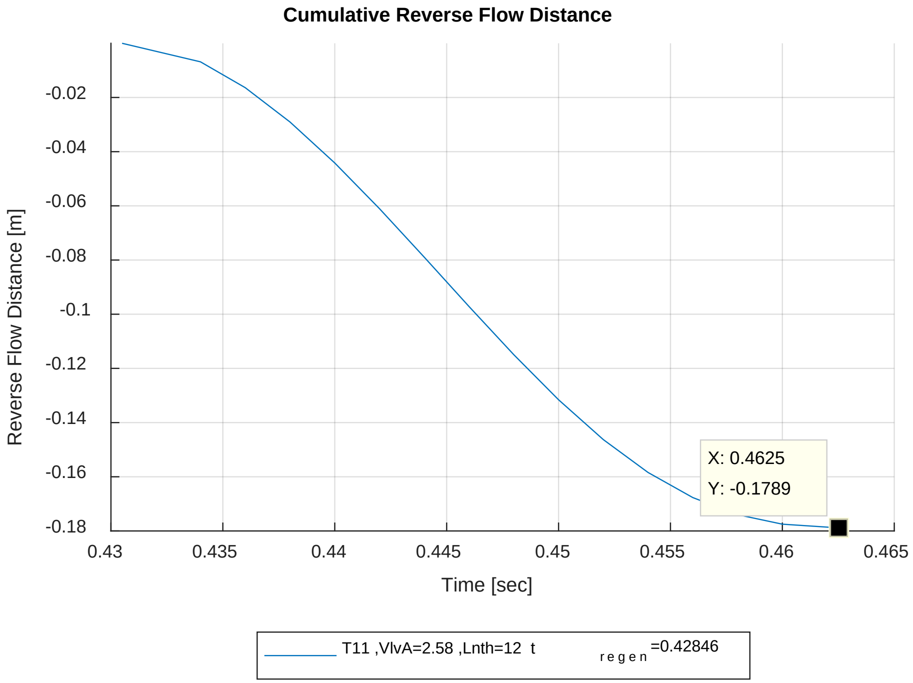

Pressure Profile
Pressure [kPa]
Time [sec]
P3 ,VlvA=2.58 ,Lnth=8 t
P9 ,VlvA=2.58 ,Lnth=8 t
P3 ,VlvA=2.58 ,Lnth=10 t
P9 ,VlvA=2.58 ,Lnth=10 t
P3 ,VlvA=2.58 ,Lnth=12 t
P9 ,VlvA=2.58 ,Lnth=12 t
P3 ,VlvA=2.58 ,Lnth=14 t
P9 ,VlvA=2.58 ,Lnth=14 t
P3 ,VlvA=2.58 ,Lnth=16 t
P9 ,VlvA=2.58 ,Lnth=16 t

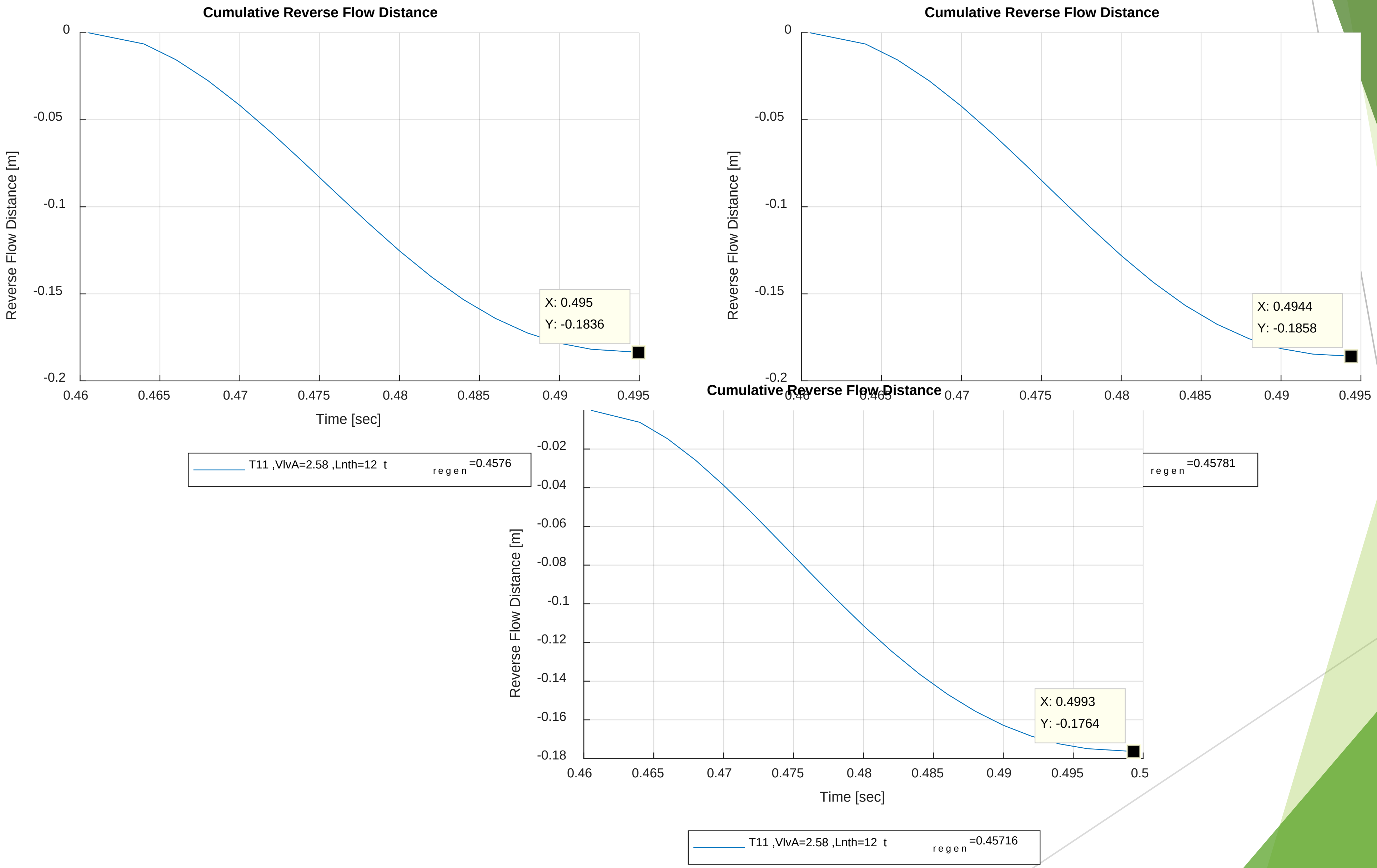

delta Pressure Profile
Z11 ,VlvA=2.58 ,Lnth=8 t regen =0.42846
Z11 ,VlvA=2.58 ,Lnth=10 t regen =0.42846
Z11 ,VlvA=2.58 ,Lnth=12 t regen =0.42846
Z11 ,VlvA=2.58 ,Lnth=14 t regen =0.42846
Z11 ,VlvA=2.58 ,Lnth=16 t regen =0.42846

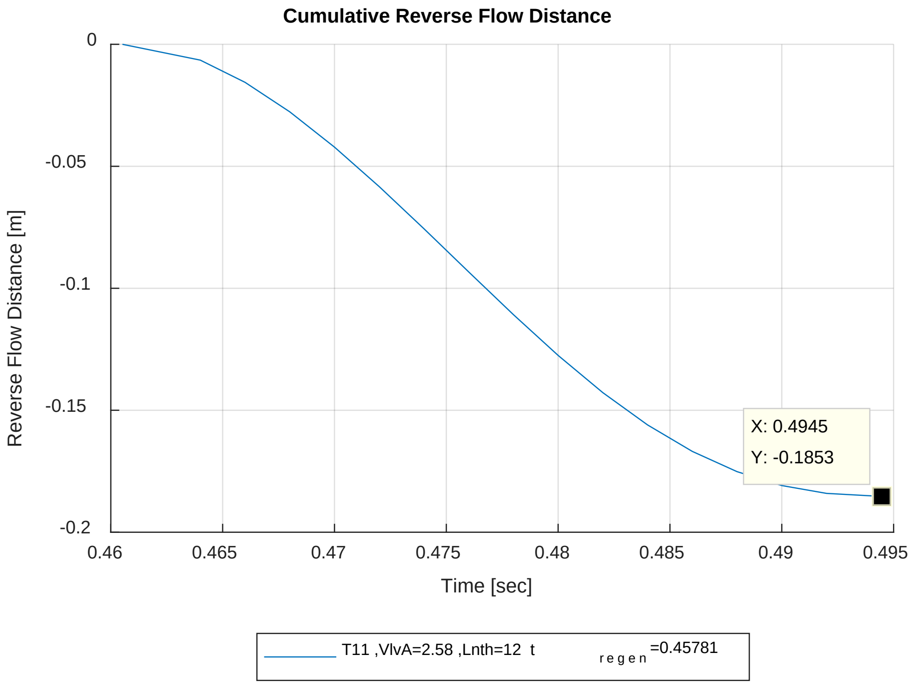

Cumulative Reverse Flow Distance
T11 ,VlvA=2.58 ,Lnth=8 t regen =0.42846
T11 ,VlvA=2.58 ,Lnth=10 t regen =0.42846
T11 ,VlvA=2.58 ,Lnth=12 t regen =0.42846
T11 ,VlvA=2.58 ,Lnth=14 t regen =0.42846
T11 ,VlvA=2.58 ,Lnth=16 t regen =0.42846
X: 0.4582
Y: -0.1445
Y: -0.163
Y: -0.1789
X: 0.464
Y: -0.1927
Y: -0.2054

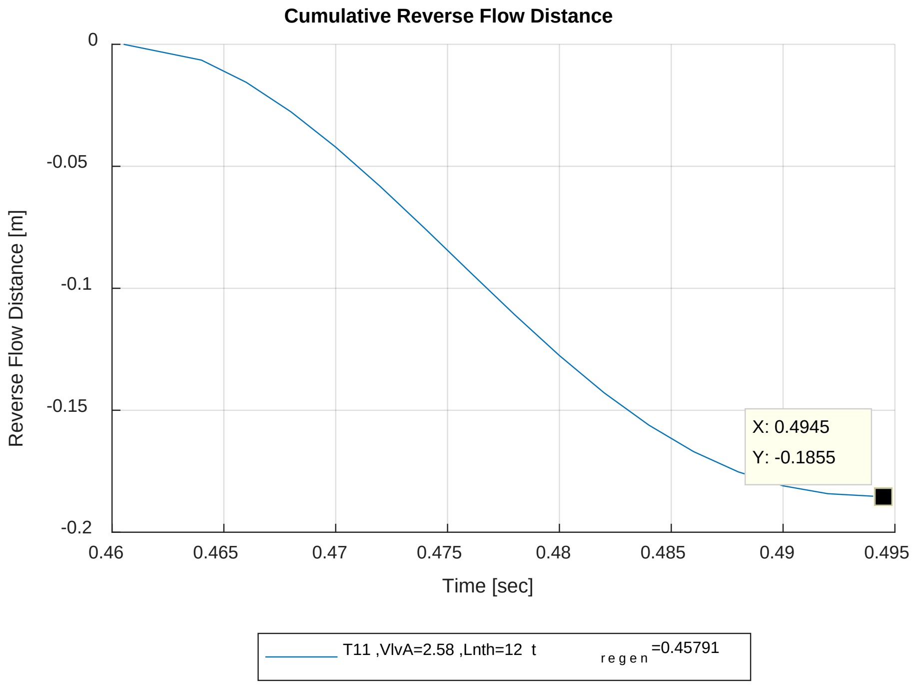

Flow Acceleration Profile
Flow Acceleration [m/sec 2]
Time [sec]
V70 ,VlvA=2.58 ,Lnth=8 t regen =0.42846
V70 ,VlvA=2.58 ,Lnth=10 t regen =0.42846
V70 ,VlvA=2.58 ,Lnth=12 t regen =0.42846
V70 ,VlvA=2.58 ,Lnth=14 t regen =0.42846
V70 ,VlvA=2.58 ,Lnth=16 t regen =0.42846

4 gal settling tank 35psi Regen Press



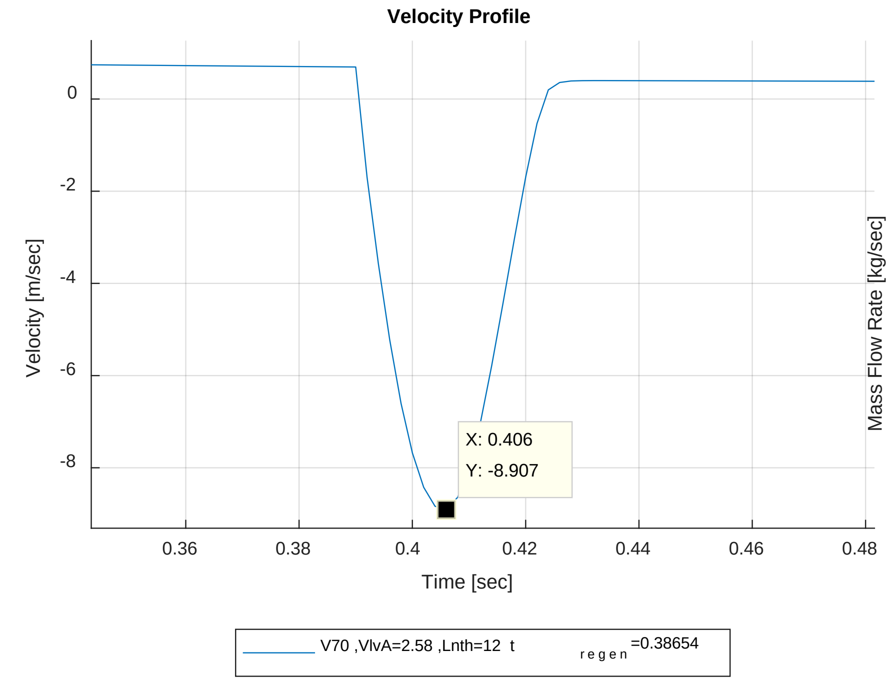

Cumulative Reverse Flow Distance
Reverse Flow Distance [m]
Time [sec]
X: 0.495
Y: -0.1836
T11 ,VlvA=2.58 ,Lnth=12 t regen =0.4576
Cumulative Reverse Flow Distance
Reverse Flow Distance [m]
X: 0.4944
Y: -0.1858
regen =0.45781
Cumulative Reverse Flow Distance
Reverse Flow Distance [m]
Time [sec]
X: 0.4993
Y: -0.1764
T11 ,VlvA=2.58 ,Lnth=12 t regen =0.45716


Cumulative Reverse Flow Distance
0
-0.05
-0.1
-0.15
-0.2
Reverse Flow Distance [m]
0.46
0.465
0.47
0.475
0.48
0.485
0.49
0.495
Time [sec]
X: 0.4945
Y: -0.1853
T11 ,VlvA=2.58 ,Lnth=12 t regen =0.45781

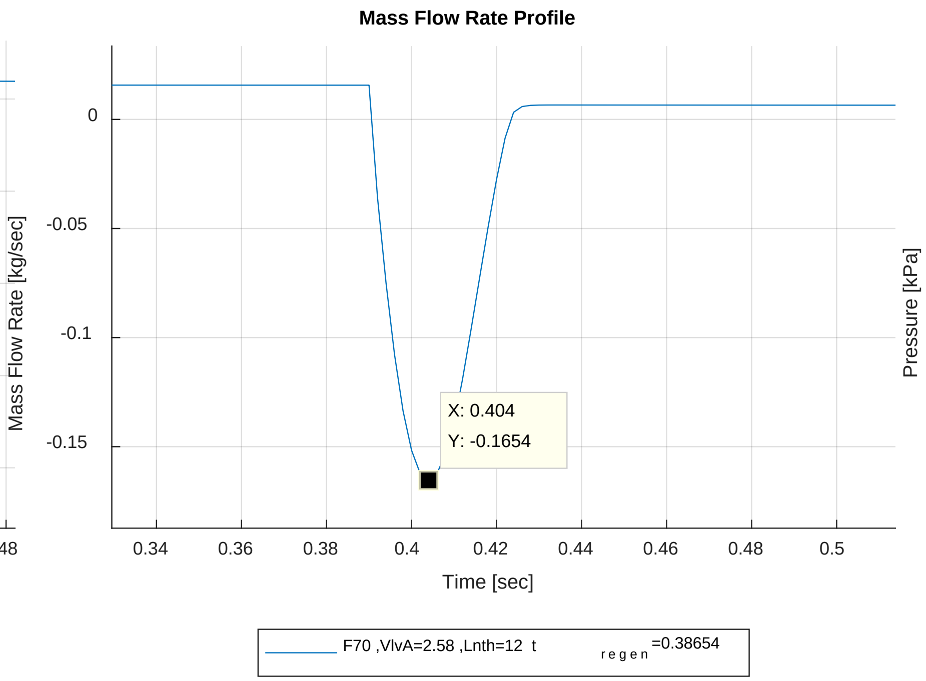

Cumulative Reverse Flow Distance
0
-0.05
-0.1
-0.15
-0.2
Reverse Flow Distance [m]
0.46
0.465
0.47
0.475
0.48
0.485
0.49
0.495
Time [sec]
X: 0.4945
Y: -0.1855
T11 ,VlvA=2.58 ,Lnth=12 t regen =0.45791

240kPa 10l Holding

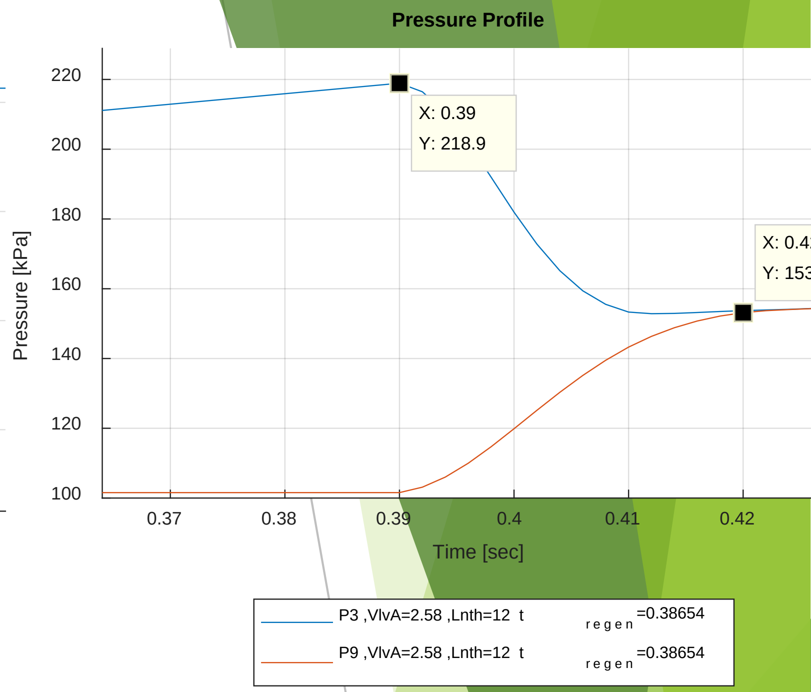
Base Holding Tank Size (12L)



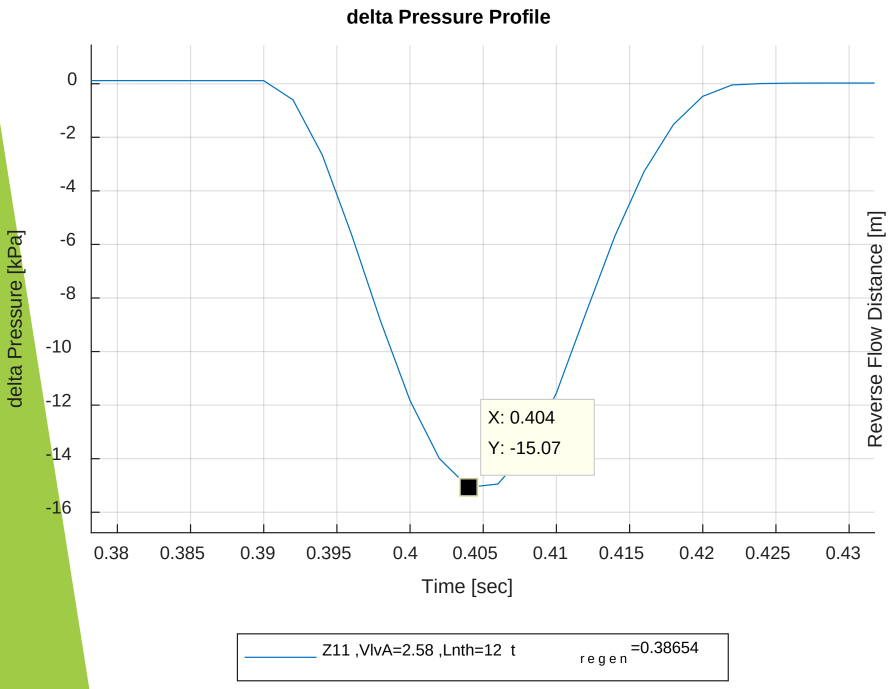
Velocity Profile
Velocity [m/sec]
Time [sec]
X: 0.406
Y: -8.907
V70 ,VlvA=2.58 ,Lnth=12 t regen =0.38654



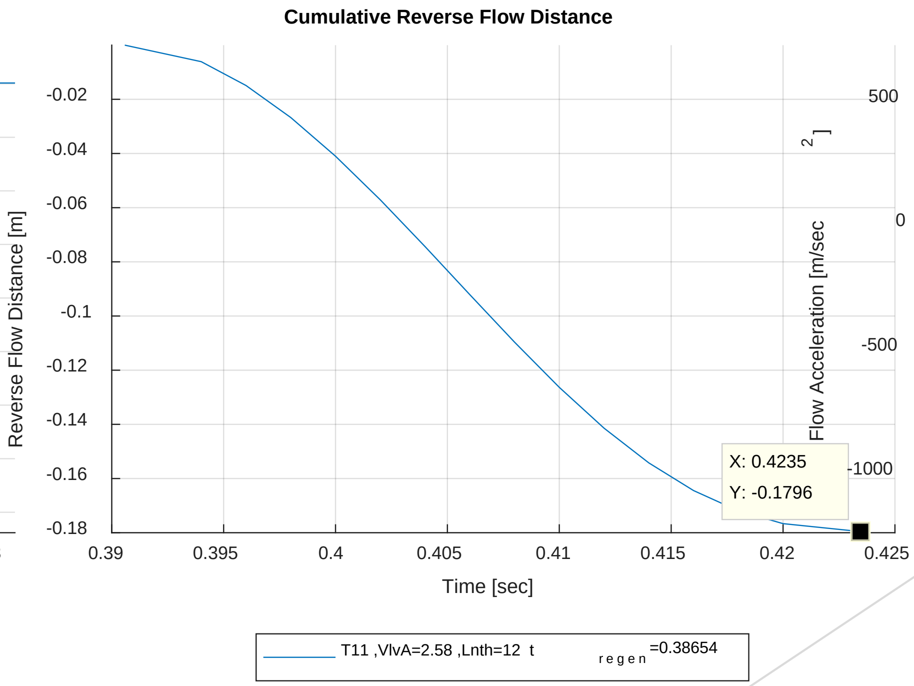
Mass Flow Rate Profile
Mass Flow Rate [kg/sec]
Time [sec]
X: 0.404
Y: -0.1654
F70 ,VlvA=2.58 ,Lnth=12 t regen =0.38654



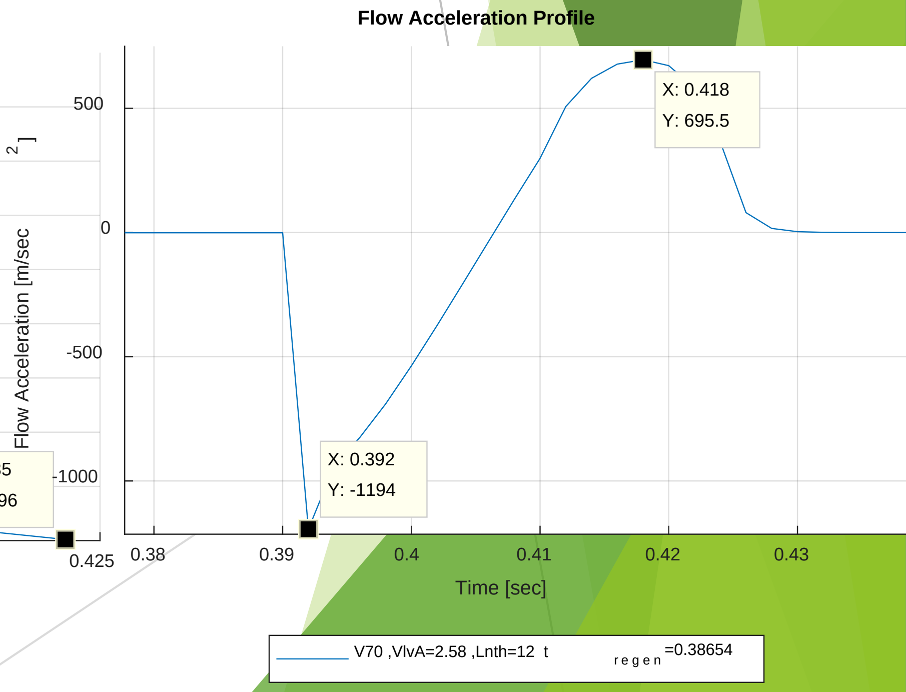
Pressure Profile
Pressure [kPa]
Time [sec]
X: 0.39
Y: 218.9
P3 ,VlvA=2.58 ,Lnth=12 t regen =0.38654
P9 ,VlvA=2.58 ,Lnth=12 t regen =0.38654



delta Pressure Profile
delta Pressure [kPa]
Time [sec]
X: 0.404
Y: -15.07
Z11 ,VlvA=2.58 ,Lnth=12 t regen =0.38654



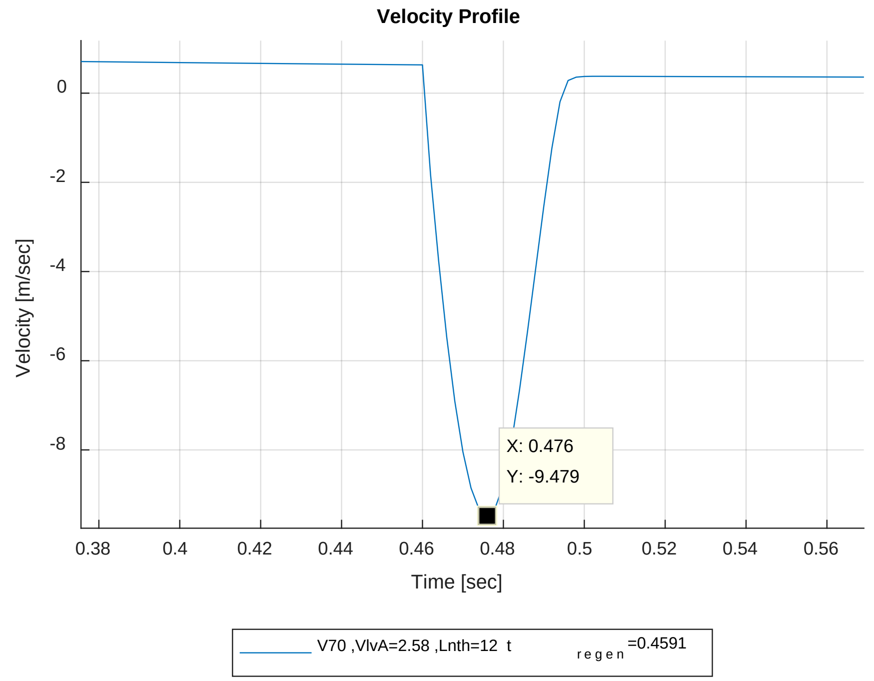
Cumulative Reverse Flow Distance
Reverse Flow Distance [m]
Time [sec]
X: 0.4235
Y: -0.1796
T11 ,VlvA=2.58 ,Lnth=12 t regen =0.38654

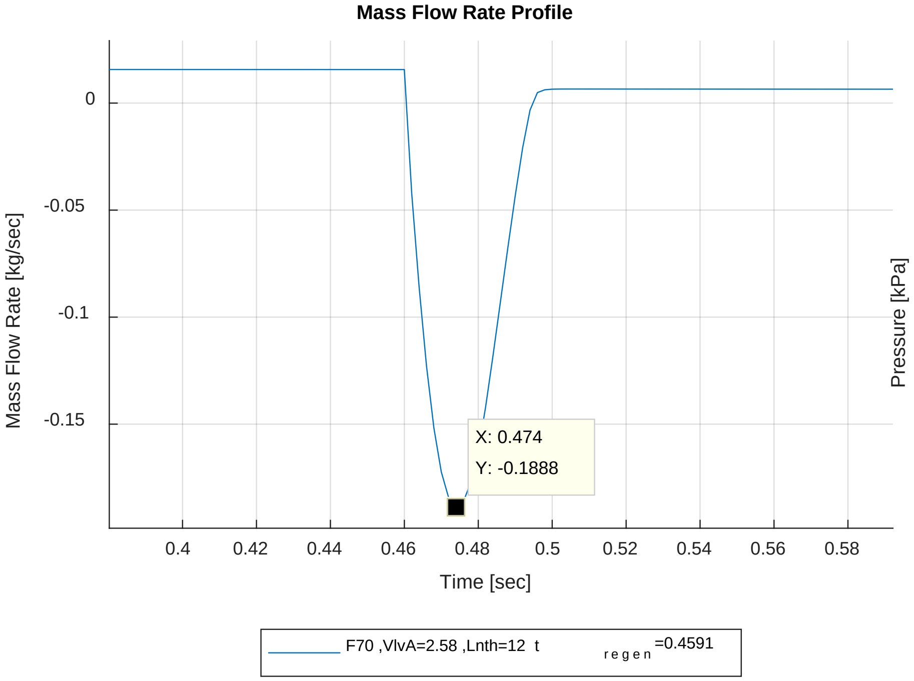


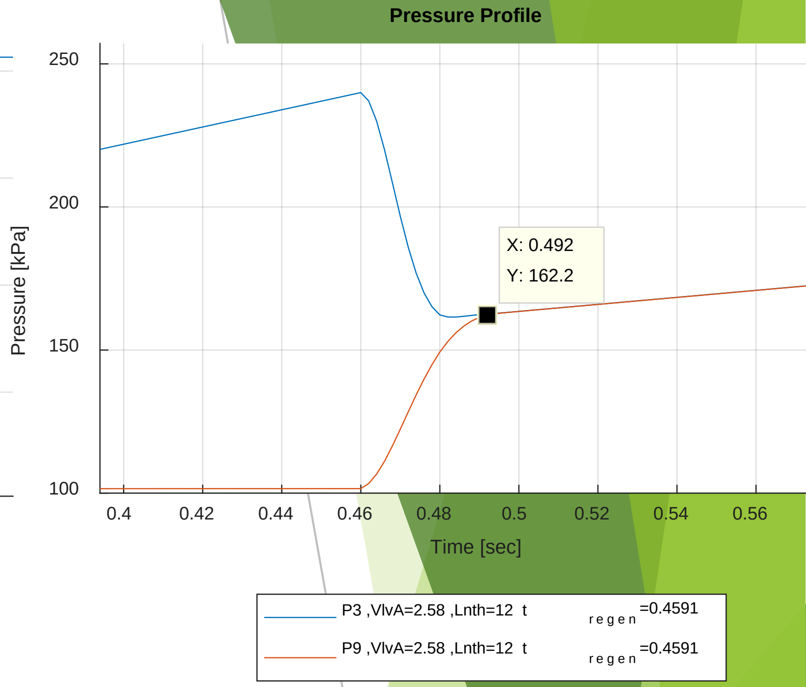
Flow Acceleration Profile
Flow Acceleration [m/sec 2]
Time [sec]
X: 0.418
Y: 695.5
X: 0.392
Y: -1194
V70 ,VlvA=2.58 ,Lnth=12 t regen =0.38654

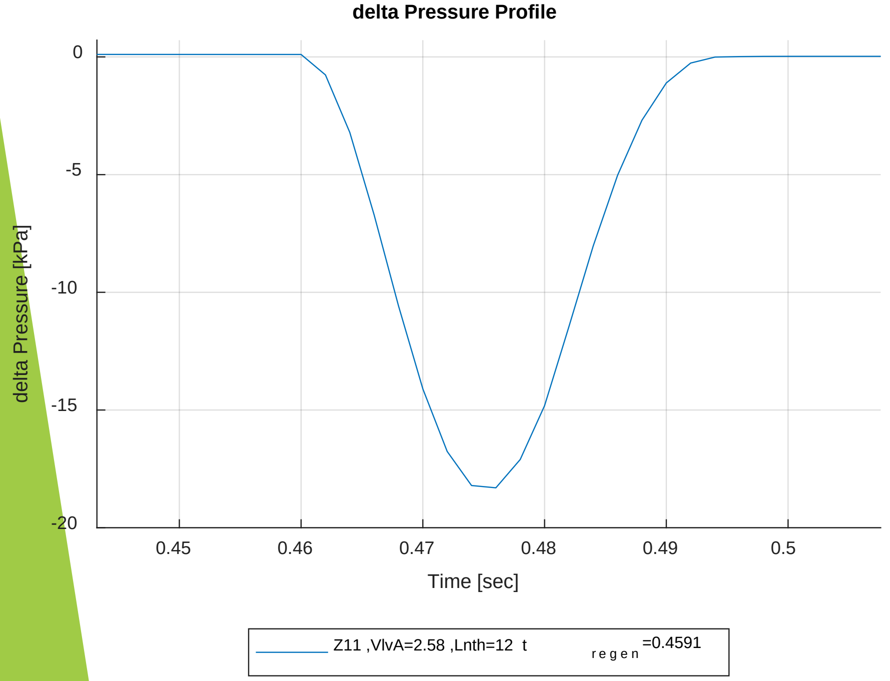
240kPa 15l Holding

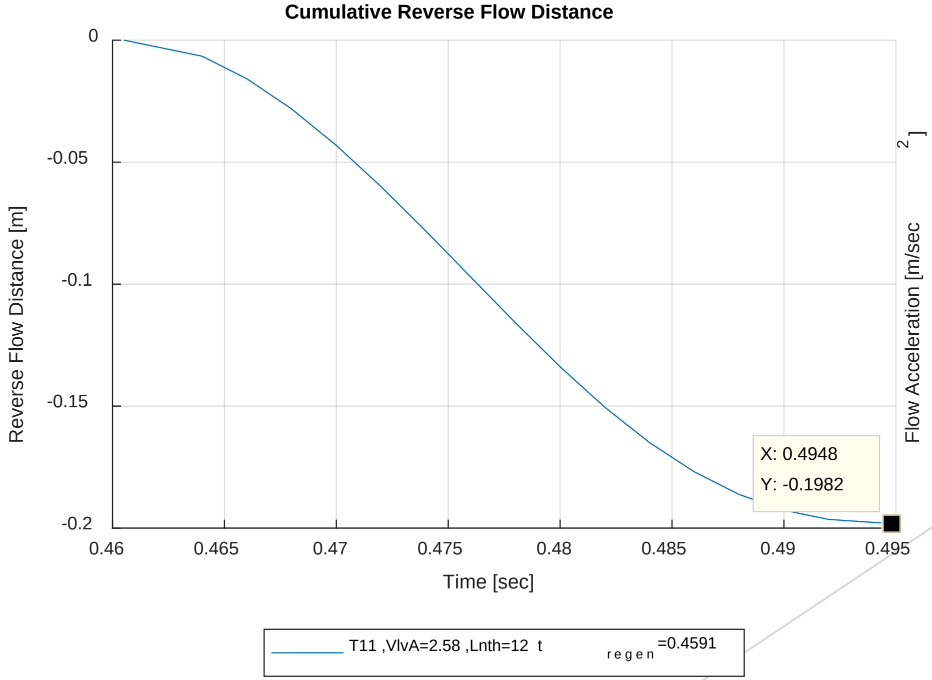
46mm Regeneration valve

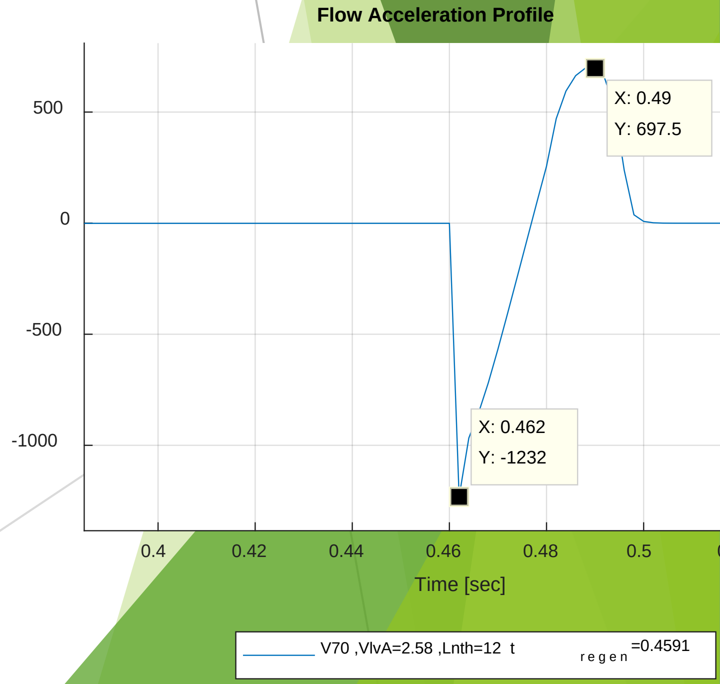

Velocity Profile
Velocity [m/sec]
0
-2
-4
-6
-8
X: 0.476
Y: -9.479
0.38 0.4 0.42 0.44 0.46 0.48 0.5 0.52 0.54 0.56
Time [sec]
V70 ,VlvA=2.58 ,Lnth=12 t regen =0.4591


Mass Flow Rate Profile
Mass Flow Rate [kg/sec]
0
-0.05
-0.1
-0.15
X: 0.474
Y: -0.1888
0.4 0.42 0.44 0.46 0.48 0.5 0.52 0.54 0.56 0.58
Time [sec]
F70 ,VlvA=2.58 ,Lnth=12 t regen =0.4591

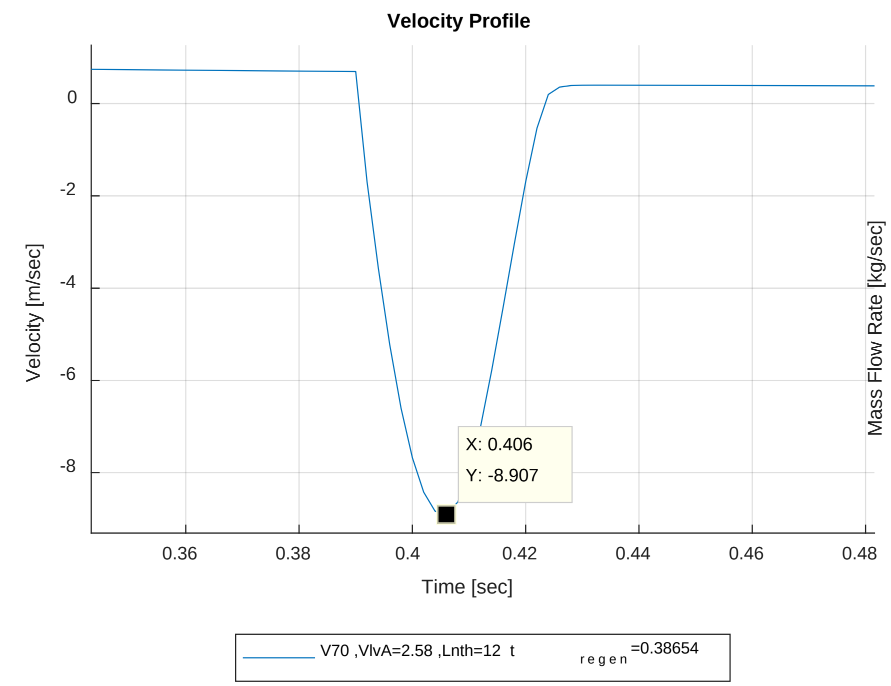

Pressure Profile
Pressure [kPa]
250
200
150
100
X: 0.492
Y: 162.2
0.4 0.42 0.44 0.46 0.48 0.5 0.52 0.54 0.56
Time [sec]
P3 ,VlvA=2.58 ,Lnth=12 t regen =0.4591
P9 ,VlvA=2.58 ,Lnth=12 t regen =0.4591

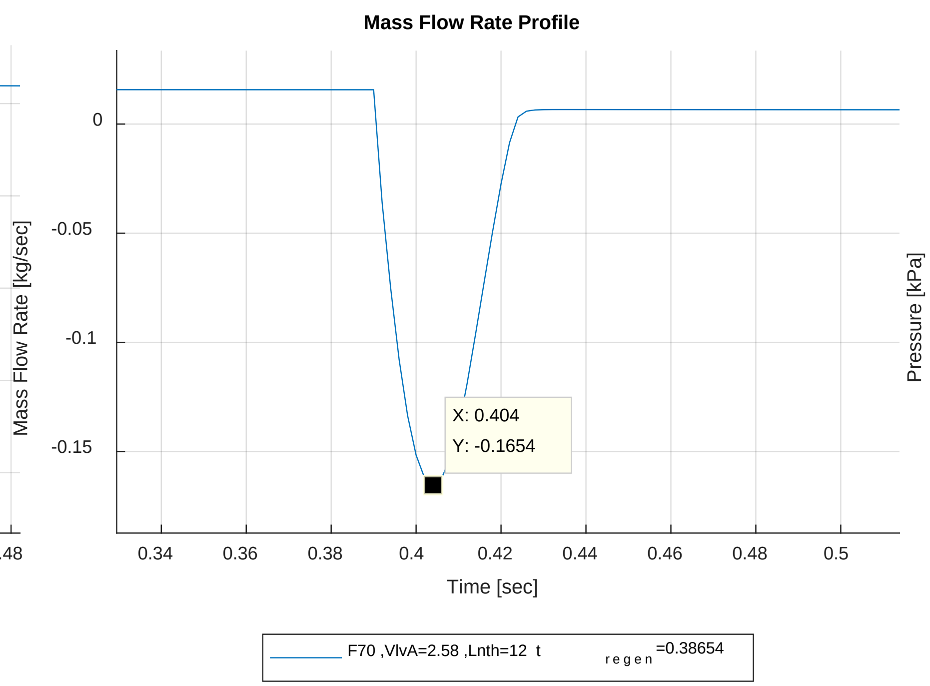

delta Pressure Profile
delta Pressure [kPa]
0
-5
-10
-15
-20
0.45 0.46 0.47 0.48 0.49 0.5
Time [sec]
Z11 ,VlvA=2.58 ,Lnth=12 t regen =0.4591

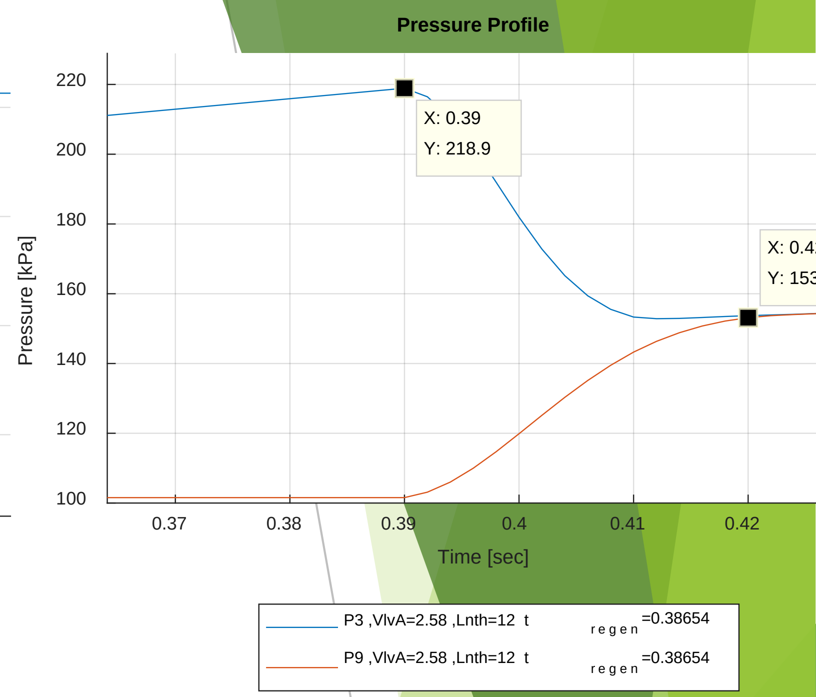

Cumulative Reverse Flow Distance
Reverse Flow Distance [m]
0
-0.05
-0.1
-0.15
-0.2
X: 0.4948
Y: -0.1982
0.46 0.465 0.47 0.475 0.48 0.485 0.49 0.495
Time [sec]
T11 ,VlvA=2.58 ,Lnth=12 t regen =0.4591

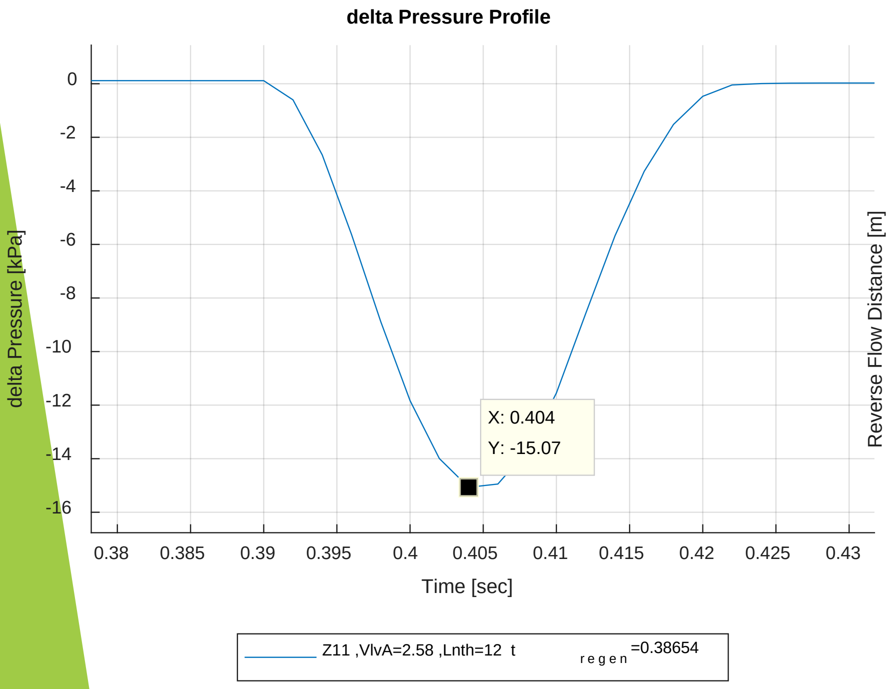

Flow Acceleration Profile
Flow Acceleration [m/sec 2]
500
0
-500
-1000
X: 0.49
Y: 697.5
X: 0.462
Y: -1232
0.4 0.42 0.44 0.46 0.48 0.5
Time [sec]
V70 ,VlvA=2.58 ,Lnth=12 t regen =0.4591

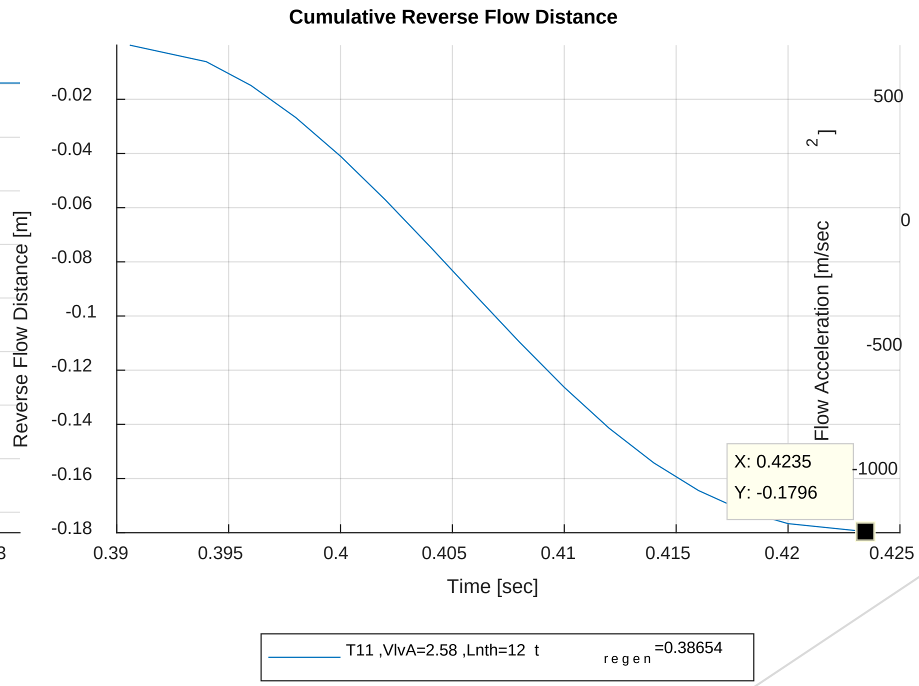
220kPa 15l Holding

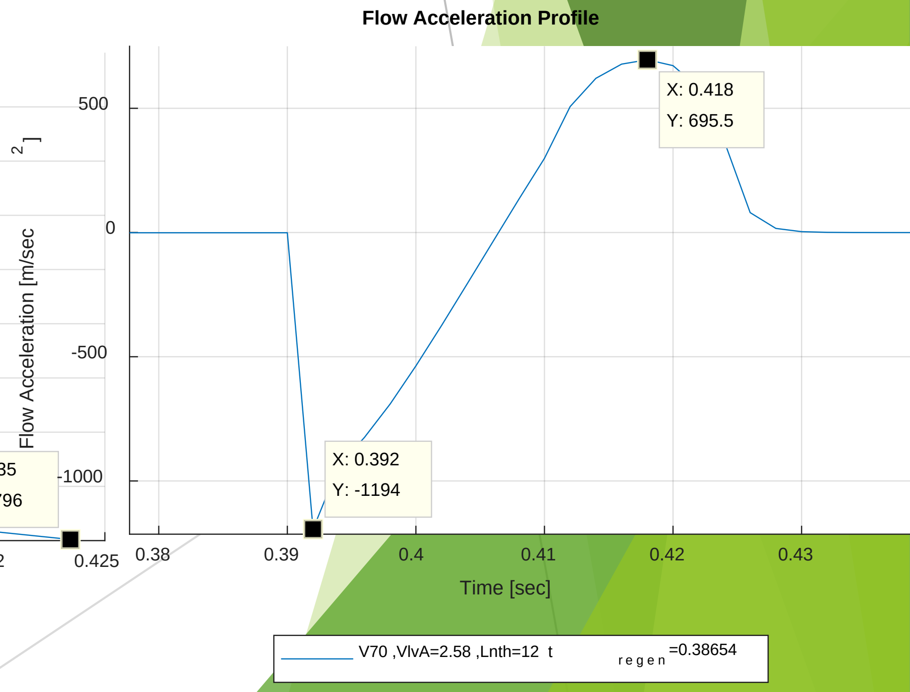

Velocity Profile
Velocity [m/sec]
Time [sec]
X: 0.406
Y: -8.907
V70 ,VlvA=2.58 ,Lnth=12 t regen =0.38654


Mass Flow Rate Profile
Mass Flow Rate [kg/sec]
Time [sec]
X: 0.404
Y: -0.1654
F70 ,VlvA=2.58 ,Lnth=12 t regen =0.38654

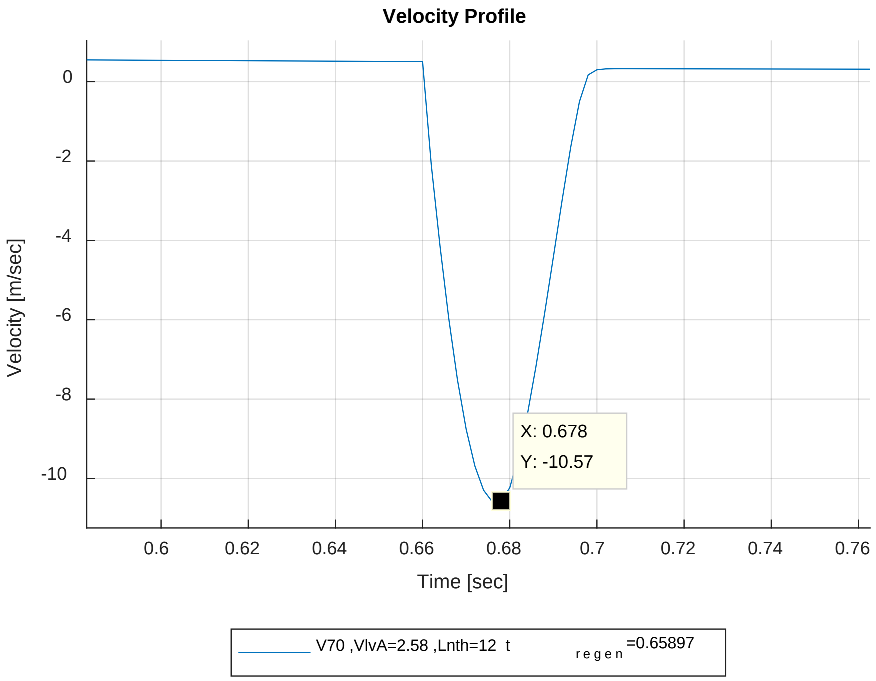

Pressure Profile
Pressure [kPa]
Time [sec]
X: 0.39
Y: 218.9
P3 ,VlvA=2.58 ,Lnth=12 t regen =0.38654
P9 ,VlvA=2.58 ,Lnth=12 t regen =0.38654

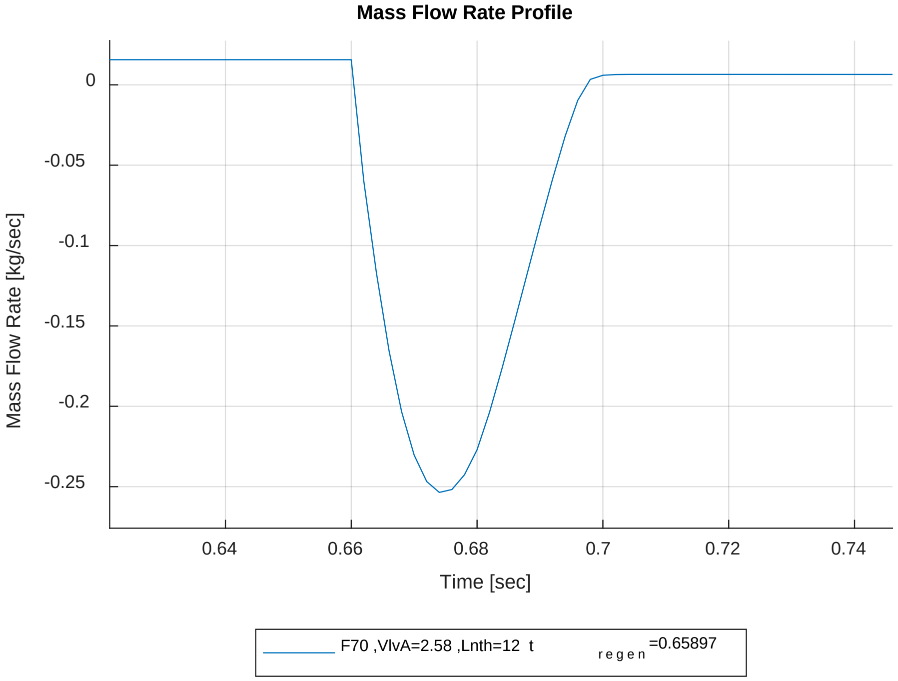

delta Pressure Profile
delta Pressure [kPa]
Time [sec]
X: 0.404
Y: -15.07
Z11 ,VlvA=2.58 ,Lnth=12 t regen =0.38654

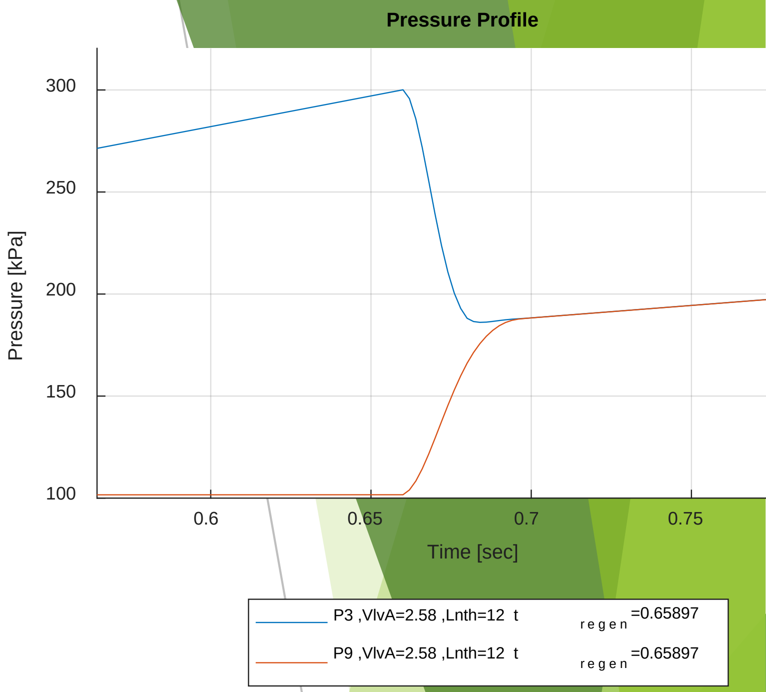

Cumulative Reverse Flow Distance
Reverse Flow Distance [m]
Time [sec]
X: 0.4235
Y: -0.1796
T11 ,VlvA=2.58 ,Lnth=12 t regen =0.38654

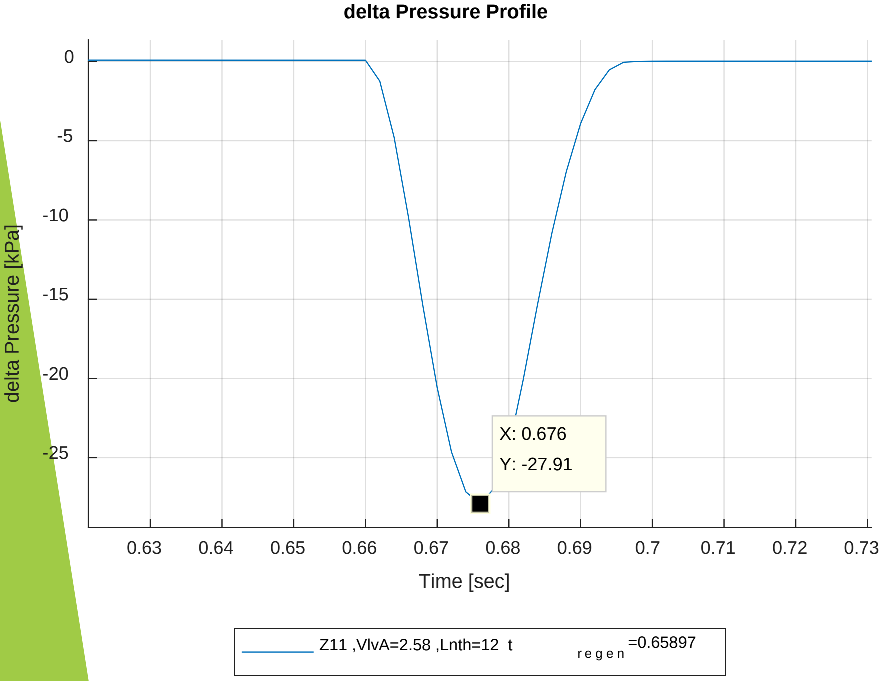

Flow Acceleration Profile
Flow Acceleration [m/sec 2]
Time [sec]
X: 0.418
Y: 695.5
X: 0.392
Y: -1194
V70 ,VlvA=2.58 ,Lnth=12 t regen =0.38654

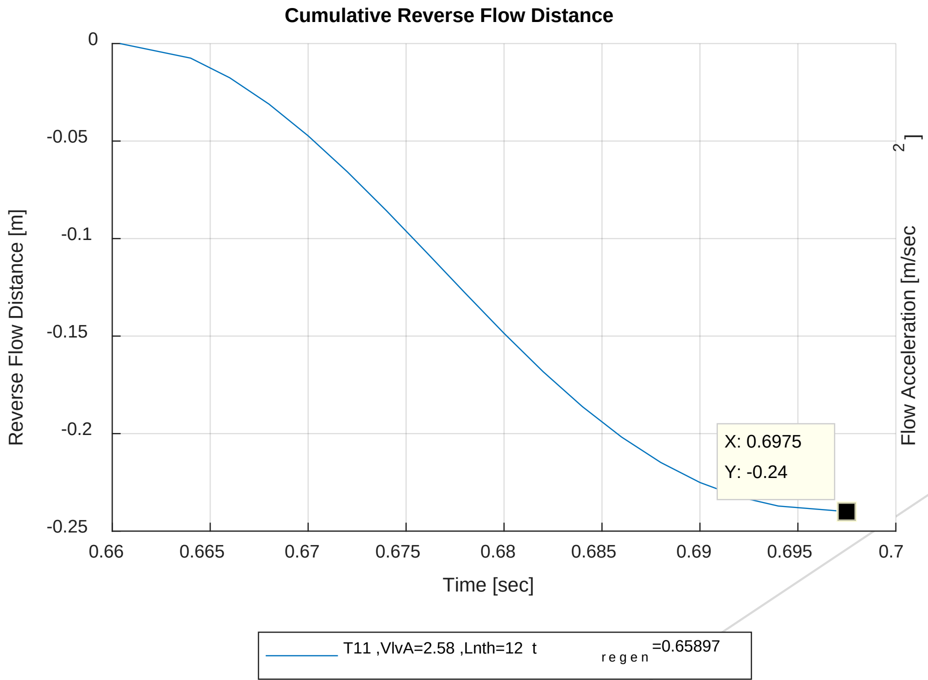
300kPa 15l Holding

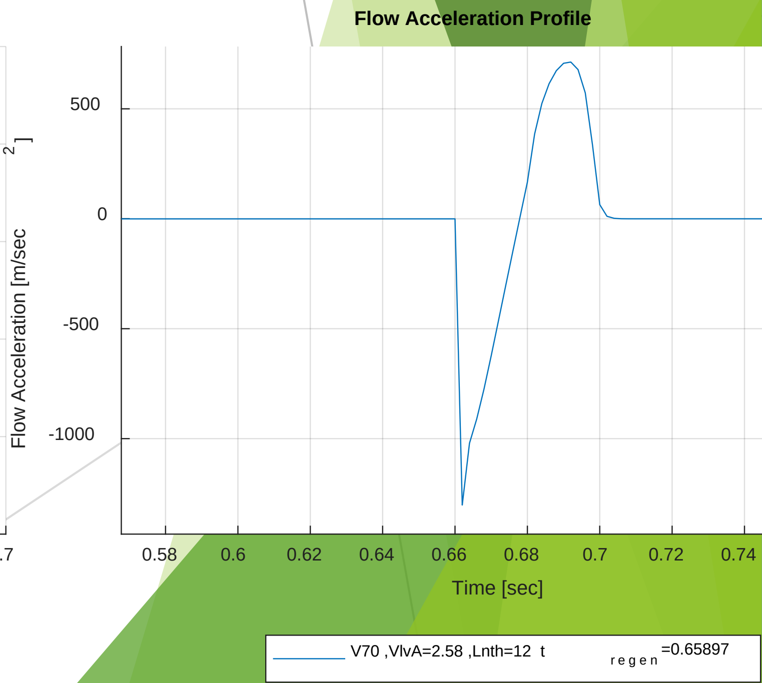

Velocity Profile
Velocity [m/sec]
Time [sec]
X: 0.678
Y: -10.57
V70 ,VlvA=2.58 ,Lnth=12 t regen =0.65897

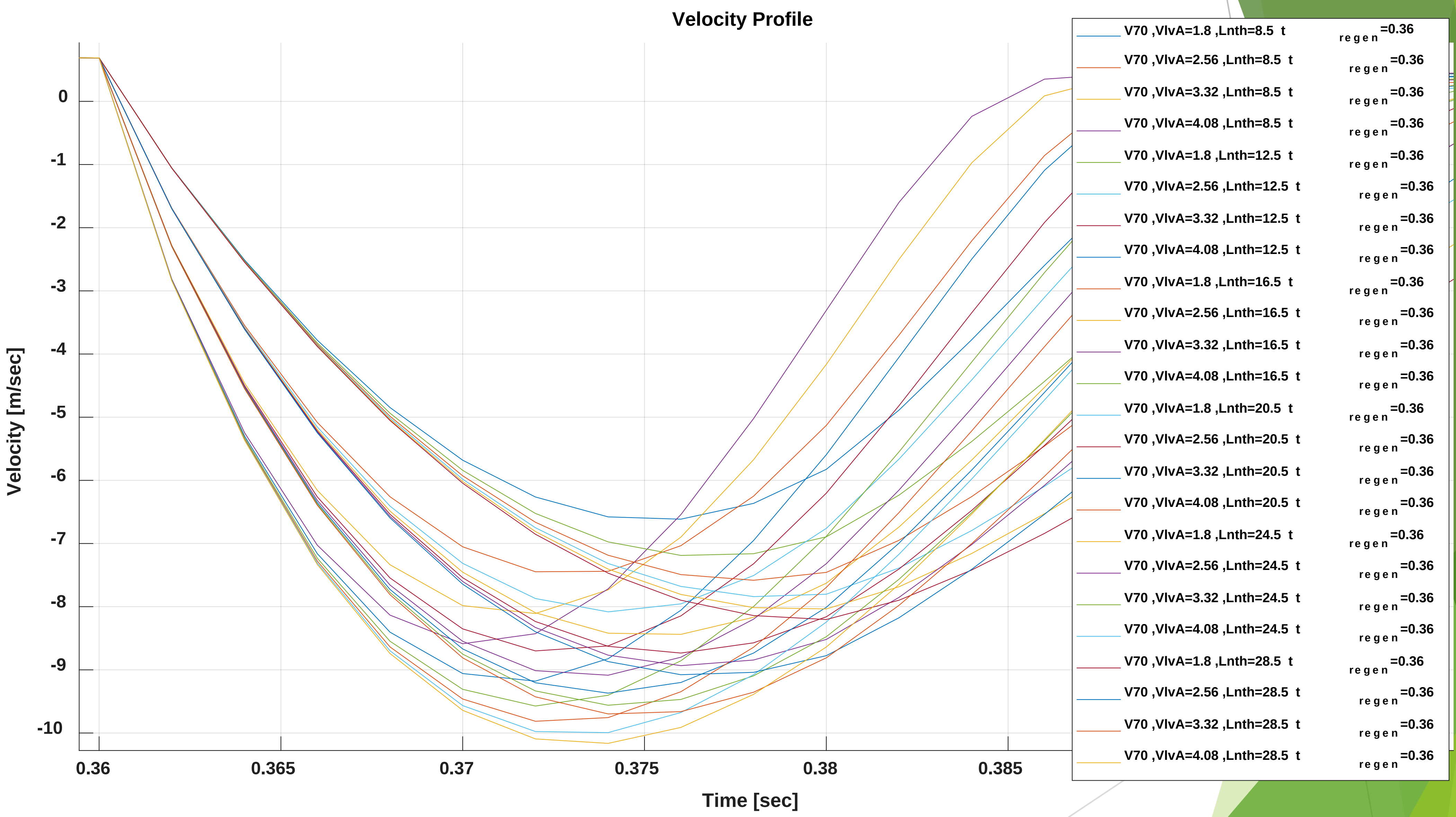

Mass Flow Rate Profile
Mass Flow Rate [kg/sec]
Time [sec]
F70 ,VlvA=2.58 ,Lnth=12 t regen =0.65897

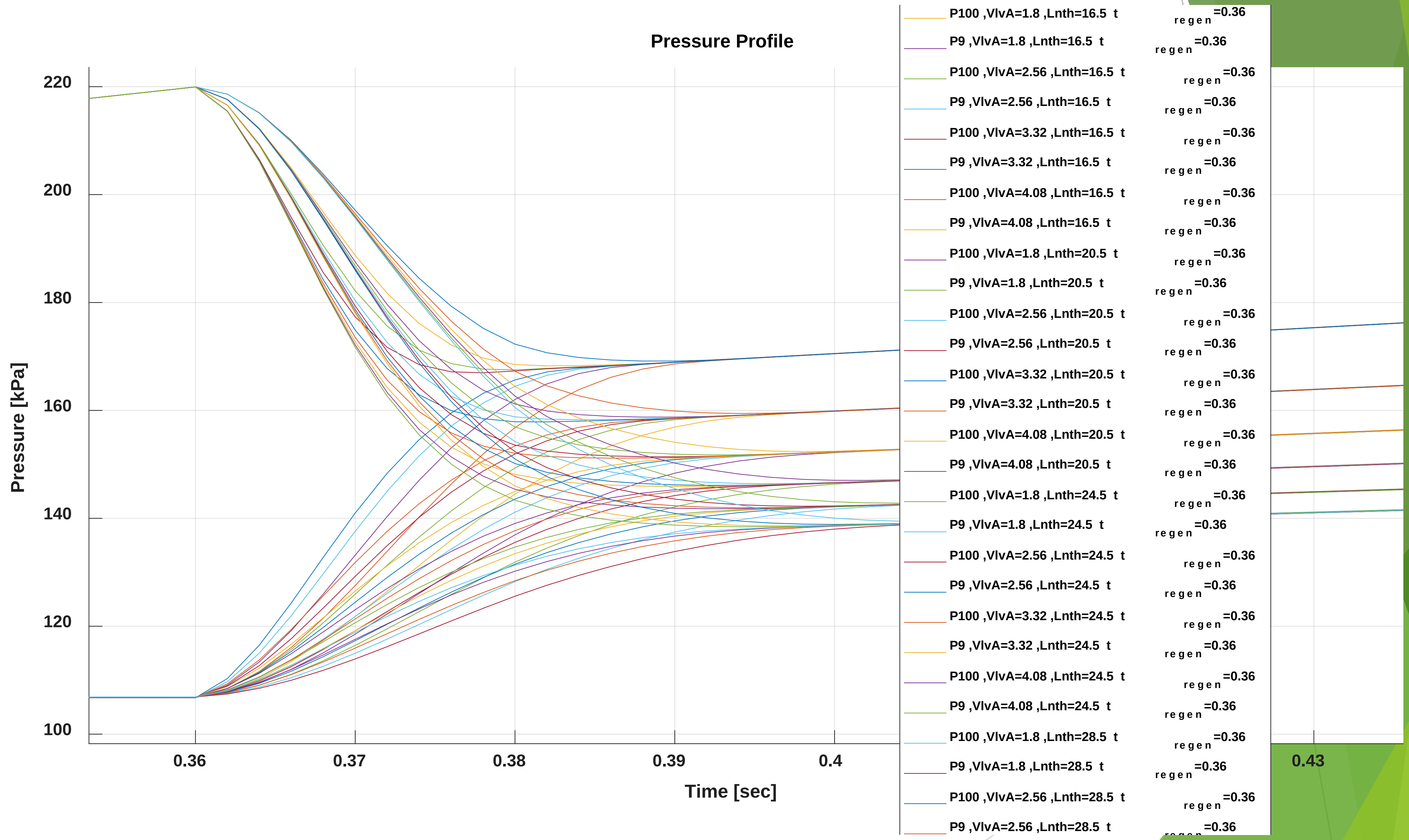

Pressure Profile
Pressure [kPa]
Time [sec]
P3 ,VlvA=2.58 ,Lnth=12 t regen =0.65897
P9 ,VlvA=2.58 ,Lnth=12 t regen =0.65897

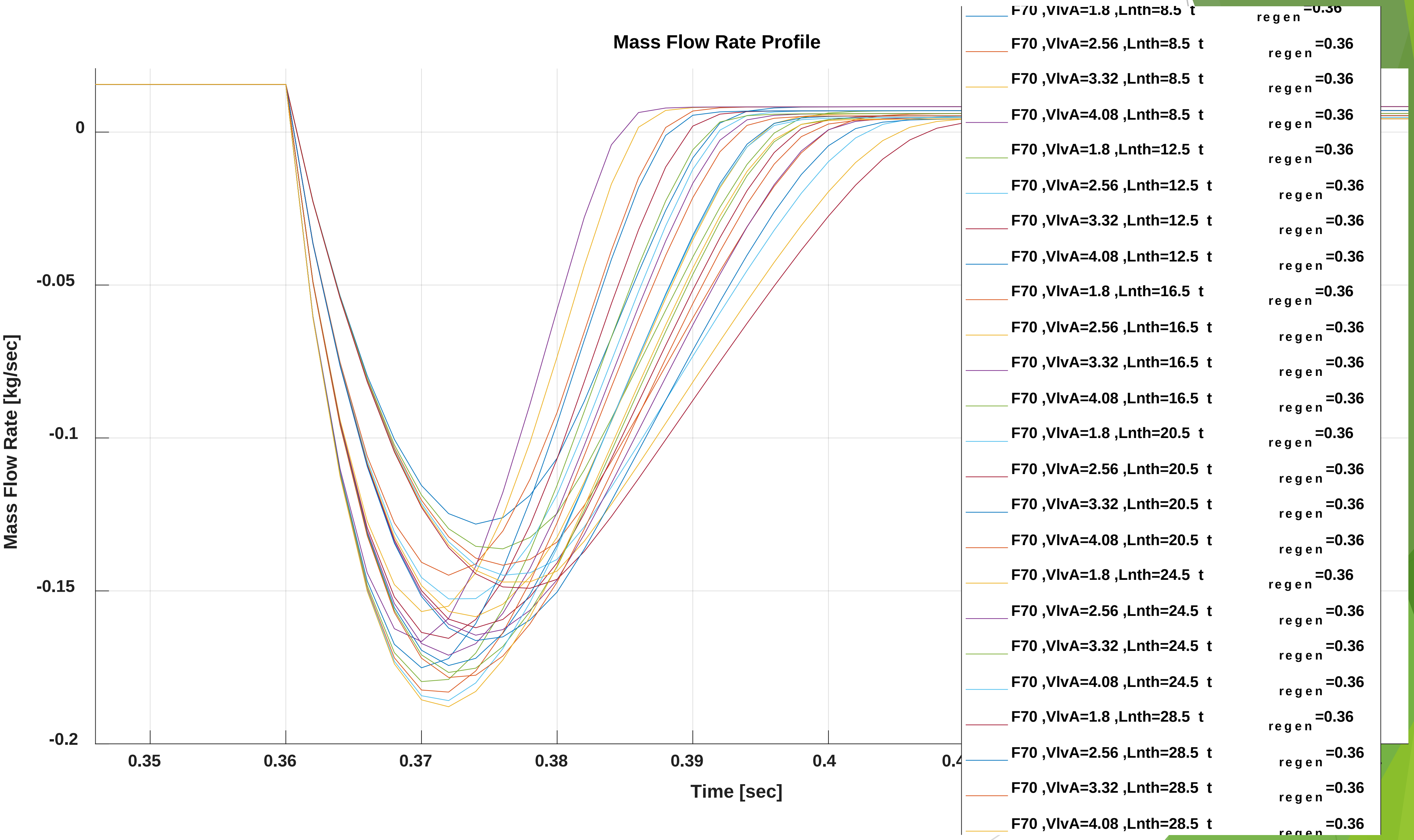

delta Pressure Profile
delta Pressure [kPa]
Time [sec]
X: 0.676
Y: -27.91
Z11 ,VlvA=2.58 ,Lnth=12 t regen =0.65897


Cumulative Reverse Flow Distance
Reverse Flow Distance [m]
Time [sec]
X: 0.6975
Y: -0.24
T11 ,VlvA=2.58 ,Lnth=12 t regen =0.65897

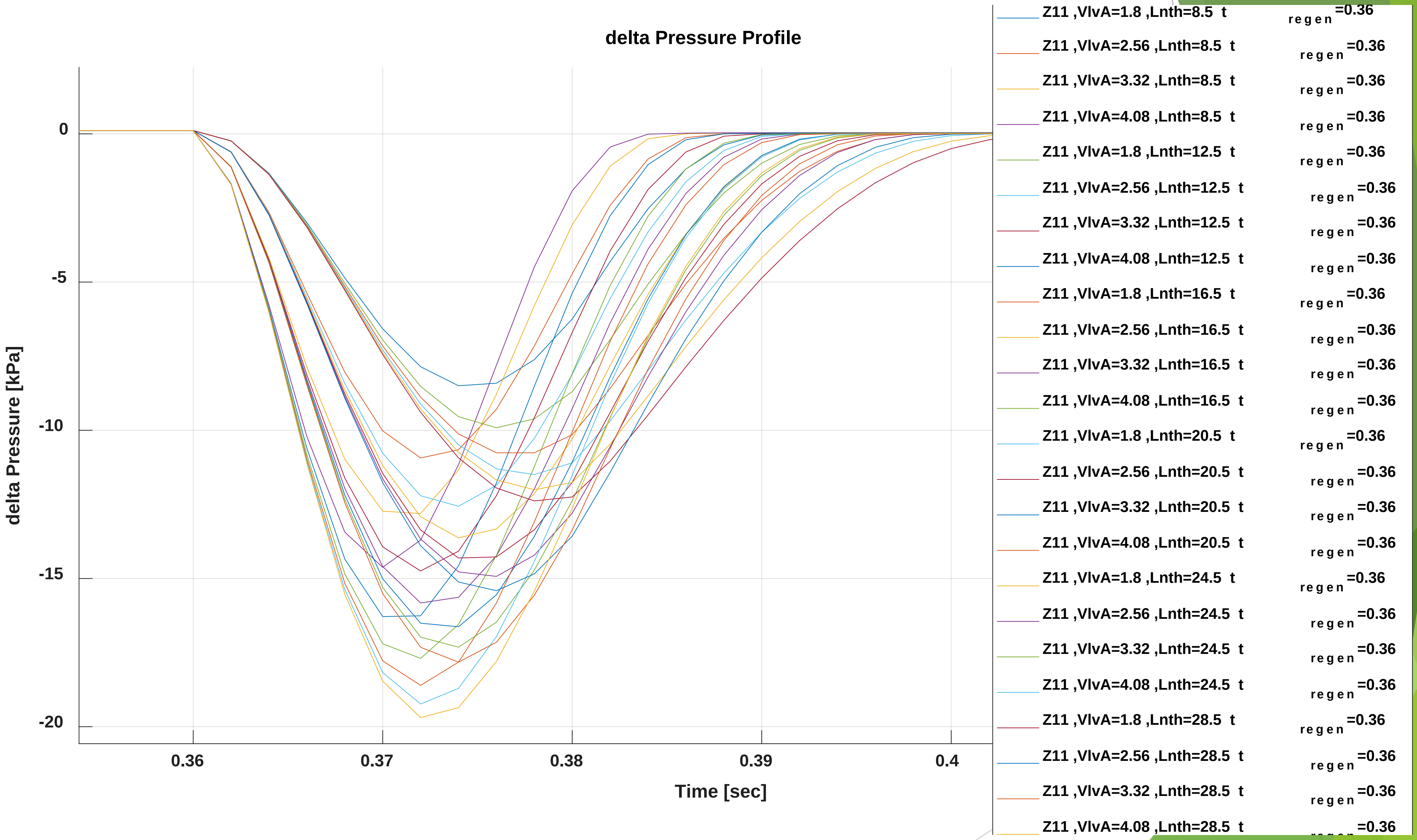

Flow Acceleration Profile
Flow Acceleration [m/sec 2]
Time [sec]
V70 ,VlvA=2.58 ,Lnth=12 t regen =0.65897

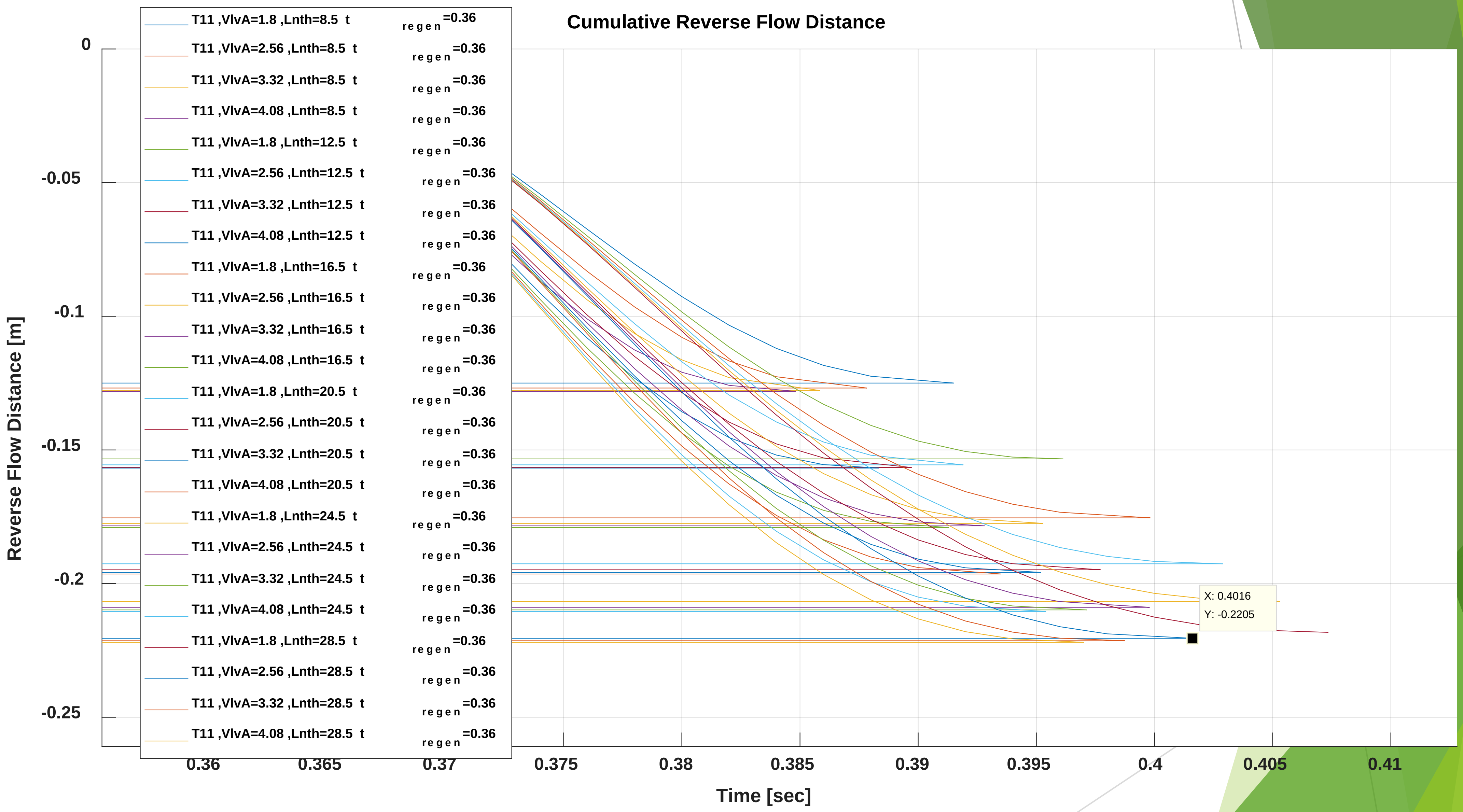

Velocity Profile
Velocity [m/sec]
0
-1
-2
-3
-4
-5
-6
-7
-8
-9
-10
0.36
0.365
0.37
0.375
0.38
0.385
Time [sec]
V70 ,VlvA=1.8 ,Lnth=8.5 t regen =0.36
V70 ,VlvA=2.56 ,Lnth=8.5 t regen =0.36
V70 ,VlvA=3.32 ,Lnth=8.5 t regen =0.36
V70 ,VlvA=4.08 ,Lnth=8.5 t regen =0.36
V70 ,VlvA=1.8 ,Lnth=12.5 t regen =0.36
V70 ,VlvA=2.56 ,Lnth=12.5 t regen =0.36
V70 ,VlvA=3.32 ,Lnth=12.5 t regen =0.36
V70 ,VlvA=4.08 ,Lnth=12.5 t regen =0.36
V70 ,VlvA=1.8 ,Lnth=16.5 t regen =0.36
V70 ,VlvA=2.56 ,Lnth=16.5 t regen =0.36
V70 ,VlvA=3.32 ,Lnth=16.5 t regen =0.36
V70 ,VlvA=4.08 ,Lnth=16.5 t regen =0.36
V70 ,VlvA=1.8 ,Lnth=20.5 t regen =0.36
V70 ,VlvA=2.56 ,Lnth=20.5 t regen =0.36
V70 ,VlvA=3.32 ,Lnth=20.5 t regen =0.36
V70 ,VlvA=4.08 ,Lnth=20.5 t regen =0.36
V70 ,VlvA=1.8 ,Lnth=24.5 t regen =0.36
V70 ,VlvA=2.56 ,Lnth=24.5 t regen =0.36
V70 ,VlvA=3.32 ,Lnth=24.5 t regen =0.36
V70 ,VlvA=4.08 ,Lnth=24.5 t regen =0.36
V70 ,VlvA=1.8 ,Lnth=28.5 t regen =0.36
V70 ,VlvA=2.56 ,Lnth=28.5 t regen =0.36
V70 ,VlvA=3.32 ,Lnth=28.5 t regen =0.36
V70 ,VlvA=4.08 ,Lnth=28.5 t regen =0.36


Pressure Profile
Pressure [kPa]
220
200
180
160
140
120
100
0.36
0.37
0.38
0.39
0.4
0.43
Time [sec]
P100 ,VlvA=1.8 ,Lnth=16.5 t regen=0.36
P9 ,VlvA=1.8 ,Lnth=16.5 t regen=0.36
P100 ,VlvA=2.56 ,Lnth=16.5 t regen=0.36
P9 ,VlvA=2.56 ,Lnth=16.5 t regen=0.36
P100 ,VlvA=3.32 ,Lnth=16.5 t regen=0.36
P9 ,VlvA=3.32 ,Lnth=16.5 t regen=0.36
P100 ,VlvA=4.08 ,Lnth=16.5 t regen=0.36
P9 ,VlvA=4.08 ,Lnth=16.5 t regen=0.36
P100 ,VlvA=1.8 ,Lnth=20.5 t regen=0.36
P9 ,VlvA=1.8 ,Lnth=20.5 t regen=0.36
P100 ,VlvA=2.56 ,Lnth=20.5 t regen=0.36
P9 ,VlvA=2.56 ,Lnth=20.5 t regen=0.36
P100 ,VlvA=3.32 ,Lnth=20.5 t regen=0.36
P9 ,VlvA=3.32 ,Lnth=20.5 t regen=0.36
P100 ,VlvA=4.08 ,Lnth=20.5 t regen=0.36
P9 ,VlvA=4.08 ,Lnth=20.5 t regen=0.36
P100 ,VlvA=1.8 ,Lnth=24.5 t regen=0.36
P9 ,VlvA=1.8 ,Lnth=24.5 t regen=0.36
P100 ,VlvA=2.56 ,Lnth=24.5 t regen=0.36
P9 ,VlvA=2.56 ,Lnth=24.5 t regen=0.36
P100 ,VlvA=3.32 ,Lnth=24.5 t regen=0.36
P9 ,VlvA=3.32 ,Lnth=24.5 t regen=0.36
P100 ,VlvA=4.08 ,Lnth=24.5 t regen=0.36
P9 ,VlvA=4.08 ,Lnth=24.5 t regen=0.36
P100 ,VlvA=1.8 ,Lnth=28.5 t regen=0.36
P9 ,VlvA=1.8 ,Lnth=28.5 t regen=0.36
P100 ,VlvA=2.56 ,Lnth=28.5 t regen=0.36
P9 ,VlvA=2.56 ,Lnth=28.5 t regen=0.36

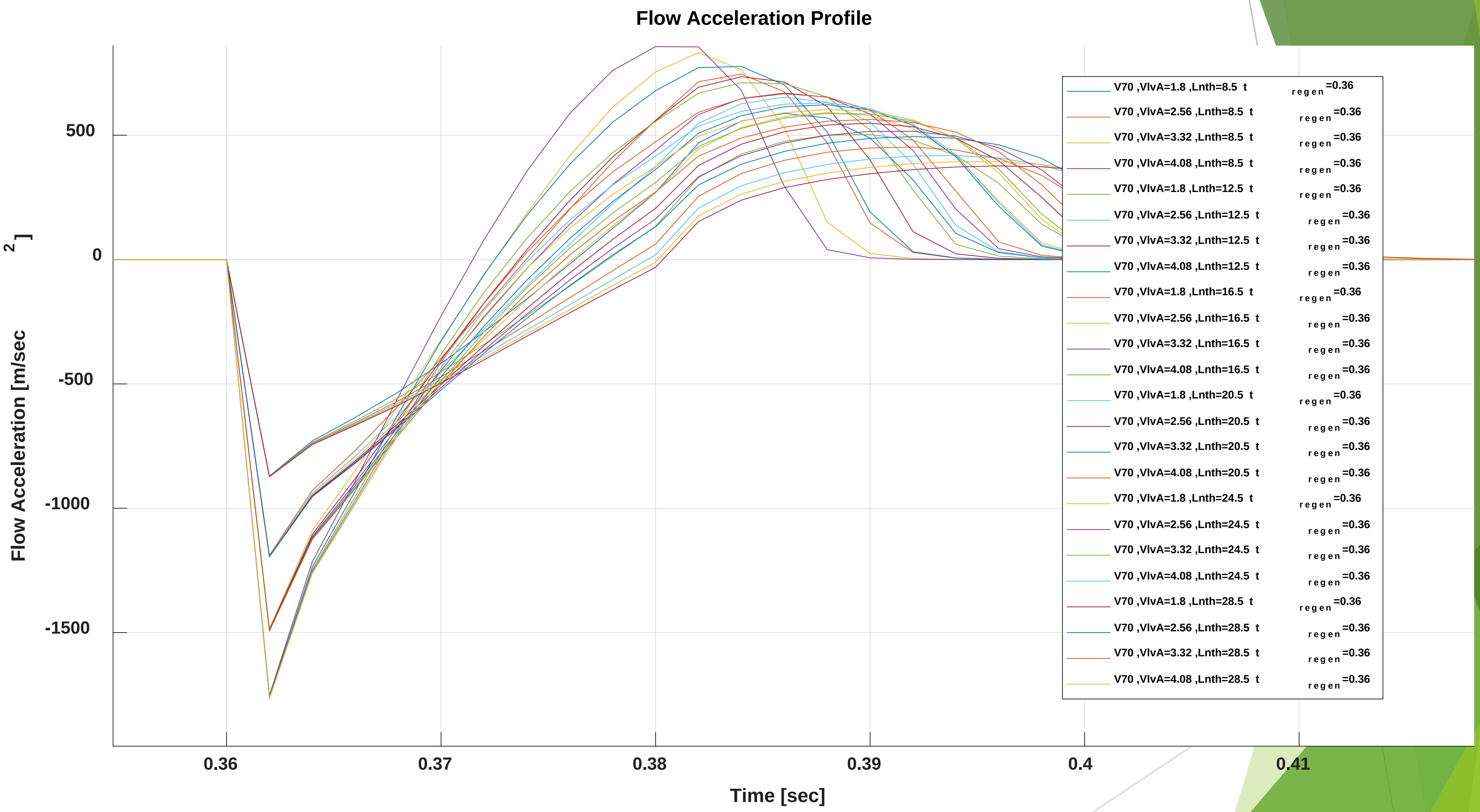


Mass Flow Rate Profile
Mass Flow Rate [kg/sec]
0
-0.05
-0.1
-0.15
-0.2
0.35
0.36
0.37
0.38
0.39
0.4
Time [sec]
F70 ,VlvA=1.8 ,Lnth=8.5 t regen =0.36
F70 ,VlvA=2.56 ,Lnth=8.5 t regen =0.36
F70 ,VlvA=3.32 ,Lnth=8.5 t regen =0.36
F70 ,VlvA=4.08 ,Lnth=8.5 t regen =0.36
F70 ,VlvA=1.8 ,Lnth=12.5 t regen =0.36
F70 ,VlvA=2.56 ,Lnth=12.5 t regen =0.36
F70 ,VlvA=3.32 ,Lnth=12.5 t regen =0.36
F70 ,VlvA=4.08 ,Lnth=12.5 t regen =0.36
F70 ,VlvA=1.8 ,Lnth=16.5 t regen =0.36
F70 ,VlvA=2.56 ,Lnth=16.5 t regen =0.36
F70 ,VlvA=3.32 ,Lnth=16.5 t regen =0.36
F70 ,VlvA=4.08 ,Lnth=16.5 t regen =0.36
F70 ,VlvA=1.8 ,Lnth=20.5 t regen =0.36
F70 ,VlvA=2.56 ,Lnth=20.5 t regen =0.36
F70 ,VlvA=3.32 ,Lnth=20.5 t regen =0.36
F70 ,VlvA=4.08 ,Lnth=20.5 t regen =0.36
F70 ,VlvA=1.8 ,Lnth=24.5 t regen =0.36
F70 ,VlvA=2.56 ,Lnth=24.5 t regen =0.36
F70 ,VlvA=3.32 ,Lnth=24.5 t regen =0.36
F70 ,VlvA=4.08 ,Lnth=24.5 t regen =0.36
F70 ,VlvA=1.8 ,Lnth=28.5 t regen =0.36
F70 ,VlvA=2.56 ,Lnth=28.5 t regen =0.36
F70 ,VlvA=3.32 ,Lnth=28.5 t regen =0.36
F70 ,VlvA=4.08 ,Lnth=28.5 t regen =0.36

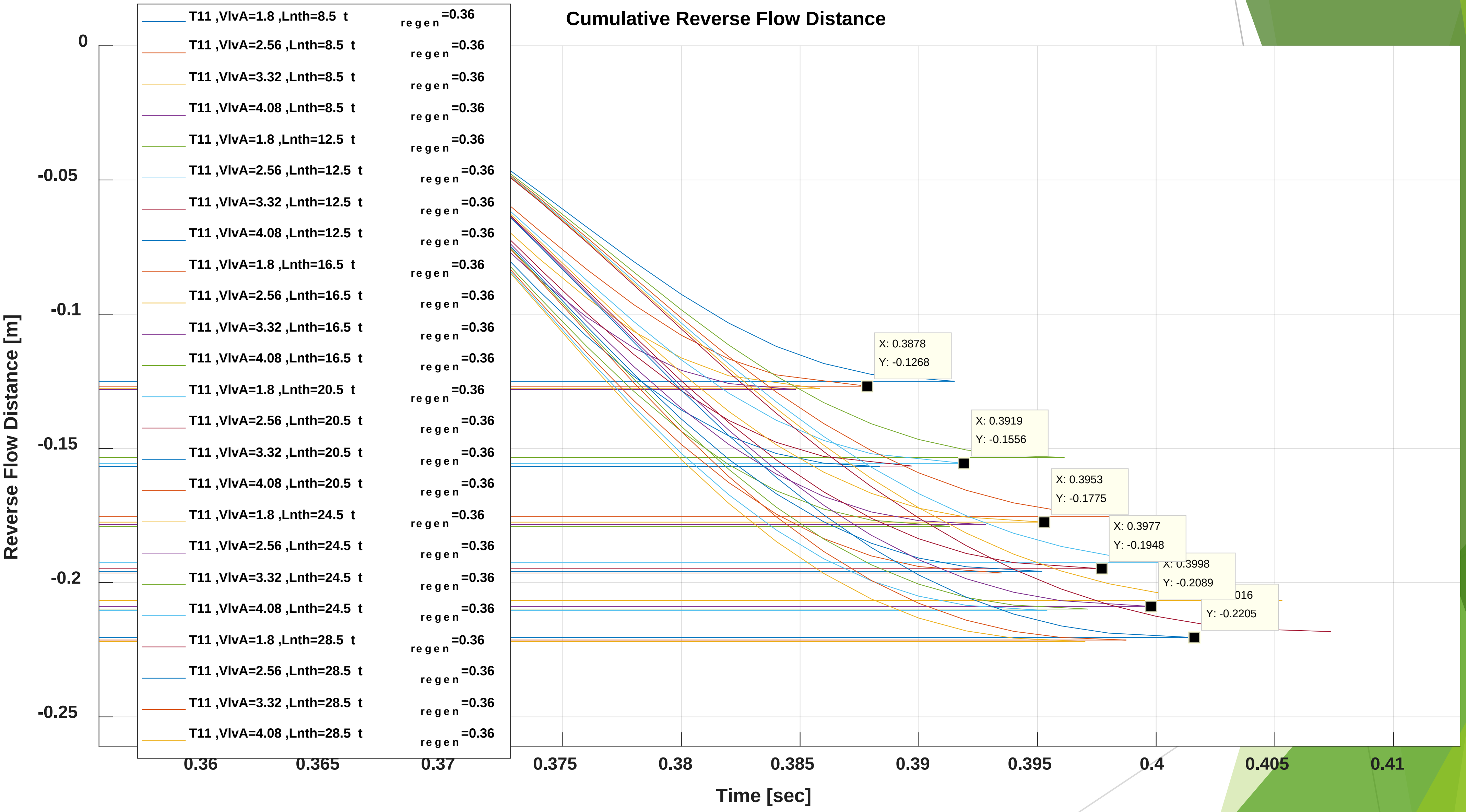

delta Pressure Profile
delta Pressure [kPa]
0
-5
-10
-15
-20
0.36
0.37
0.38
0.39
0.4
Time [sec]
Z11 ,VlvA=1.8 ,Lnth=8.5 t regen =0.36
Z11 ,VlvA=2.56 ,Lnth=8.5 t regen =0.36
Z11 ,VlvA=3.32 ,Lnth=8.5 t regen =0.36
Z11 ,VlvA=4.08 ,Lnth=8.5 t regen =0.36
Z11 ,VlvA=1.8 ,Lnth=12.5 t regen =0.36
Z11 ,VlvA=2.56 ,Lnth=12.5 t regen =0.36
Z11 ,VlvA=3.32 ,Lnth=12.5 t regen =0.36
Z11 ,VlvA=4.08 ,Lnth=12.5 t regen =0.36
Z11 ,VlvA=1.8 ,Lnth=16.5 t regen =0.36
Z11 ,VlvA=2.56 ,Lnth=16.5 t regen =0.36
Z11 ,VlvA=3.32 ,Lnth=16.5 t regen =0.36
Z11 ,VlvA=4.08 ,Lnth=16.5 t regen =0.36
Z11 ,VlvA=1.8 ,Lnth=20.5 t regen =0.36
Z11 ,VlvA=2.56 ,Lnth=20.5 t regen =0.36
Z11 ,VlvA=3.32 ,Lnth=20.5 t regen =0.36
Z11 ,VlvA=4.08 ,Lnth=20.5 t regen =0.36
Z11 ,VlvA=1.8 ,Lnth=24.5 t regen =0.36
Z11 ,VlvA=2.56 ,Lnth=24.5 t regen =0.36
Z11 ,VlvA=3.32 ,Lnth=24.5 t regen =0.36
Z11 ,VlvA=4.08 ,Lnth=24.5 t regen =0.36
Z11 ,VlvA=1.8 ,Lnth=28.5 t regen =0.36
Z11 ,VlvA=2.56 ,Lnth=28.5 t regen =0.36
Z11 ,VlvA=3.32 ,Lnth=28.5 t regen =0.36
Z11 ,VlvA=4.08 ,Lnth=28.5 t =0.36



Cumulative Reverse Flow Distance
Reverse Flow Distance [m]
Time [sec]
0
-0.05
-0.1
-0.15
-0.2
-0.25
0.36
0.365
0.37
0.375
0.38
0.385
0.39
0.395
0.4
0.405
0.41
X: 0.4016
Y: -0.2205
T11 ,VlvA=1.8 ,Lnth=8.5 t regen =0.36
T11 ,VlvA=2.56 ,Lnth=8.5 t regen =0.36
T11 ,VlvA=3.32 ,Lnth=8.5 t regen =0.36
T11 ,VlvA=4.08 ,Lnth=8.5 t regen =0.36
T11 ,VlvA=1.8 ,Lnth=12.5 t regen =0.36
T11 ,VlvA=2.56 ,Lnth=12.5 t regen =0.36
T11 ,VlvA=3.32 ,Lnth=12.5 t regen =0.36
T11 ,VlvA=4.08 ,Lnth=12.5 t regen =0.36
T11 ,VlvA=1.8 ,Lnth=16.5 t regen =0.36
T11 ,VlvA=2.56 ,Lnth=16.5 t regen =0.36
T11 ,VlvA=3.32 ,Lnth=16.5 t regen =0.36
T11 ,VlvA=4.08 ,Lnth=16.5 t regen =0.36
T11 ,VlvA=1.8 ,Lnth=20.5 t regen =0.36
T11 ,VlvA=2.56 ,Lnth=20.5 t regen =0.36
T11 ,VlvA=3.32 ,Lnth=20.5 t regen =0.36
T11 ,VlvA=4.08 ,Lnth=20.5 t regen =0.36
T11 ,VlvA=1.8 ,Lnth=24.5 t regen =0.36
T11 ,VlvA=2.56 ,Lnth=24.5 t regen =0.36
T11 ,VlvA=3.32 ,Lnth=24.5 t regen =0.36
T11 ,VlvA=4.08 ,Lnth=24.5 t regen =0.36
T11 ,VlvA=1.8 ,Lnth=28.5 t regen =0.36
T11 ,VlvA=2.56 ,Lnth=28.5 t regen =0.36
T11 ,VlvA=3.32 ,Lnth=28.5 t regen =0.36
T11 ,VlvA=4.08 ,Lnth=28.5 t regen =0.36



Flow Acceleration Profile
Flow Acceleration [m/sec 2]
Time [sec]
500
0
-500
-1000
-1500
0.36
0.37
0.38
0.39
0.4
0.41
V70 ,VlvA=1.8 ,Lnth=8.5 t regen =0.36
V70 ,VlvA=2.56 ,Lnth=8.5 t regen =0.36
V70 ,VlvA=3.32 ,Lnth=8.5 t regen =0.36
V70 ,VlvA=4.08 ,Lnth=8.5 t regen =0.36
V70 ,VlvA=1.8 ,Lnth=12.5 t regen =0.36
V70 ,VlvA=2.56 ,Lnth=12.5 t regen =0.36
V70 ,VlvA=3.32 ,Lnth=12.5 t regen =0.36
V70 ,VlvA=4.08 ,Lnth=12.5 t regen =0.36
V70 ,VlvA=1.8 ,Lnth=16.5 t regen =0.36
V70 ,VlvA=2.56 ,Lnth=16.5 t regen =0.36
V70 ,VlvA=3.32 ,Lnth=16.5 t regen =0.36
V70 ,VlvA=4.08 ,Lnth=16.5 t regen =0.36
V70 ,VlvA=1.8 ,Lnth=20.5 t regen =0.36
V70 ,VlvA=2.56 ,Lnth=20.5 t regen =0.36
V70 ,VlvA=3.32 ,Lnth=20.5 t regen =0.36
V70 ,VlvA=4.08 ,Lnth=20.5 t regen =0.36
V70 ,VlvA=1.8 ,Lnth=24.5 t regen =0.36
V70 ,VlvA=2.56 ,Lnth=24.5 t regen =0.36
V70 ,VlvA=3.32 ,Lnth=24.5 t regen =0.36
V70 ,VlvA=4.08 ,Lnth=24.5 t regen =0.36
V70 ,VlvA=1.8 ,Lnth=28.5 t regen =0.36
V70 ,VlvA=2.56 ,Lnth=28.5 t regen =0.36
V70 ,VlvA=3.32 ,Lnth=28.5 t regen =0.36
V70 ,VlvA=4.08 ,Lnth=28.5 t regen =0.36

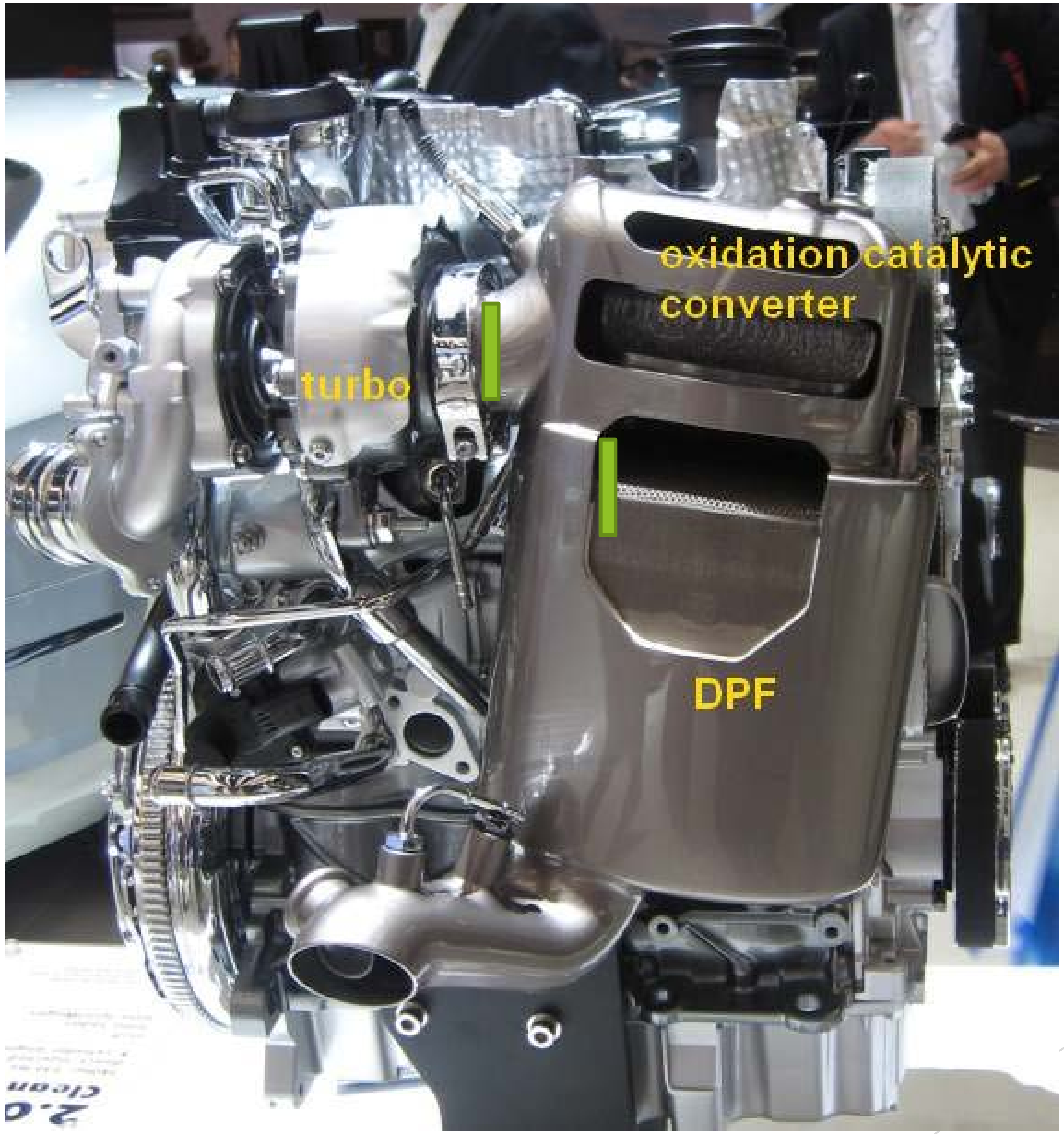


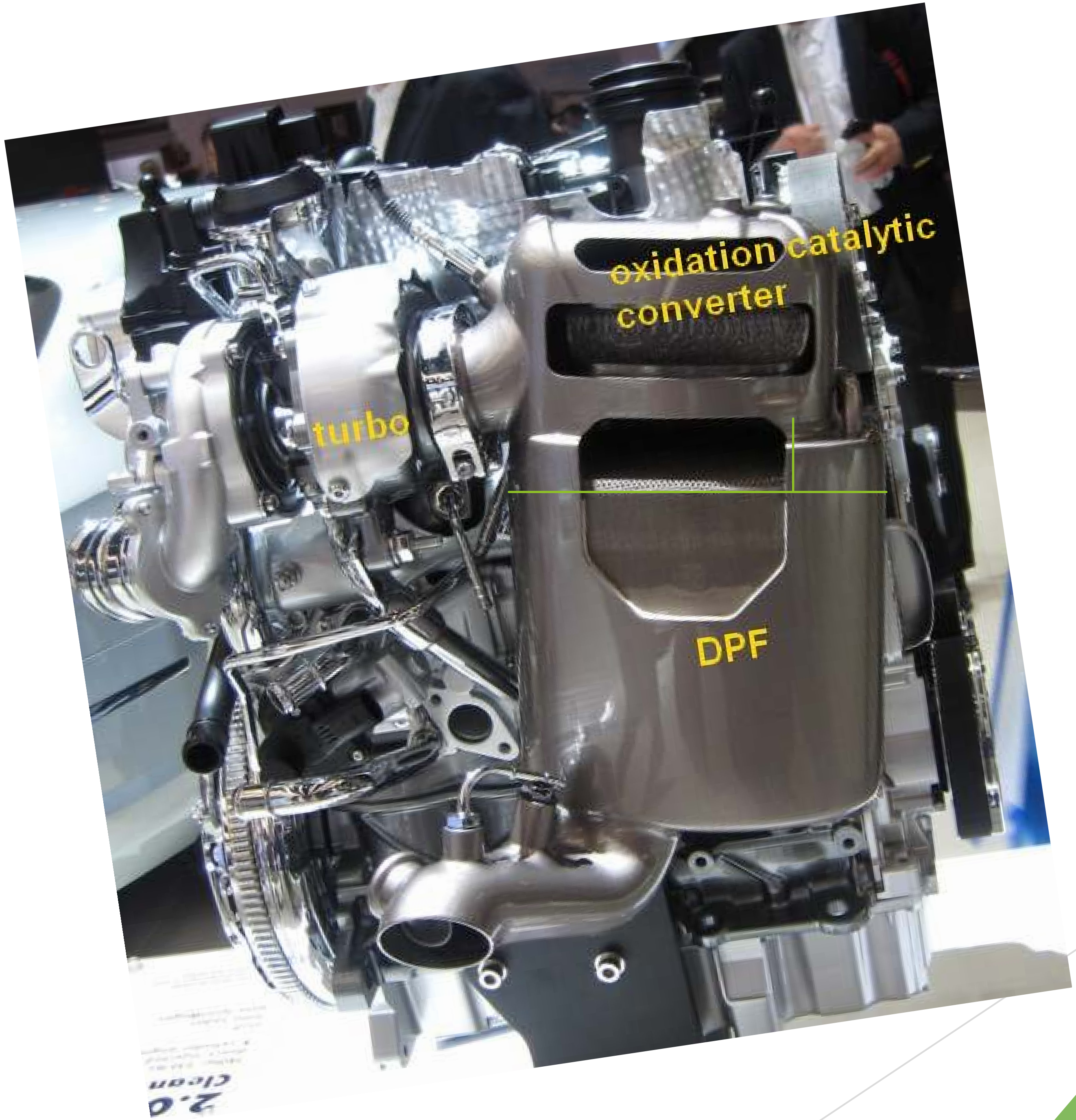
Cumulative Reverse Flow Distance
T11 ,VlvA=1.8 ,Lnth=8.5 t regen =0.36
T11 ,VlvA=2.56 ,Lnth=8.5 t regen =0.36
T11 ,VlvA=3.32 ,Lnth=8.5 t regen =0.36
T11 ,VlvA=4.08 ,Lnth=8.5 t regen =0.36
T11 ,VlvA=1.8 ,Lnth=12.5 t regen =0.36
T11 ,VlvA=2.56 ,Lnth=12.5 t regen =0.36
T11 ,VlvA=3.32 ,Lnth=12.5 t regen =0.36
T11 ,VlvA=4.08 ,Lnth=12.5 t regen =0.36
T11 ,VlvA=1.8 ,Lnth=16.5 t regen =0.36
T11 ,VlvA=2.56 ,Lnth=16.5 t regen =0.36
T11 ,VlvA=3.32 ,Lnth=16.5 t regen =0.36
T11 ,VlvA=4.08 ,Lnth=16.5 t regen =0.36
T11 ,VlvA=1.8 ,Lnth=20.5 t regen =0.36
T11 ,VlvA=2.56 ,Lnth=20.5 t regen =0.36
T11 ,VlvA=3.32 ,Lnth=20.5 t regen =0.36
T11 ,VlvA=4.08 ,Lnth=20.5 t regen =0.36
T11 ,VlvA=1.8 ,Lnth=24.5 t regen =0.36
T11 ,VlvA=2.56 ,Lnth=24.5 t regen =0.36
T11 ,VlvA=3.32 ,Lnth=24.5 t regen =0.36
T11 ,VlvA=4.08 ,Lnth=24.5 t regen =0.36
T11 ,VlvA=1.8 ,Lnth=28.5 t regen =0.36
T11 ,VlvA=2.56 ,Lnth=28.5 t regen =0.36
T11 ,VlvA=3.32 ,Lnth=28.5 t regen =0.36
T11 ,VlvA=4.08 ,Lnth=28.5 t regen =0.36
X: 0.3878
Y: -0.1268
X: 0.3919
Y: -0.1556
X: 0.3953
Y: -0.1775
X: 0.3977
Y: -0.1948
X: 0.3998
Y: -0.2089
Y: -0.2205
0
-0.05
-0.1
-0.15
-0.2
-0.25
Reverse Flow Distance [m]
0.36
0.365
0.37
0.375
0.38
0.385
0.39
0.395
0.4
0.405
0.41
Time [sec]

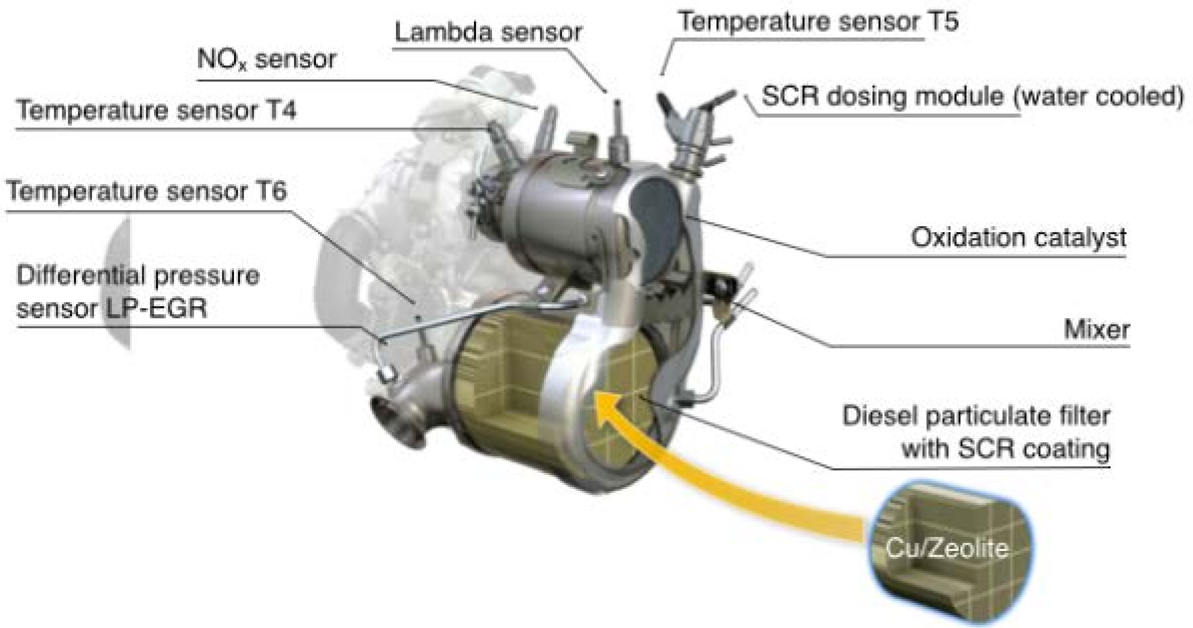
```
%Specify the complete path where the executable is located
path_exe = 'C:\Program Files (x86)\GFSSP701\';
%Specify the complete path where the case files are located
%Files required in the directory include:
%[case]IN.dat,ExhBrake.dat,RegenValve.dat,
path_case = 'C:\Users\brett\Desktop\1dCode\Jetta1DMod2\';
name_case = 'Jetta220kPa4inafterDPF'; %name of the case, used to generate
file names
Run_steady = 1; %Do you want to perform a steady simulation? 0=No 1=Yesgf
Run_unsteady = 1; %Do you want to perform an unsteady simulation? 0=No 1=Yes
% if both steady and unsteady sumlations are performed, the steady
% siumulation will occur first.

%OUTPUT OPTIONS
SIoutput = 1; %set to 0 for english units on plots, or 1 for SI
PressurePlot = [100,9];% enter the NODE numbers for the pressures you want to
plot
VelPlot = [70];% enter the BRANCH numbers for the velocities you want to plot
MFPlot = [70];% enter the BRANCH numbers for the mass flows you want to plot
dPPlot = [70];% enter the BRANCH numbers for the Pressure Difference you want
to plot
DistRevF = [70];%enter the BRANCH numbers for the reverse flow distance you
want to plot

TargetPressure = 220;%kPa %note: set in kPa for SIoutput=1, in psi for
SIoutput=0
dP = 1.0; %kPa %accuracy desired for target pressure match, set to high
number to skip
tGuessSav = 0.36; %initial guess for regen valve timing
PNode = 3; %please enter the node entry position for the intereated pressure,
i.e. 3 = third entry in pressure output

%Note: these inputs are in english units
Variable = 'VlvA'; %specify for output labeling
Range1 = [1.8:0.76:4.08];

Variable2 = 'Lnth';
Range2 = [8.5:4:28.5]; %currently set to valve area
```

https://www.performanceexhaust.com.au/p/Mitsubishi/Pajero-NS-NT-NW/3.2TD/MITSUBISHI-PAJERO-NS-NT-NW-3.2LT-TD-DIESEL-DPF/DPF036

GLOBAL CLEAN DIESEL

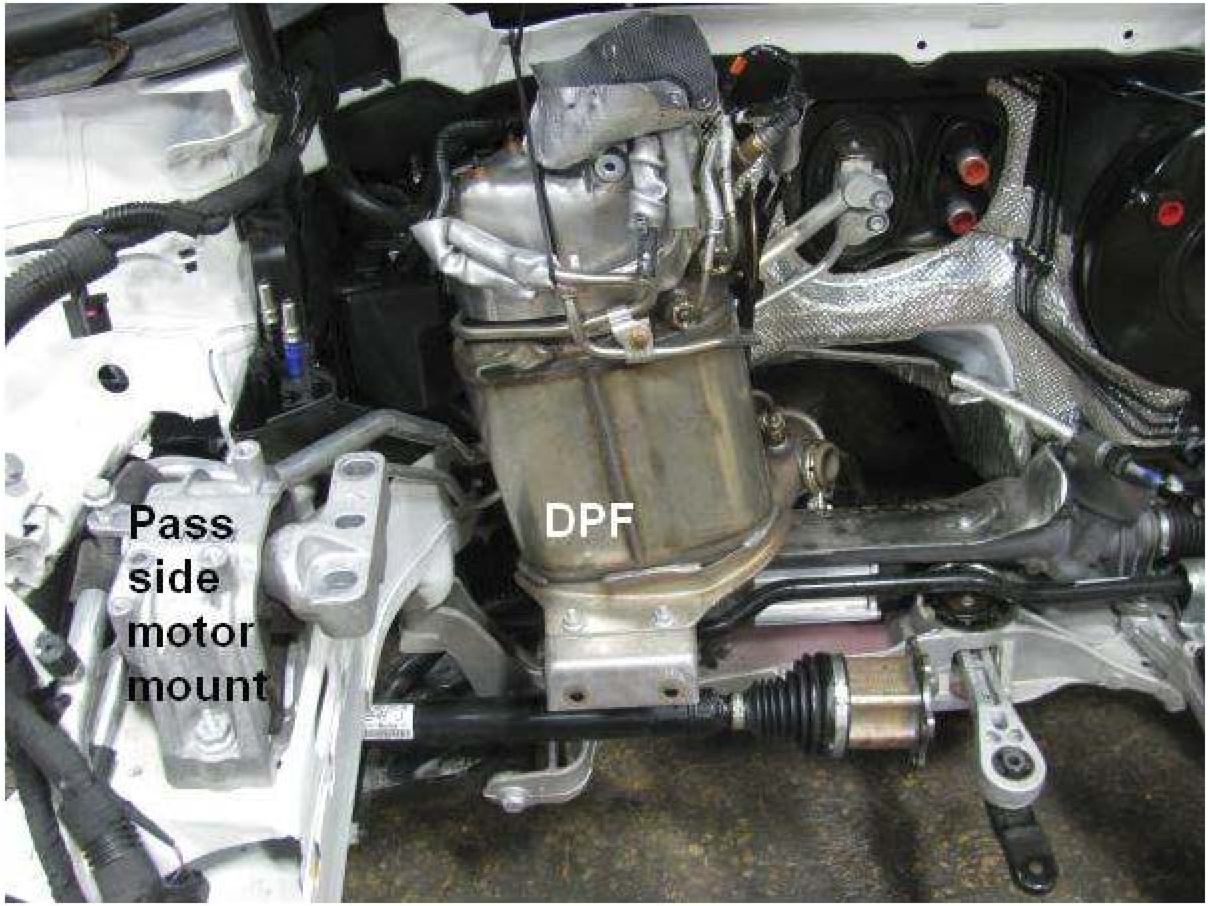

oxidation catalytic
converter
turbo
DPF


oxidation catalytic converter
turbo
DPF

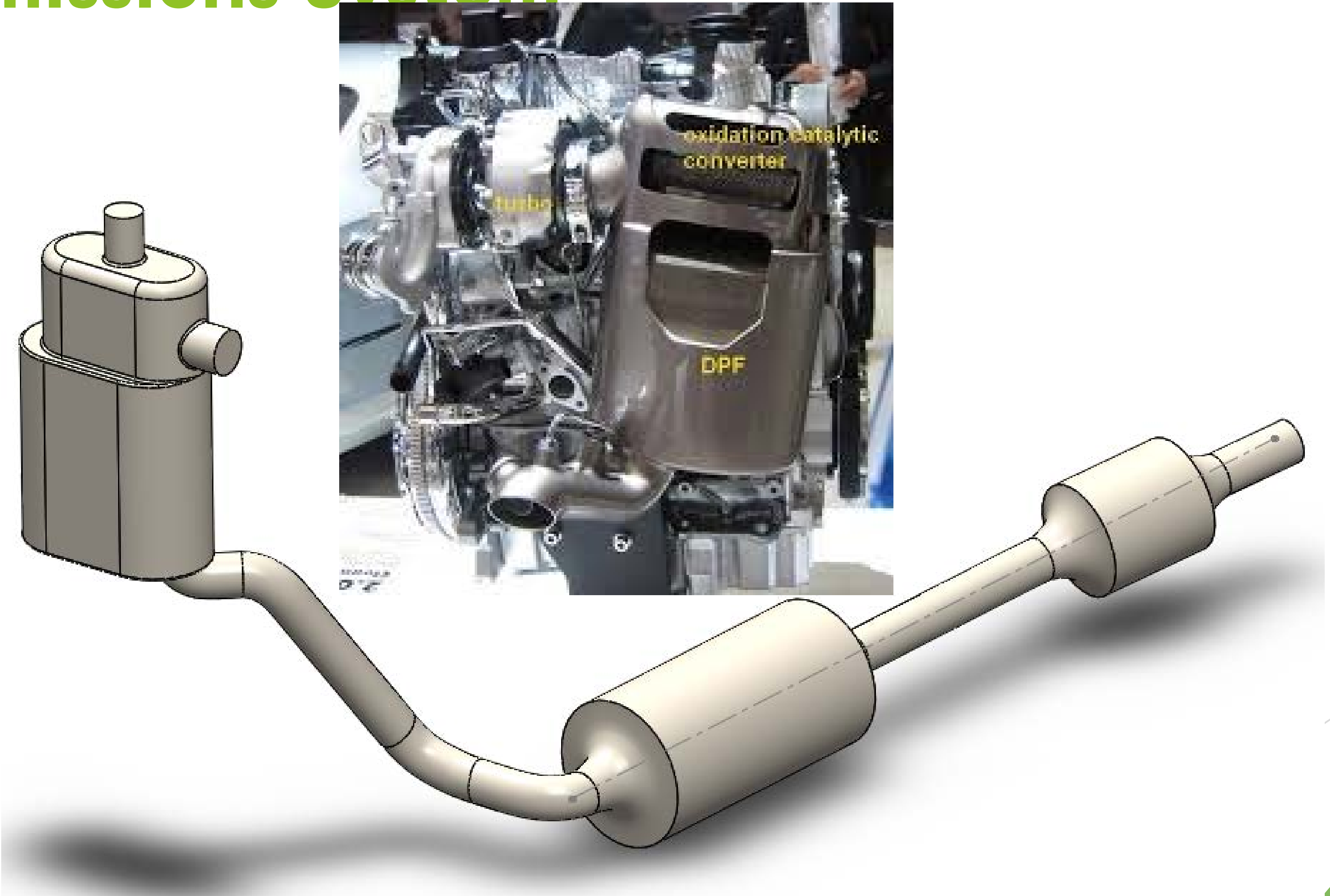

Lambda sensor
Temperature sensor T5
NO_x sensor
SCR dosing module (water cooled)
Temperature sensor T4
Temperature sensor T6
Oxidation catalyst
Differential pressure
sensor LP-EGR
Mixer
Diesel particulate filter
with SCR coating
Cu/Zeolite

Volkswagen Jetta DPF Outlet

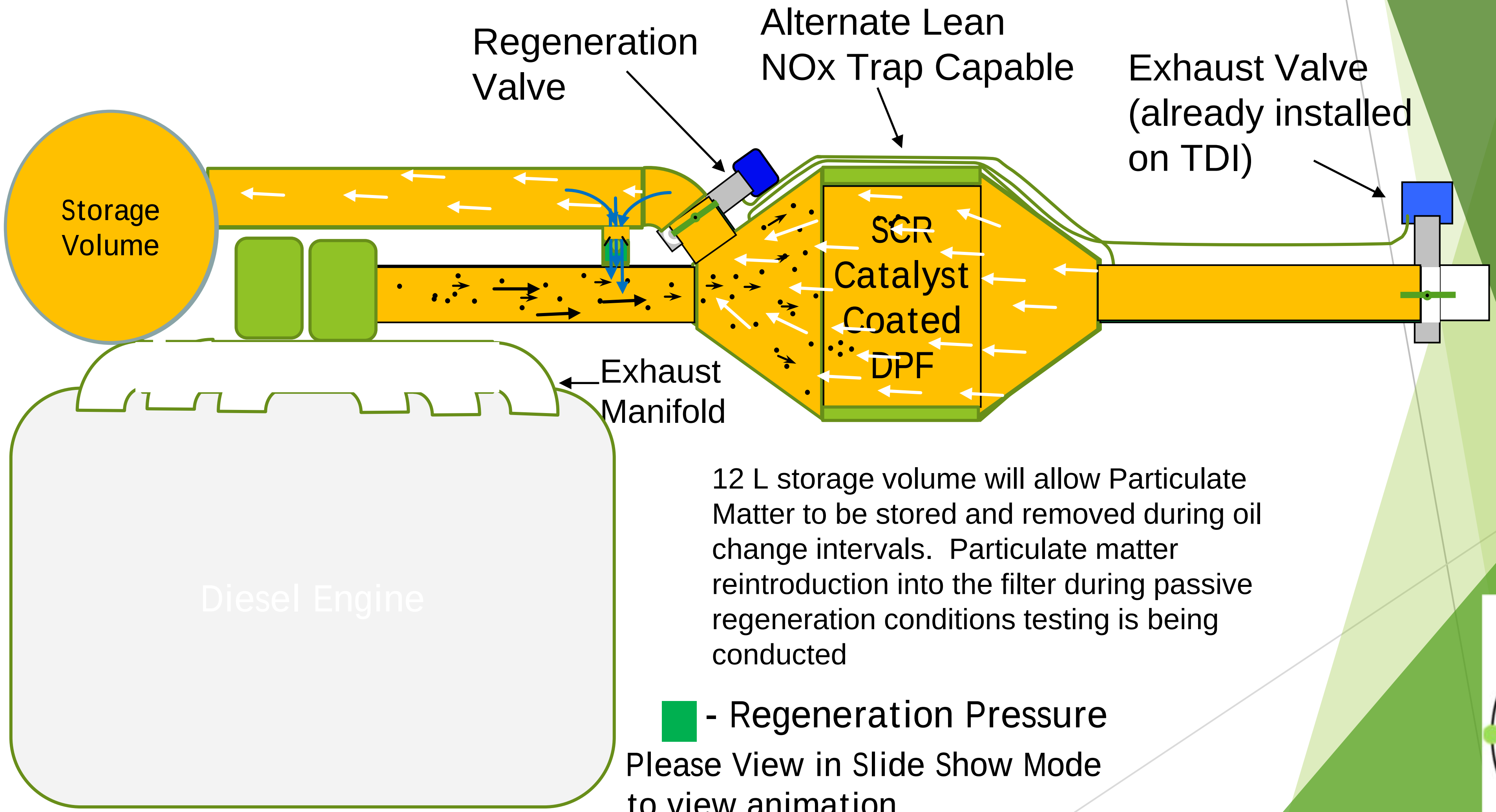

pic by Greg Roles
myturbodiesel.com


DPF
Pass
side
motor
mount

2011 Volkswagen Jetta Sportwagen Emissions System



Cool Particulate Regeneration™, CPR™ How it works



12 L storage volume will allow Particulate Matter to be stored and removed during oil change intervals. Particulate matter reintroduction into the filter during passive regeneration conditions testing is being conducted

- Regeneration Pressure

Please View in Slide Show Mode to view animation

DOC – Diesel Oxidation Catalyst DPF – Diesel Particulate Filter LNT – Lean NOx Trap

Table 4-17 Estimated costs of emission control technologies for European diesel LDV, Vd>2.0 L

REGULATION	EURO 1	EURO 2	EURO 3	EURO 4	EURO 5	EURO 6
INTRODUCTION YEAR	1992	1996	2000	2005	2009	2014
REGULATED POLLUTANTS	(NO_x+HC/PM/CO)	(NO_x+HC/PM/CO)	(NO_x/PM/CO)	(NO_x/PM/CO)	(NO_x/PM/CO)	(NO_x/PM/CO)
EMISSION LEVELS, G/KM	1.13/0.18/3.16	0.7/0.08/1	0.5/0.05/0.64	0.25/0.025/0.5	0.18/0.005/0.5	0.08/.0045/0.5
1. A/F control & engine-out emissions	**Assuming a 4-cyl engine, Vd= 2.5 liters**					
Fuel system - 50% of cost (a)	-	$50	$345	$380	$417	$459
Turbocharger - 50% of cost (b)	-	-	-	$80	$80	$147
Intercooler - 50% of costs (b)	-	-	-	$34	$34	$34
VGT (extra cost) - 50% of costs (b)	-	-	-	-	$60	$60
EGR valves (c)	$30	$30	$30	$38	$38	$38
EGR cooling system (c)	-	$39	$39	$47	$54	$62
Engine mapping and tuning (d)	-	R&D	R&D	R&D	R&D	R&D
Improvements on combustion chamber & nozzle geometry (e)	-	R&D	R&D	R&D	R&D	R&D
Cost of A/F control & engine-out emissions	**$30**	**$119**	**$414**	**$578**	**$684**	**$800**
2. Aftertreatment systems	**Assuming a 4-cyl engine, Vd= 2.5 liters**					
Diesel oxidation catalyst (DOC) (f)	-	-	$99	$99	$99	$99
Diesel particulate filter (DPF) (f)	-	-	-	-	$402	$402
Lean NO_x trap (LNT) (f)	-	-	-	-	-	$509
Selective catalytic reduction (SCR) (f,g)	-	-	-	-	-	-
Cost of aftertreatment systems (h)	**$0**	**$0**	**$99**	**$99**	**$501**	**$1,011**
3. Total cost of hardware [1+2]	$30	$119	$513	$677	$1,185	$1,811
4. Fixed costs (R&D, tooling, certification)	$26	$26	$51	$51	$51	$51
5. Total cost of emissions control tech [3+4]	$56	$145	$564	$728	$1,236	$1,862

(a) Cost of rotary pump, HPFI pump, valves, common rail, and injectors. 50% of cost is charged to non-CO_2 regulated emissions

(b) Single stage turbocharging assumed. 50% of cost is charged to non-CO_2 regulated emissions

(c) Single loop EGR. 50% of cost is charged to non-CO_2 regulated emissions

(d) Maximization of fuel economy and minimization of emissions by fuel injection strategies, air management, turbo, EGR.

(e) Research and development focused on improving combustion (fuel efficiency and emissions) through modeling (CFD) and experiments.

(f) See diesel aftertreatment detail.

(g) SCR cost includes the cost of dosage unit and tank. NH_3 slip catalyst included. NO_x sensor and H_2S catalyst not included in cost.

(h) The cost of aftertreatment systems includes a minimum of devices for control of HC, CO, PM and NO_x. The cost presented may vary depending on specific engine applications.

Table 4-18 Estimated costs of emission control technologies for diesel passenger cars under US Tier 2-Bin 5 emission levels

DIESEL	4-CYL OR Vd<2.5 LITERS	6-CYL OR Vd>2.5 LITERS
REGULATION	TIER 2 BIN 5	TIER 2 BIN 5
INTRODUCTION YEAR	2009	2009
REGULATED POLLUTANTS	(NO_x/PM/CO)	(NO_x/PM/CO)
EMISSION LEVELS, G/KM	0.04/0.006/2.5	0.04/0.006/2.5
1. A/F control & engine-out emission	**Assuming 4-cyl, Vd=2.0L**	**Assuming 6-cyl, Vd=3.0L**
Fuel system - 50% of cost (a)	$420	$459
Turbocharger - 50% of cost (b)	$138	$155
Intercooler - 50% of costs (b)	$32	$39
VGT (extra cost) - 50% of costs (b)	$50	$60
EGR valves (c)	$38	$38
EGR cooling system (c)	$58	$66
Engine mapping and tuning (d)	R&D	R&D
Improvements on combustion chamber & nozzle geometry (e)	R&D	R&D
Cost of A/F control & engine-out emission	**$736**	**$817**
2. Aftertreatment systems	**Vd=2.0 L**	**Vd=3.0 L**
Diesel oxidation catalyst (DOC) (f)	$78	$116
Diesel particulate filter (DPF) (f)	$332	$468
Lean NO_x trap (LNT) (f)	$413	($602)*
Selective catalytic reduction (SCR) (f, g)	-	$633**
Cost of aftertreatment systems (h)	**$823**	**$1,217**
3. Total cost of hardware [1+2]	$1,559	$2,035
4. Fixed costs (R&D, tooling, certification)	$51	$51
5. Total cost of emission control tech. [3+4]	$1,610	$2,086

* Note: Cost numbers in parenthesis are informative, not added to final cost summation.

** SCR catalyst cost calculated with SVR corresponding to US requirements (SVR=2.0).

(a) Cost of rotary pump, HPFI pump, valves, common rail, and injectors. 50% of cost is charged to non-CO_2 regulated emissions.

(b) Single stage turbocharging assumed. 50% of cost is charged to non-CO_2 regulated emissions.

(c) Single loop EGR. 50% of cost is charged to non-CO_2 regulated emissions.

Table 4-18 Estimated costs of emission control technologies for diesel passenger cars under US Tier 2-Bin 5 emission levels

DIESEL	4-CYL OR Vd<2.5 LITERS	6-CYL OR Vd>2.5 LITERS
REGULATION	TIER 2 BIN 5	TIER 2 BIN 5
INTRODUCTION YEAR	2009	2009
REGULATED POLLUTANTS	(NO_x/PM/CO)	(NO_x/PM/CO)
EMISSION LEVELS, G/KM	0.04/0.006/2.5	0.04/0.006/2.5
1. A/F control & engine-out emission	**Assuming 4-cyl, Vd=2.0L**	**Assuming 6-cyl, Vd=3.0L**
Fuel system - 50% of cost (a)	$420	$459
Turbocharger - 50% of cost (b)	$138	$155
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EGR valves (c)	$38	$38
EGR cooling system (c)	$58	$66
Engine mapping and tuning (d)	R&D	R&D
Improvements on combustion chamber & nozzle geometry (e)	R&D	R&D

2. Aftertreatment systems	Vd=2.0 L	Vd=3.0 L
Diesel oxidation catalyst (DOC) (f)	$78	$116
Diesel particulate filter (DPF) (f)	$332	$468
Lean NO_x trap (LNT) (f)	$413	($602)*
Selective catalytic reduction (SCR) (f, g)	-	$633**
Cost of aftertreatment systems (h)	**$823**	**$1,217**
3. Total cost of hardware [1+2]	$1,559	$2,035
4. Fixed costs (R&D, tooling, certification)	$51	$51
5. Total cost of emission control tech. [3+4]	$1,610	$2,086

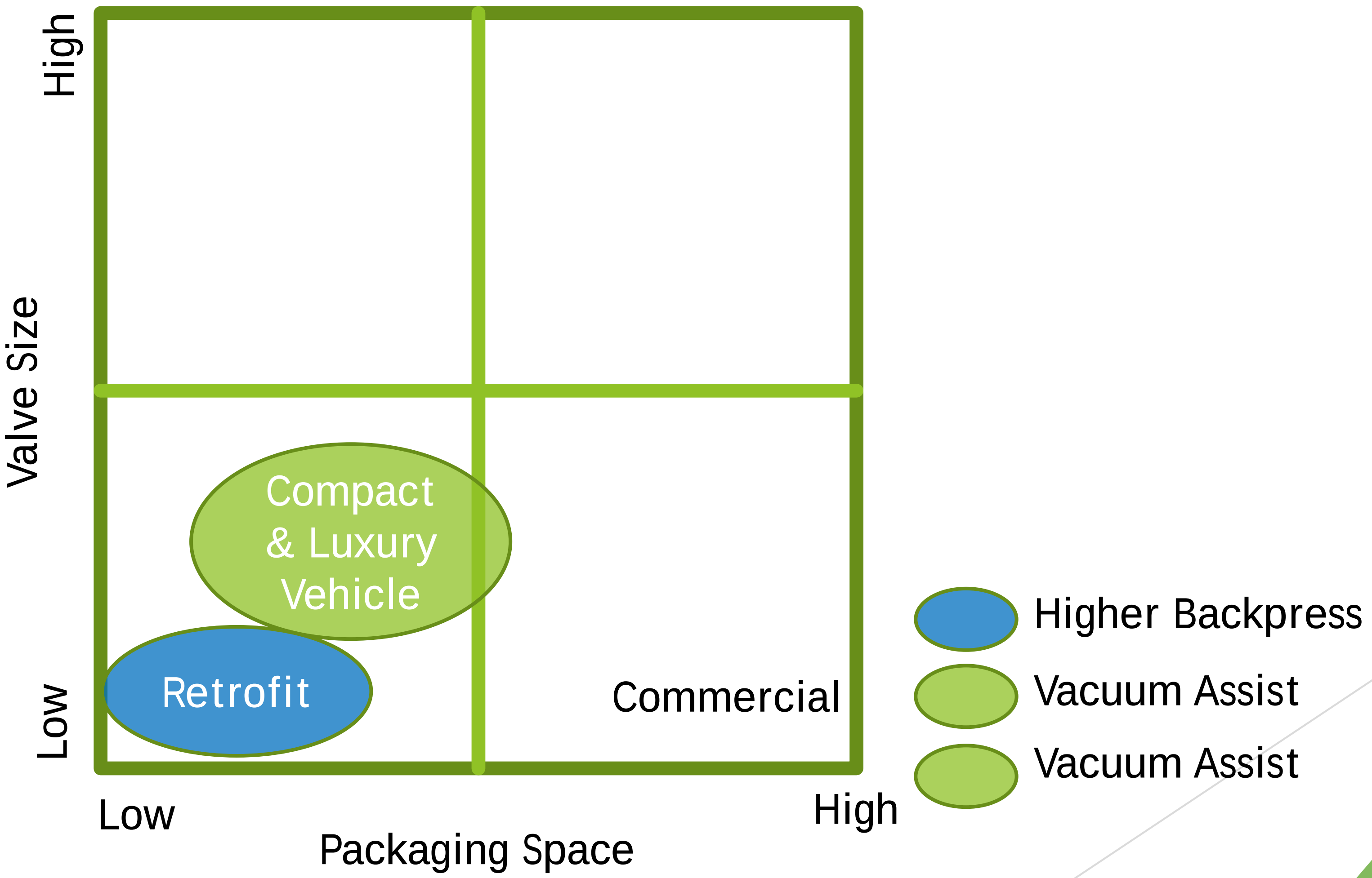
* Note: Cost numbers in parenthesis are informative, not added to final cost summation.

** SCR catalyst cost calculated with SVR corresponding to US requirements (SVR=2.0).

(a) Cost of rotary pump, HPFI pump, valves, common rail, and injectors. 50% of cost is charged to non-CO_2 regulated emissions.

(b) Single stage turbocharging assumed. 50% of cost is charged to non-CO_2 regulated emissions.

(c) Single loop EGR. 50% of cost is charged to non-CO_2 regulated emissions.



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