Fuel Injection Strategy for Soot-Filter Regeneration

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Outline

- Regeneration of Soot Filters
- Causes of Soot Filter Failures
- Modeling of Active Regeneration and Drop-to-Idle events
- Injection Strategy
- Conclusion

Soot Filters in Diesel Exhaust Systems

As the soot accumulates in the filter, the backpressure of the exhaust increases. The soot needs to be removed continuously or periodically.

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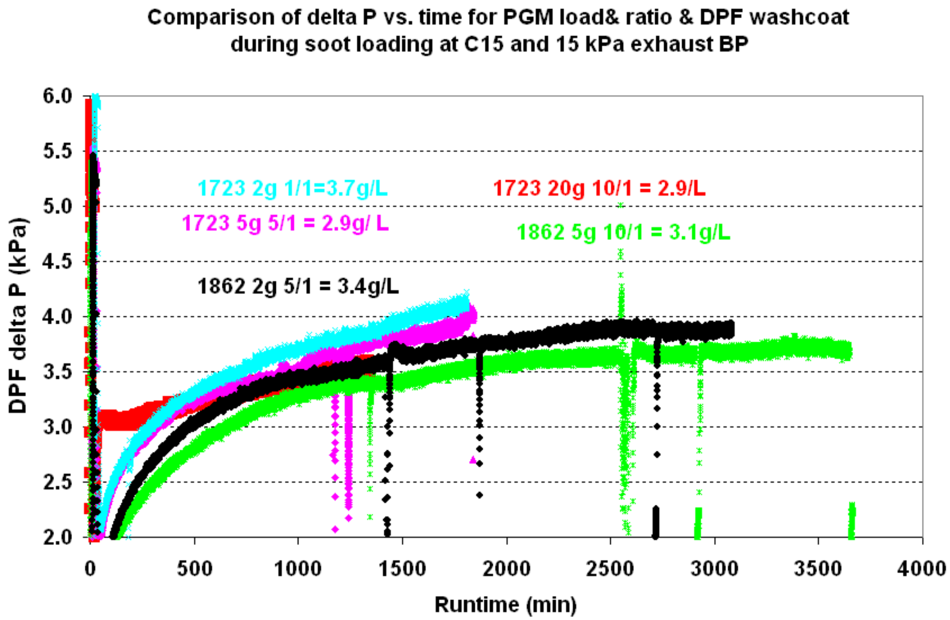
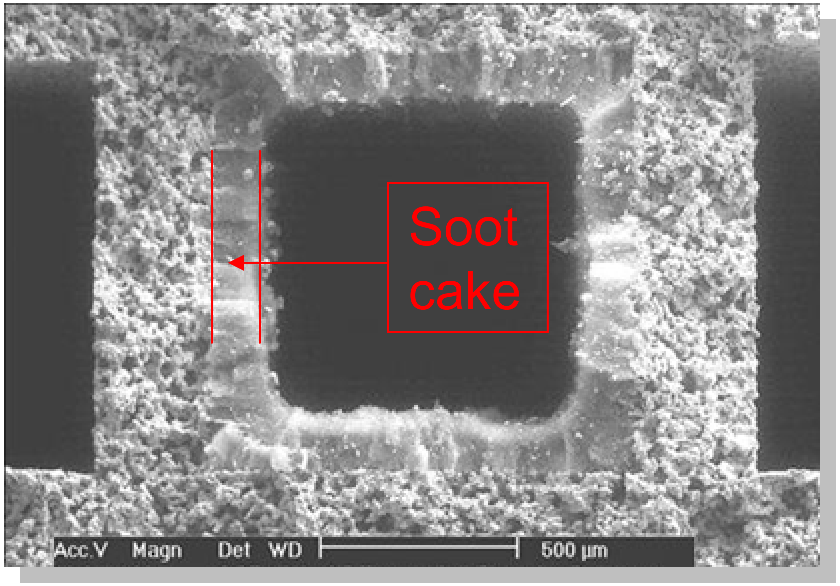
- Soot thickness increases with time
- Backpressure in the exhaust system increases = loss of engine power
- Overload can clog the filter





Passive and Active Regeneration

The exhaust temperature is not always hot enough to regenerate passively the soot filter. Then, active regeneration becomes necessary.

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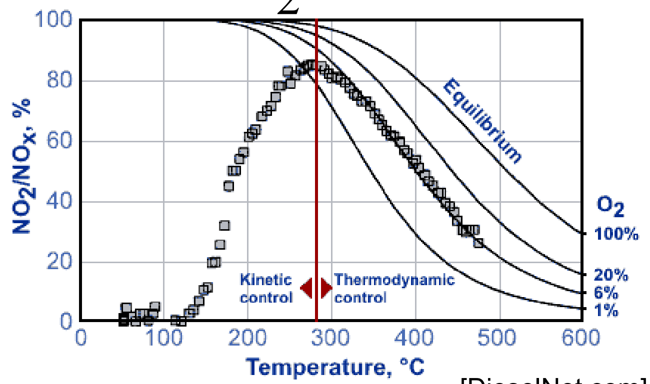
Passive Regeneration (optimal at ≈300°C)

$$NO + \frac{1}{2}O_2 \rightarrow NO_2$$

$$C(soot) + 2\,NO_2 \rightarrow CO_2 + 2\,NO$$

$$C(soot) + NO_2 \rightarrow CO + NO$$

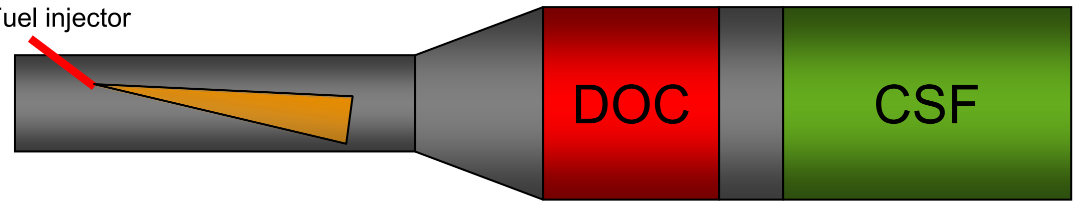


[DieselNet.com]

Active Regeneration (>550°C)

$$C(soot) + O_2 \rightarrow CO_2$$

$$C(soot) + \frac{1}{2}O_2 \rightarrow CO$$



High Temperature is a Risk of Failure for Soot Filters

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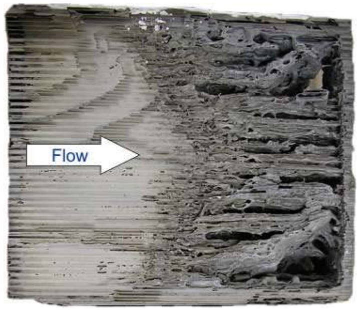
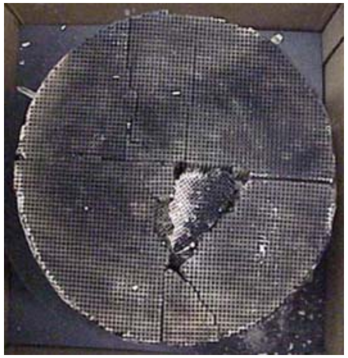
- Loss of catalytic activity
  - Sintering of PM particles
  - Alumina polymorphic transformation (1100^{o}C)
- Ash reaction with cordierite
  - Solid-state reaction with cordierite (1200^{o}C)
  - Filter-ash eutectic
- Mechanical stress
  - Thermal gradients
  - Fatigue
- Melting point of Cordierite (1450^{o}C)



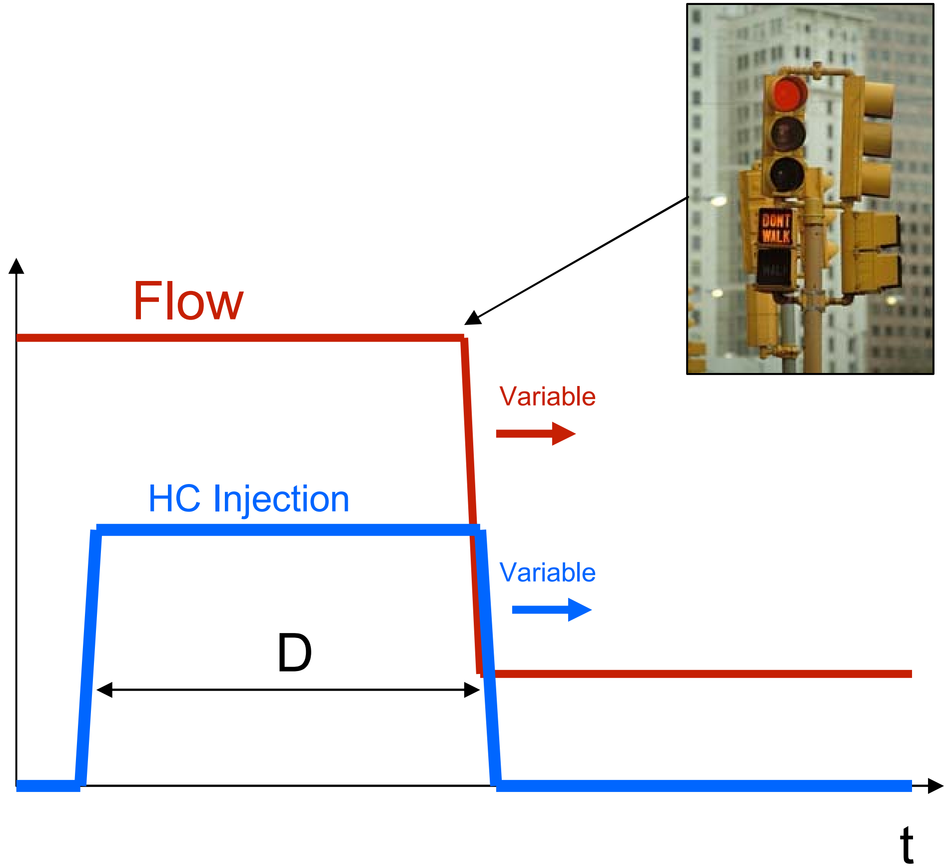


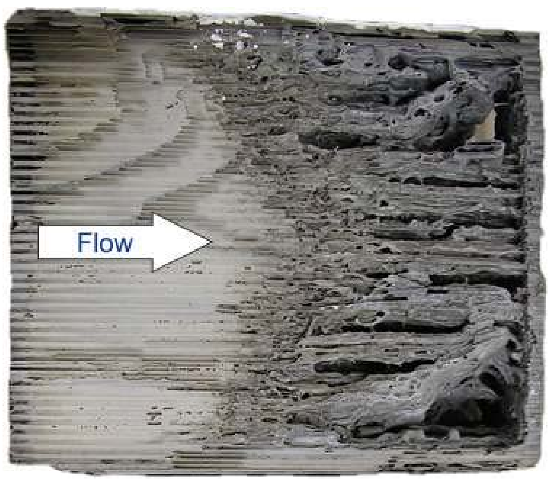
[Photos from DieselNet.com]

Drop-to-Idle:

Sudden drop of the exhaust gas flow rate during an active regeneration. The heat from the soot oxidation accumulates in the CSF and leads to a runaway reaction.

- Sudden drop of the exhaust flow rate





Active Regeneration Simulation

As the temperature increases in the CSF, the soot regeneration rate increases.

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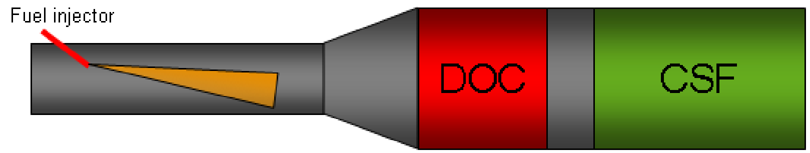
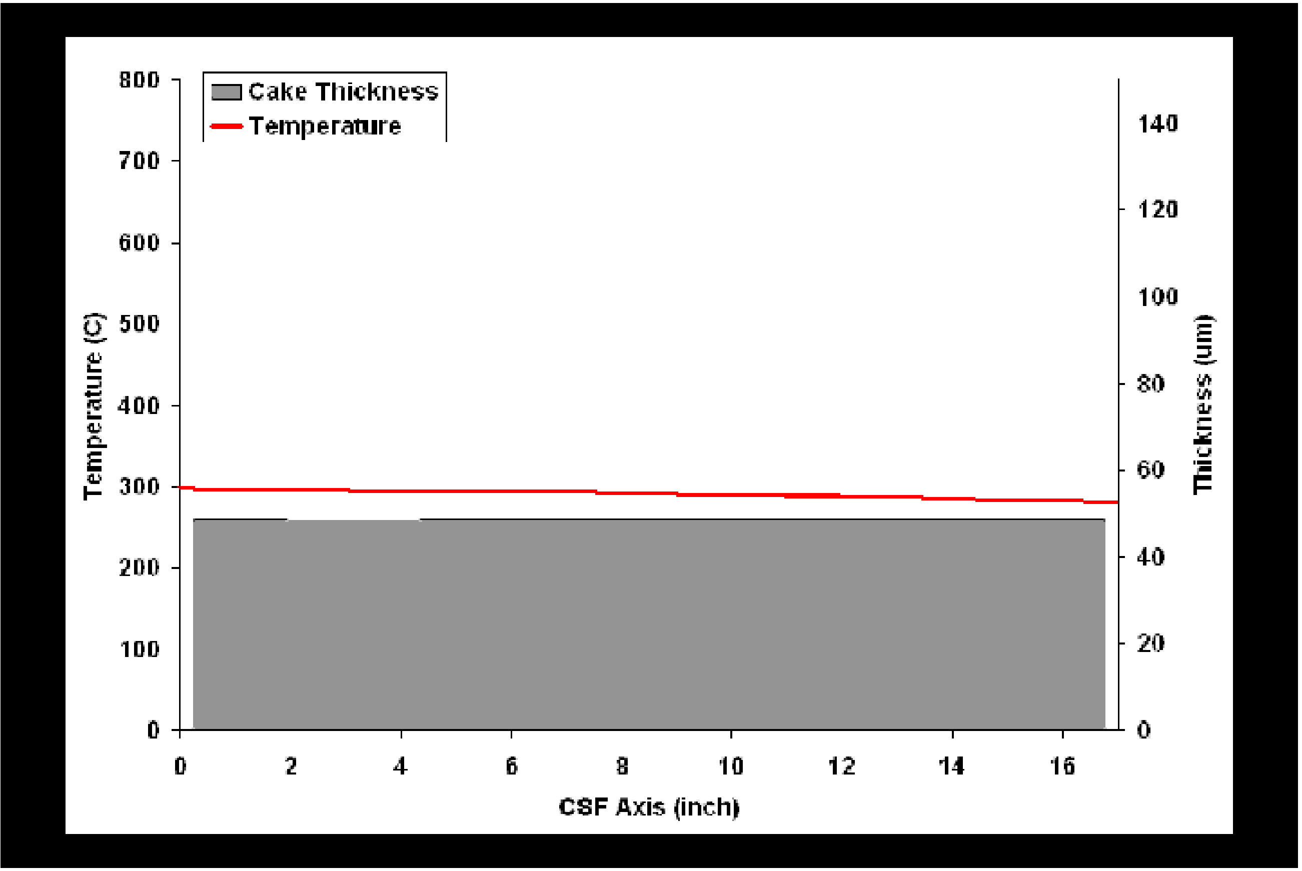
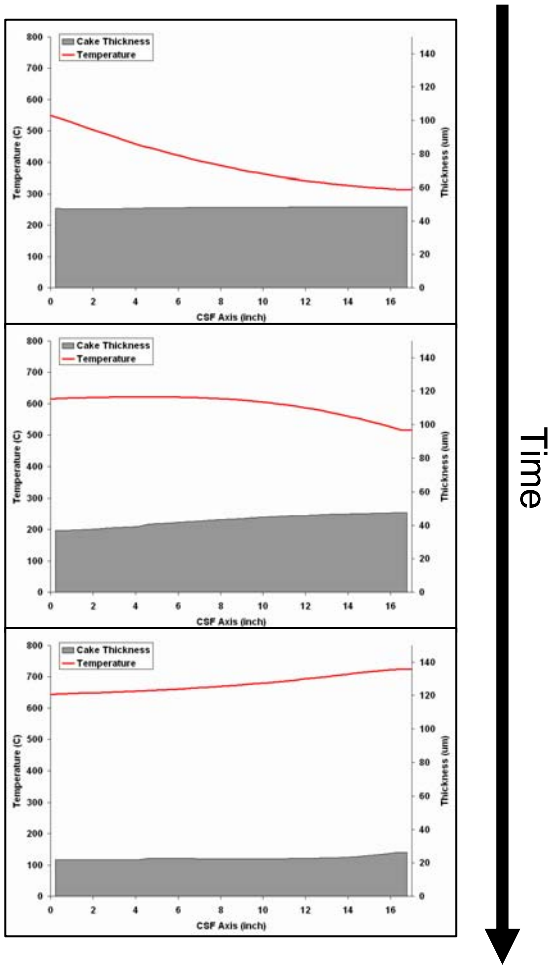
Speed = x 30







Active Regeneration with Drop-to-Idle Simulation

The flow rate is too low to evacuate the heat created by the soot oxidation.

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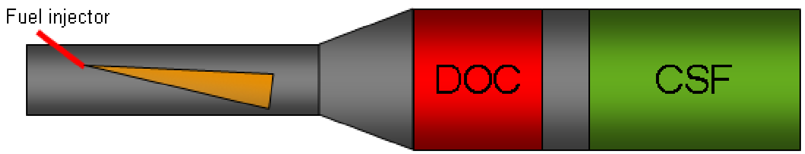
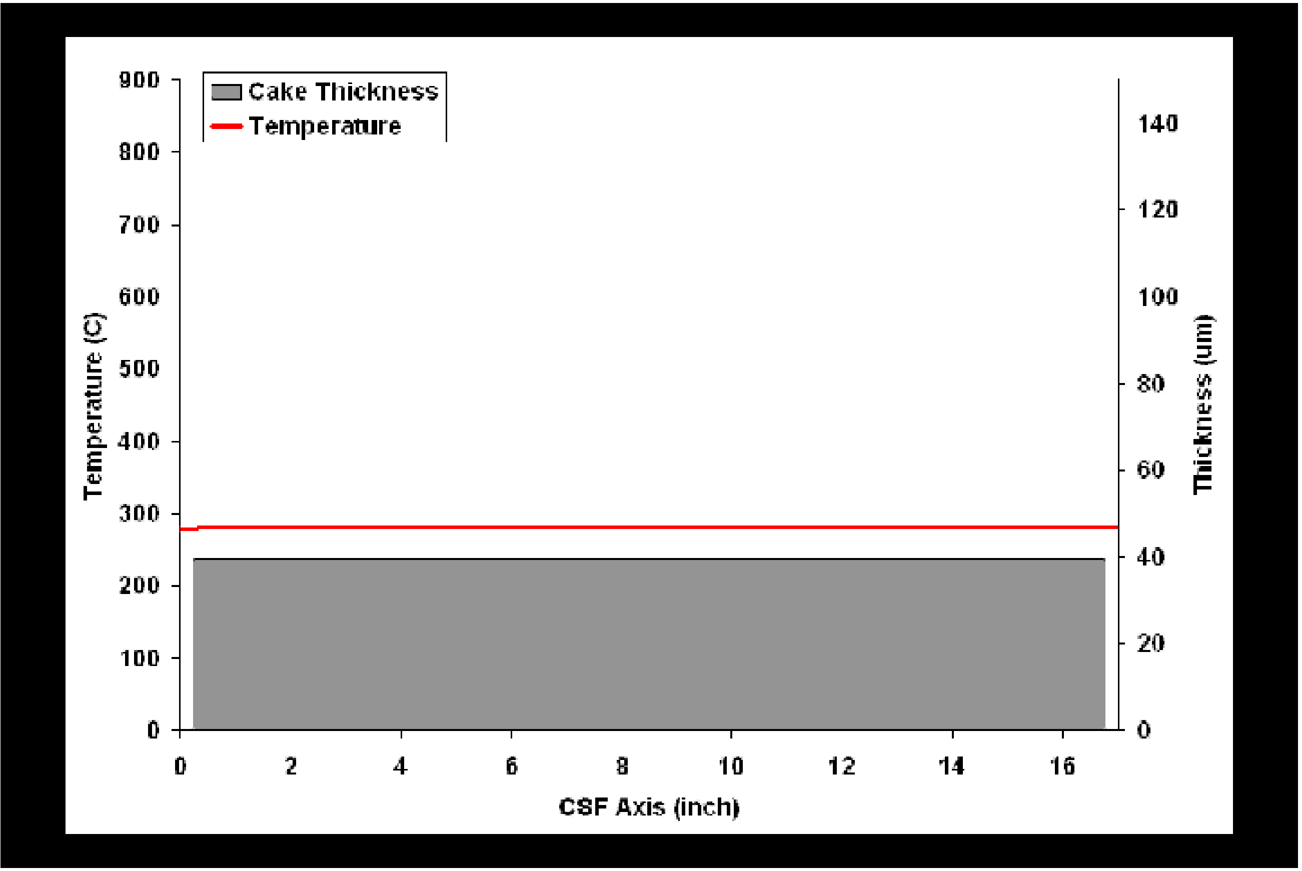
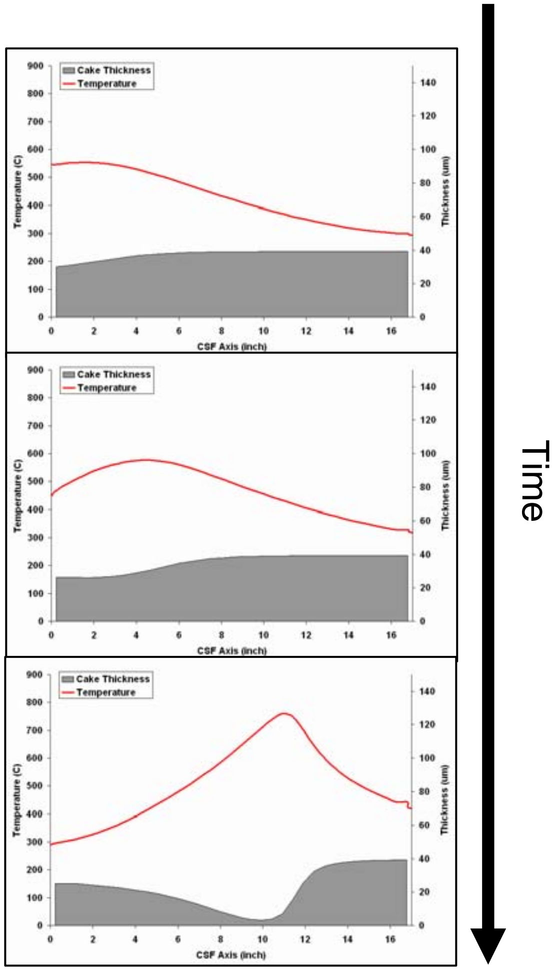
Speed = x 60







Filter Model (BASF CatSim) / Assumptions

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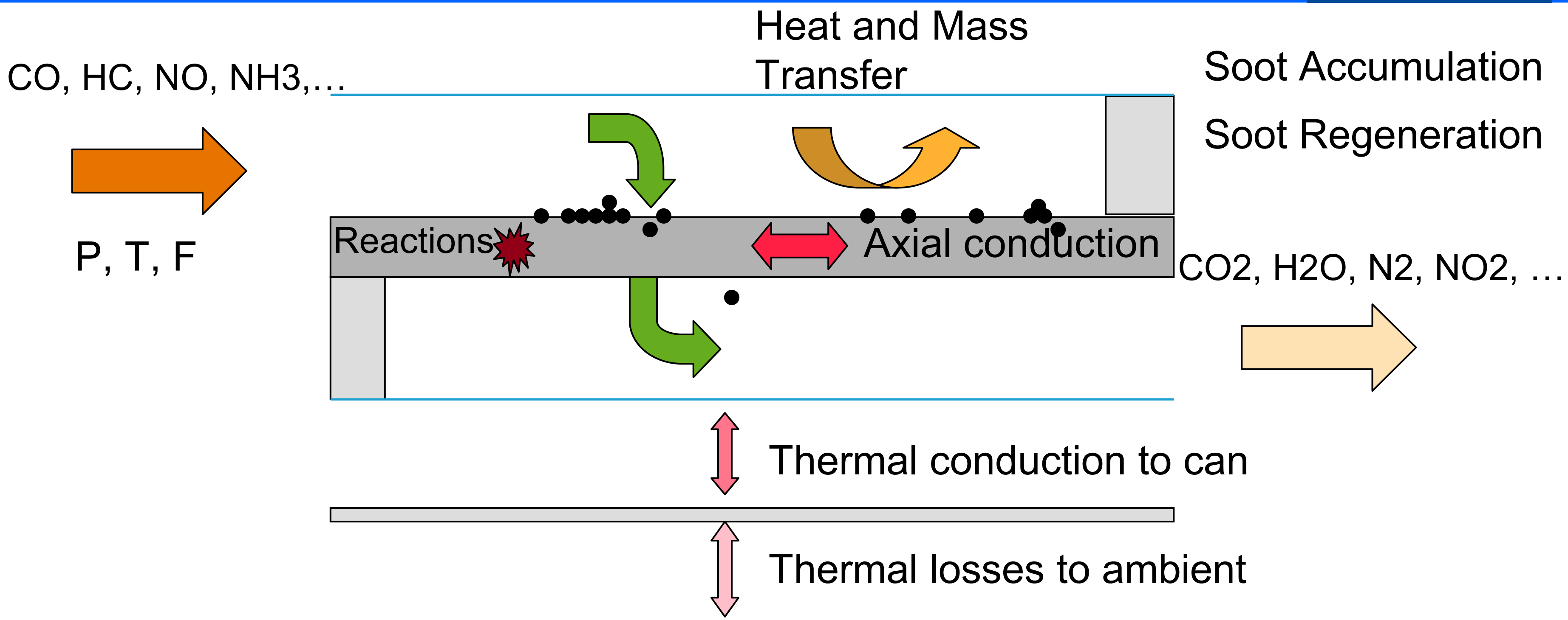
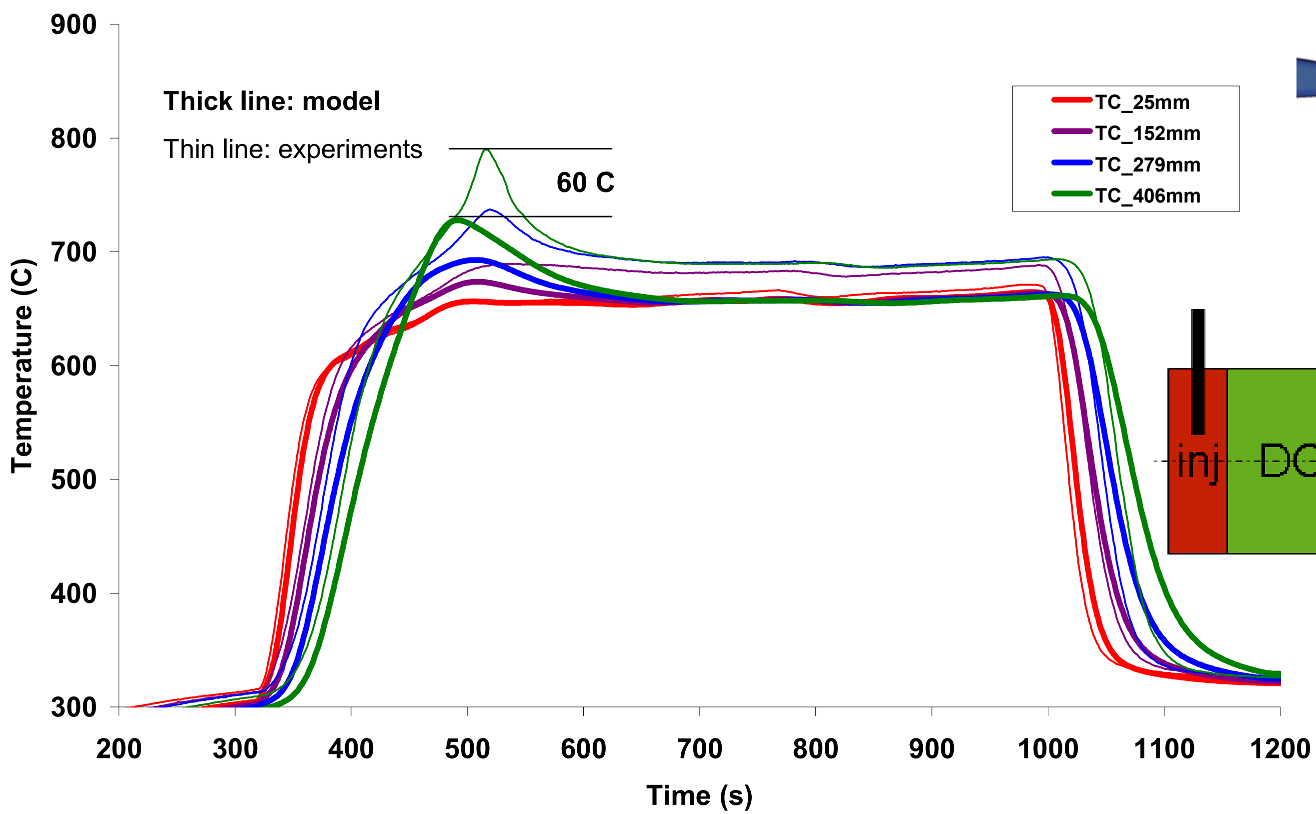


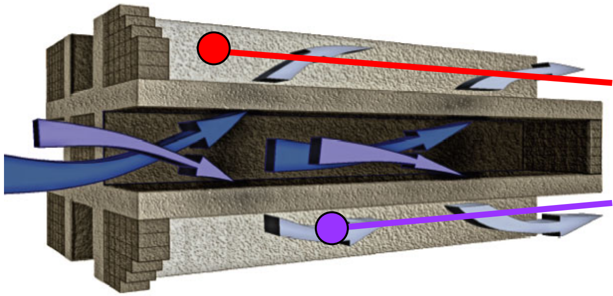
- **Soot oxidation yields equal amounts of CO and CO_2 (CO is converted over the PM function of the catalyst)**
- **No axial motion of the soot from the cake**
- **1D Model (no radial temperature gradients)**
- **Homogeneous soot distribution**
- **Uniform deactivation**

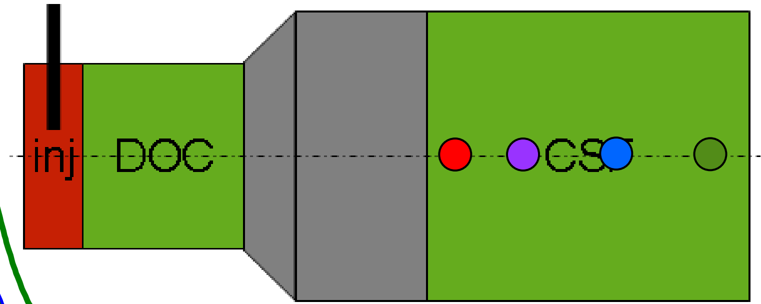
Comparison of Model to Experimental Results.

The model underestimates the maximum temperature in the CSF during an active regeneration (radial thermal gradients are not considered).

Active Regeneration - DOC+ CSF - 600C DOC out - 3.9g/l soot loading







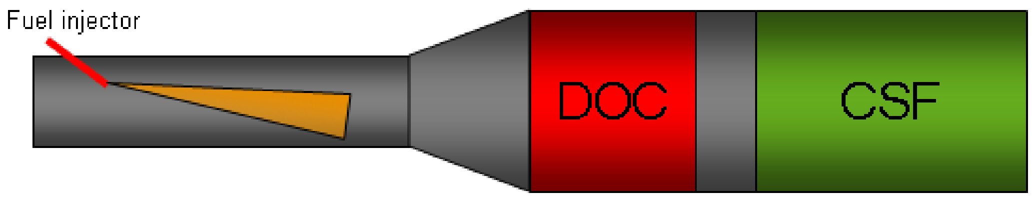
23K/hr

Fuel Injection Strategy: Objectives

- Propose an injection strategy for active regeneration with the following constraints:
  - The maximum temperature in the CSF during a drop-to-idle event must not be higher than 700^{o}C.
  - Reach 90% regeneration.
  - Decrease the duration of the regeneration.

Experimental Conditions

- Initial soot loading: 3.5 gm/l
- Inlet Gas Temperature: 280^{o}C
- Constant filter dry gain of 0.25 gm/in^3
- Drop-to-Idle: 10 to 3 K/hr ; 20 to 3 K/hr



<u>DOC + CSF</u>

Uniform DOC, 300/8, 12”x8”

PM : 60 gm/ft^3 (4:1)

Uniform CSF, 270/16, 13”x17”

PM : 1.2 gm/ft^3 (4:1)

Drop-to-Idle Test (DTI)

The maximum temperature in the CSF during drop-to-idle test has been calculated for variable injection rates and duration.

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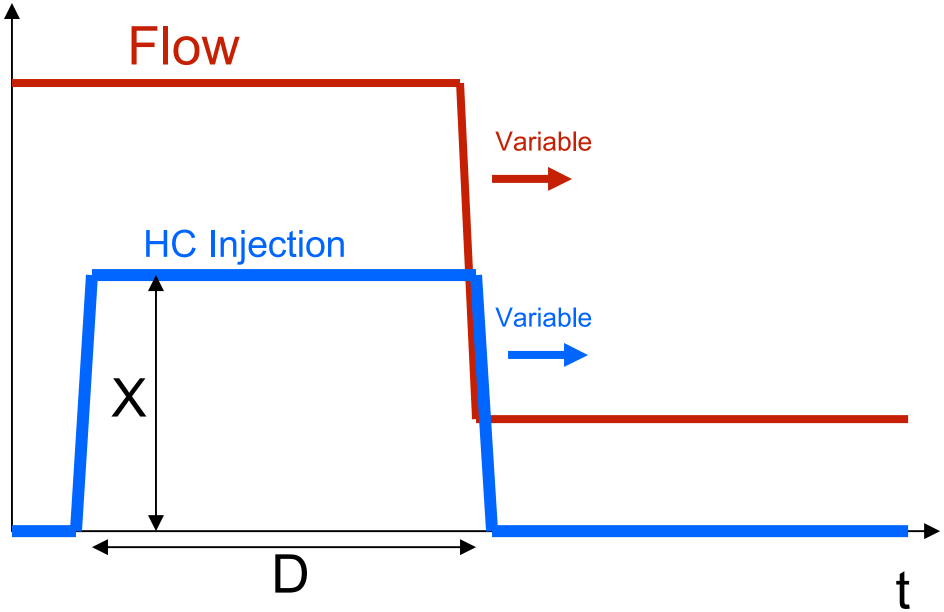
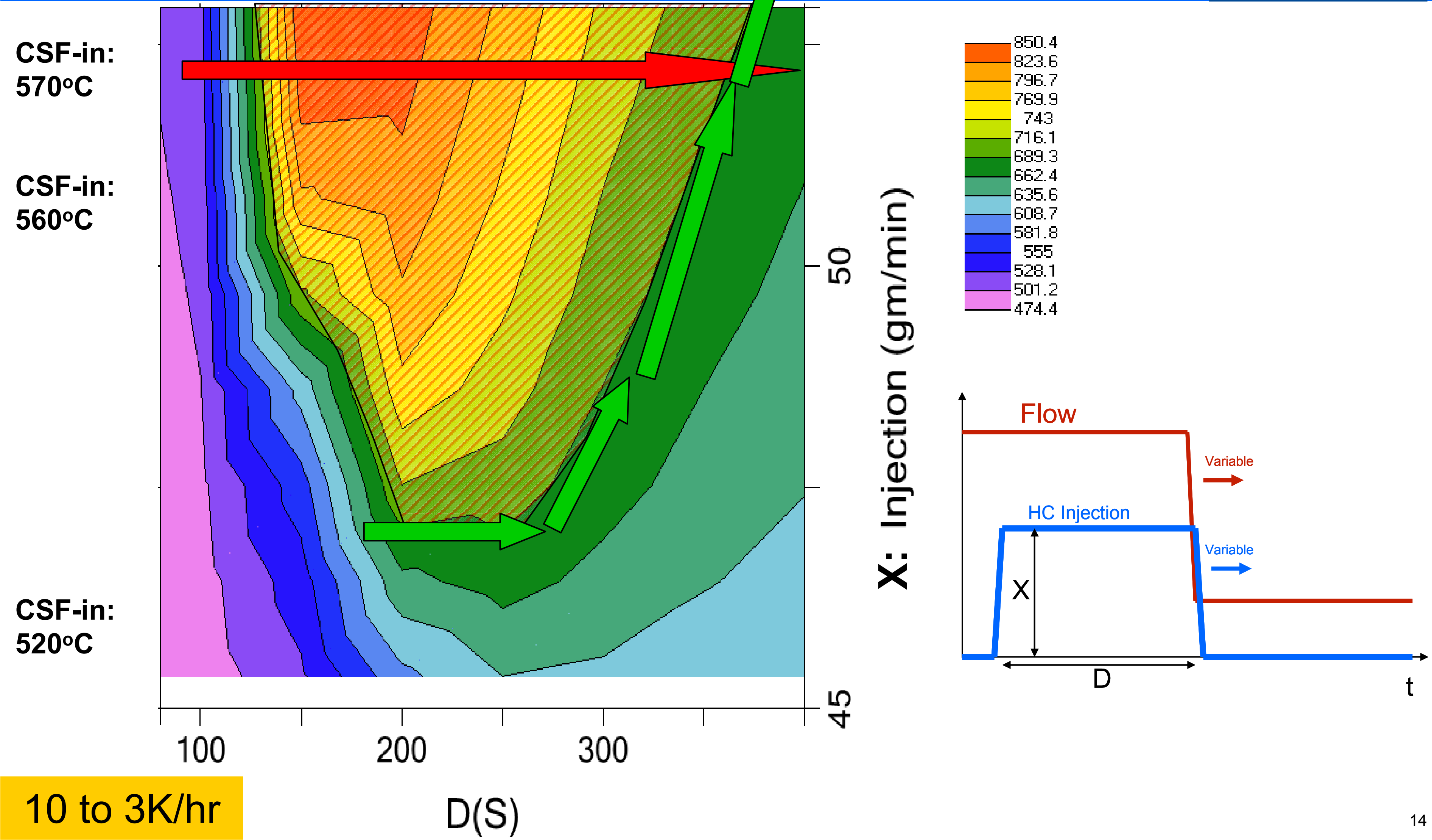
- The flow is decreased from 125 gm/s to 35 gm/s and the HC injection is decreased to 0 gm/s after a variable duration D.
- Several scenarios (different injection duration D) of drop-to-idle are considered in order to obtain the worst case.



10 to 3K/hr

Drop-to-Idle Test (DTI)

Increasing the injection rate during the regeneration will allow to avoid high temperatures in case of DTI.



10 to 3K/hr

Comparison between a Constant Injection and a Staged Injection.

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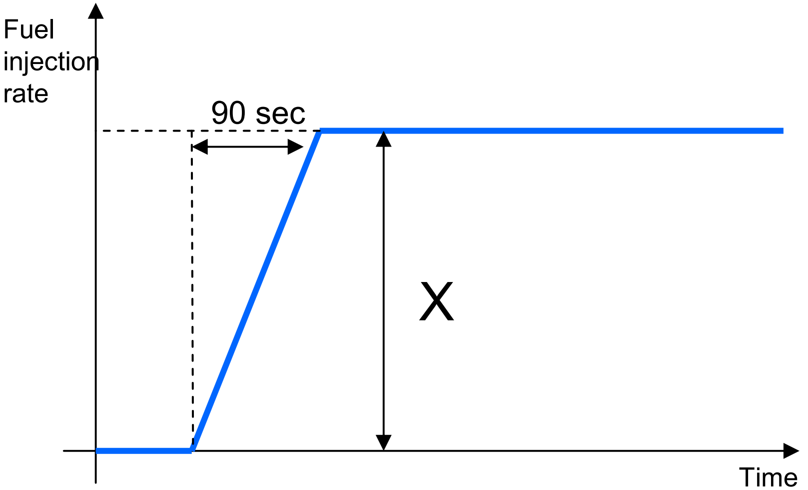
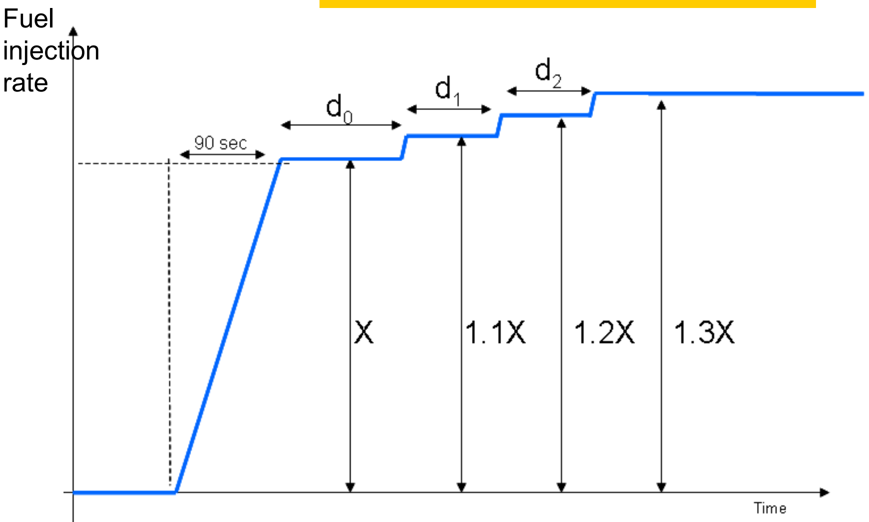
reference



3 step injection



As the soot is consumed, the injection rate can be increased. The following injection represent a 3 additional step injection respectively corresponding to 110, 120 and 130 % of the initial injection. The duration of the steps has been adjusted so that the maximum drop to idle temperature never reaches 700°C.

Constant VS Staged Injection: SV (10K/hr)

The staged injection shows a significantly shorter regeneration time and lower fuel consumption than the reference injection.

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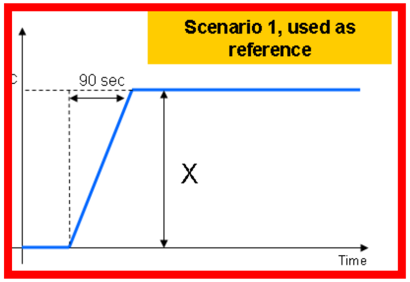
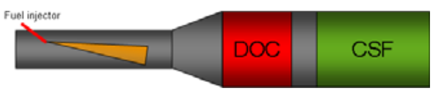
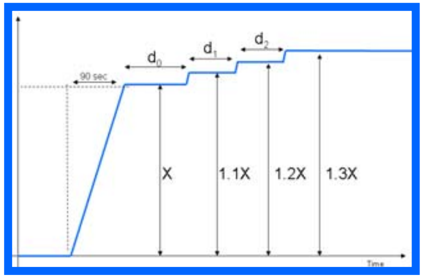


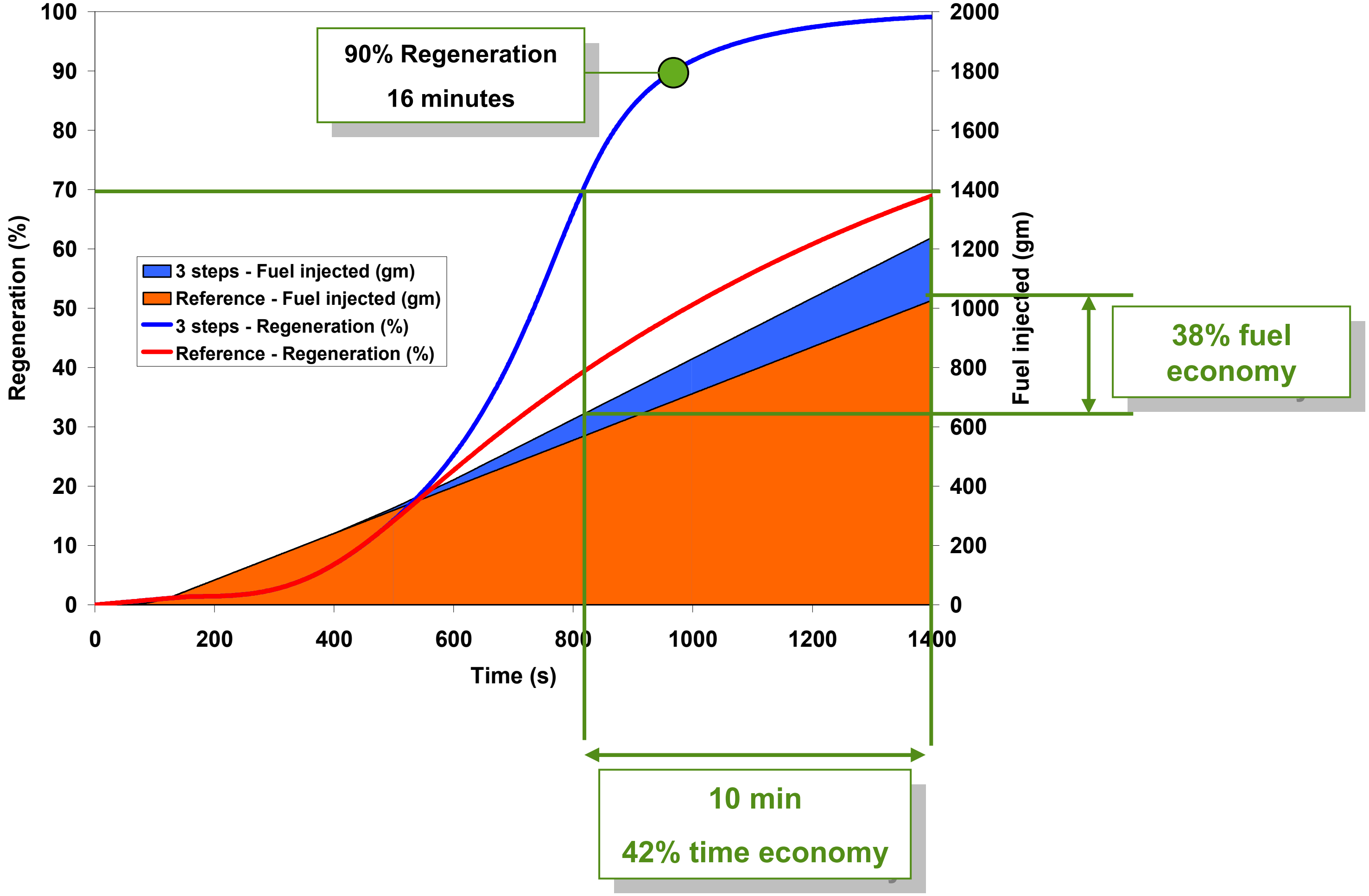




d_0=260s

d_1= d_2 =100s

10K/hr



Constant VS Staged Injection :SV (20K/hr)

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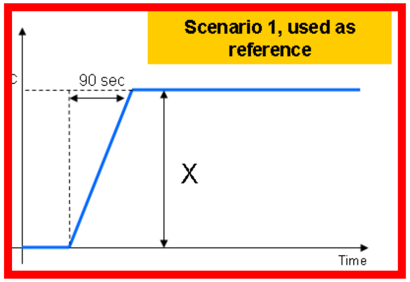
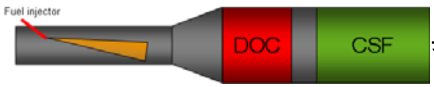
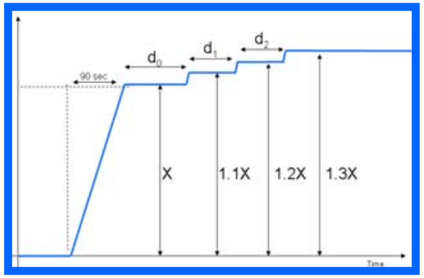
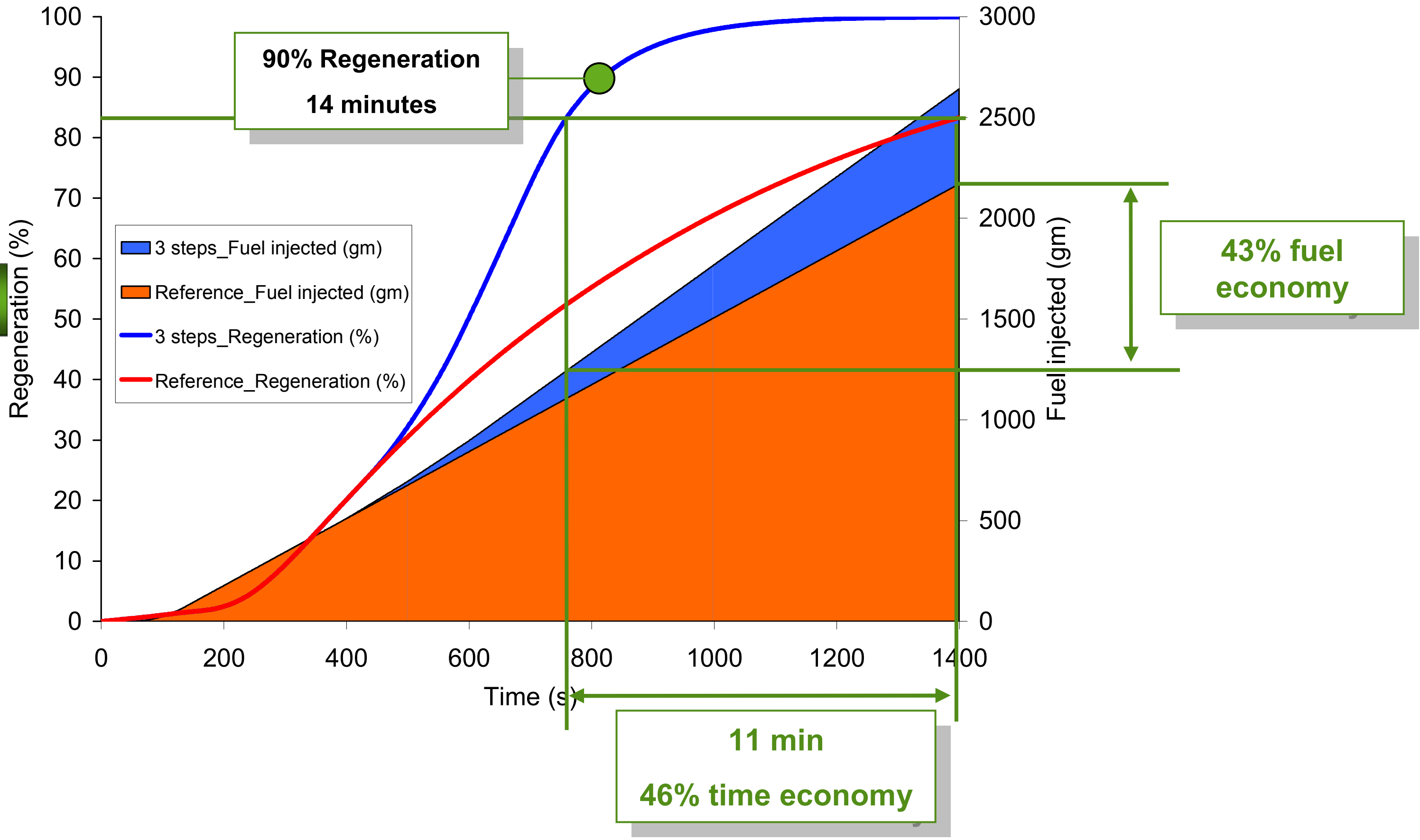






d_0=260s

d_1= d_2 =100s



20K/hr

Staged injection : DTI test

Drop-to-idle events have been simulated for variable injection duration during this stepped injection.

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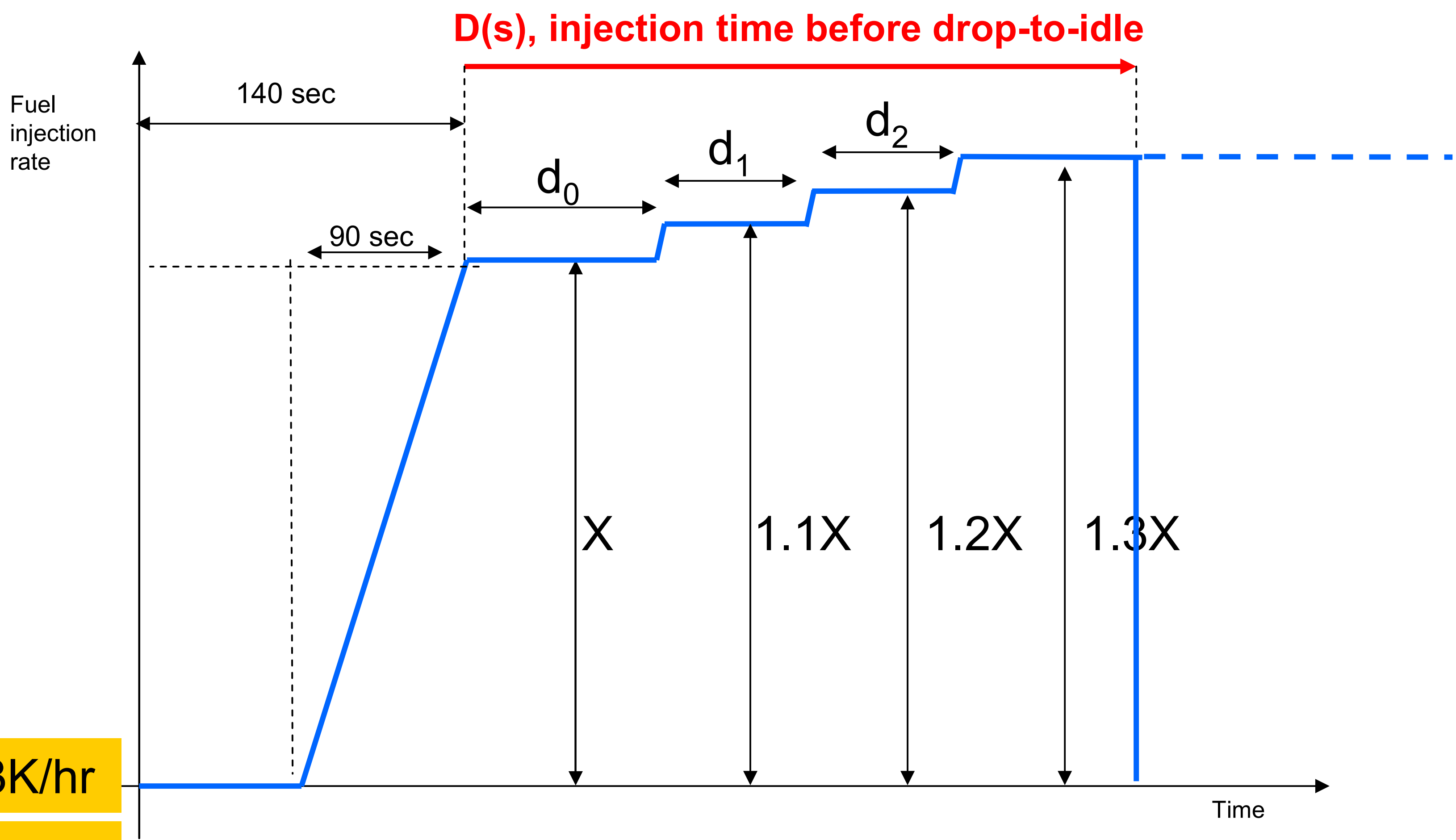
3 steps

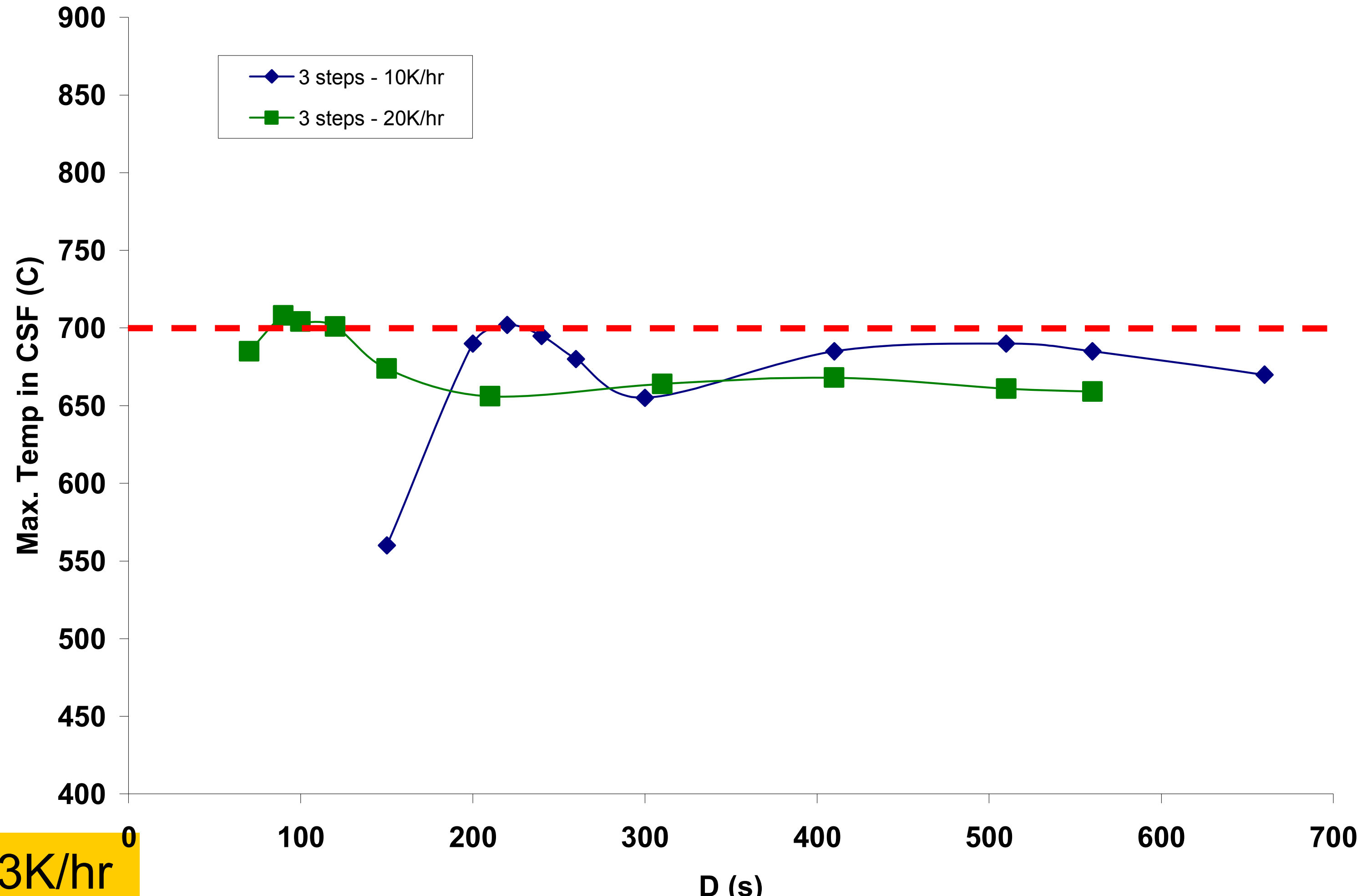


10 to 3K/hr

20 to 3K/hr

Staged injection : DTI test

The staged injection strategy allows to keep the maximum temperature of the uniform CSF (with upstream DOC) below 700ºC whenever the drop-to-idle event occurs.



10 to 3K/hr

20 to 3K/hr

Conclusion / Path Forward

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Conclusions

- Staged injection strategy allows:
  - to respect a desired maximum temperature in the CSF when a drop-to-idle event occurs (700°C for this study).
  - to decrease the fuel consumption
  - to decrease the regeneration duration = decrease risk of DTI
- A better tuning of the steps duration or the addition of intermediary steps (or even using a continuous function) would allow further improvement of the regeneration.

Path Forward

- Experimental verification of the injection strategy (Model results validation)
- Steady-state $\rightarrow$ Transient

Acknowledgement

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Thank you for your attention

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