LYBCO2 DH4 Minifrac Simulation

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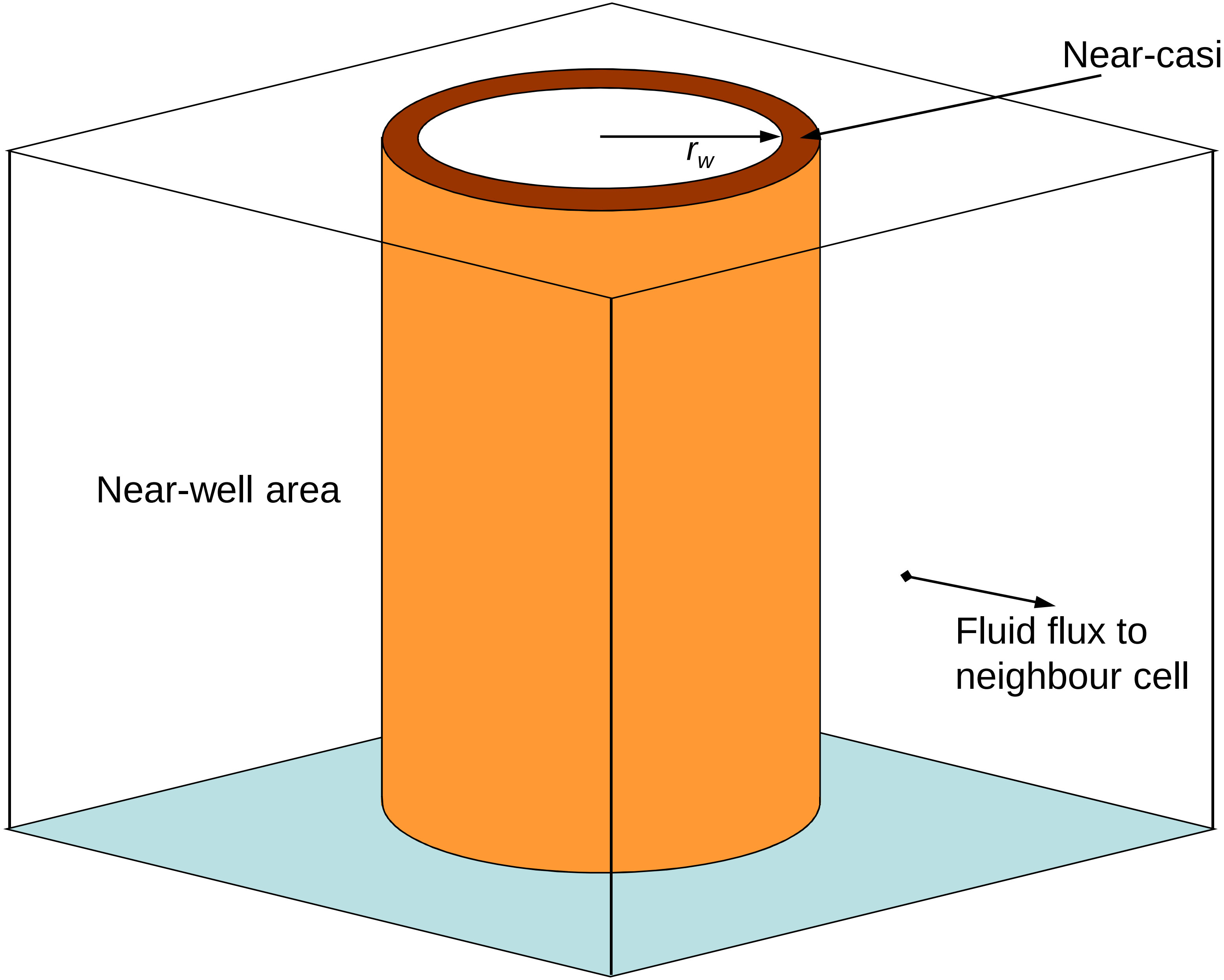
(post-workshop comments added)

Well in a Simulation Grid Cell



Pressure during injection

$$\Delta p = p_{wf} - p_b = aq/KH$$

where

p_{wf}:	Flowing bottomhole pressure
p_b:	”Average near-well pressure”
q:	Flow rate
KH:	Permeability height
a:	Proportionality constant

During injection, injected fluid

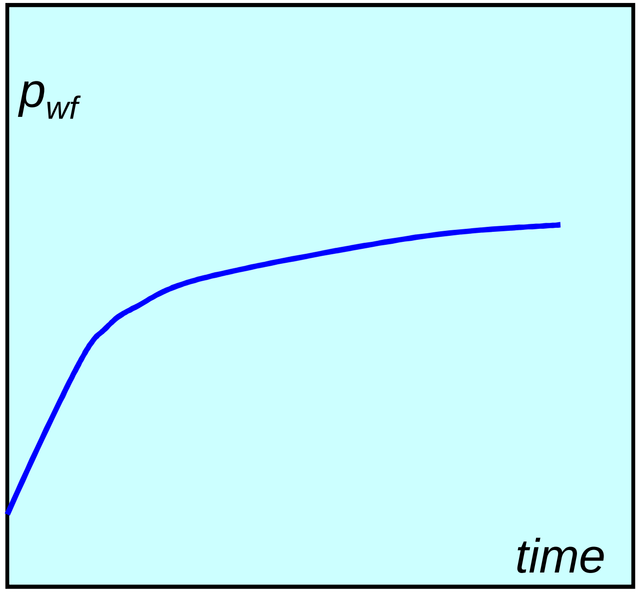
1. must overcome near-casing area (often damaged reservoir)
2. ”fills up” near-well area
3. flows into adjacent volumes (cells in simulation model)

Pressure during injection

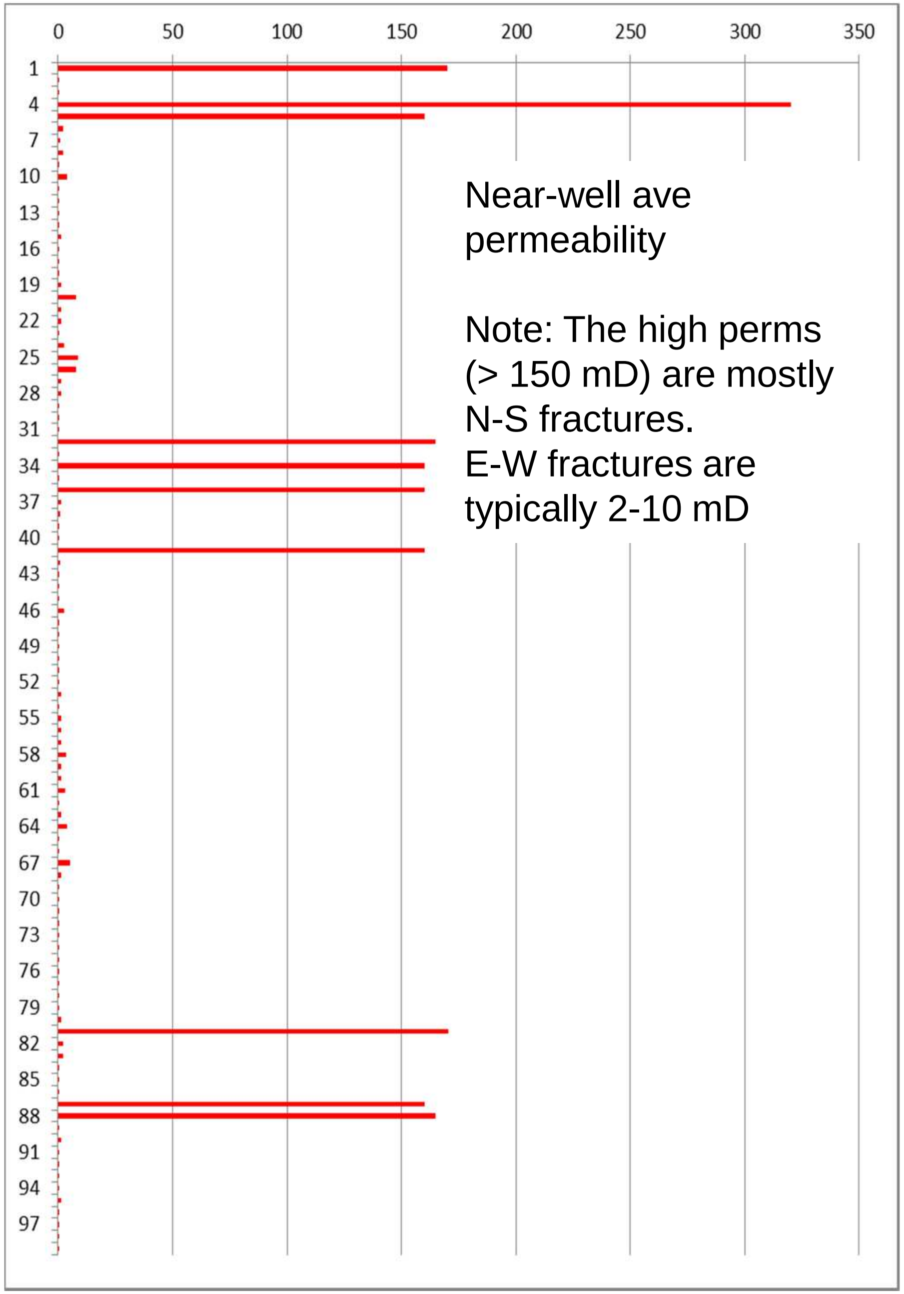
Two Extreme Cases:

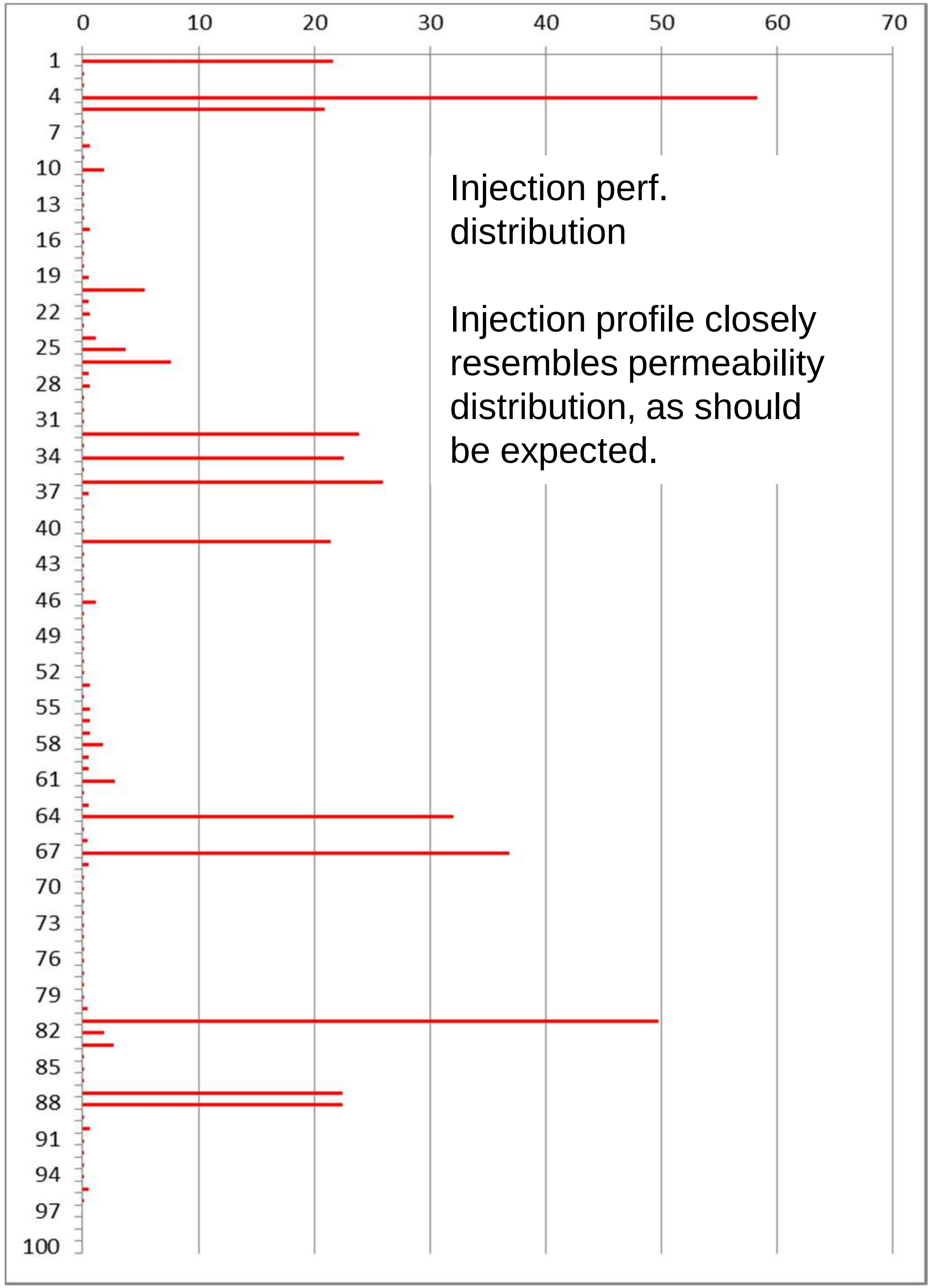
1. ”Zero conductivity” – no flow from near-well area to neighbour cells
   Bottom hole pressure and near-well pressure increase equivalently
2. ”Infinite conductivity” – injected fluid flows to neighbour areas immediately.
   Near-well pressure doesn’t change, bottom hole pressure quickly rises to value defined by Δp, and stays there

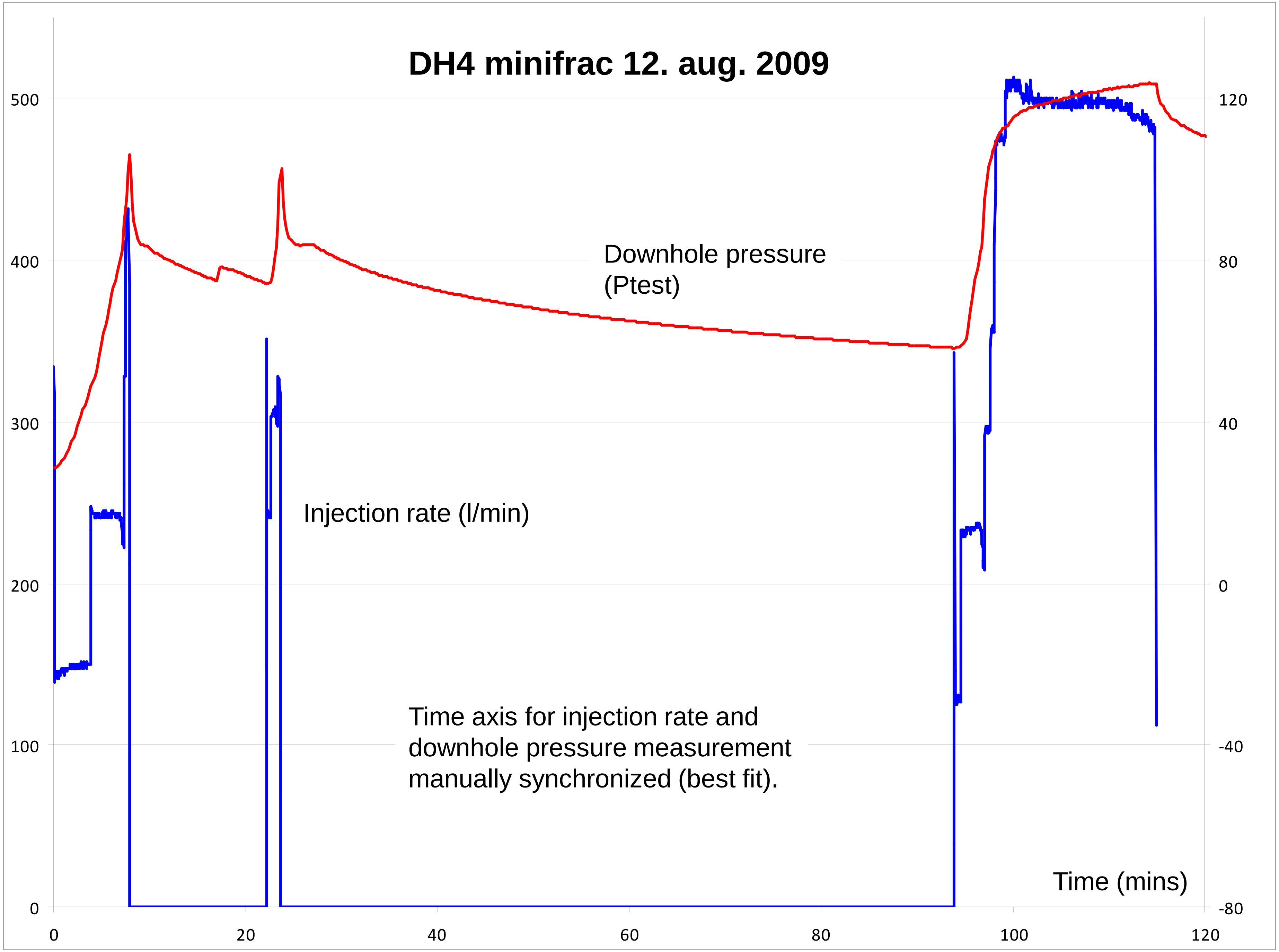
Typical behaviour:
Immediate increase in bottom hole pressure as near-well area fills up, then reduced increase as fluid flows into neighbour areas.

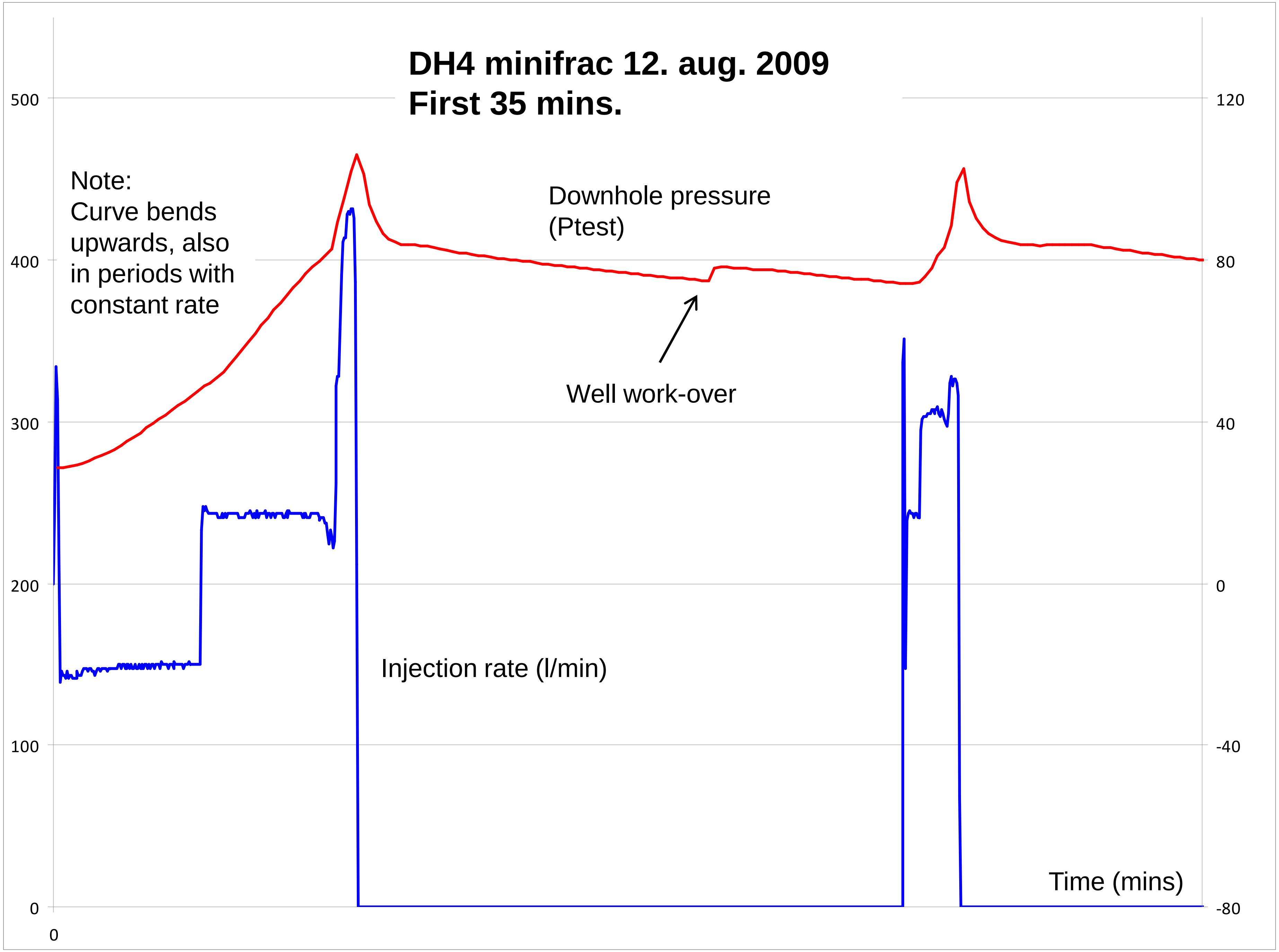


Layer Permeability and Connection flow rates in simulation model






DH4 minifrac 12. aug. 2009
Downhole pressure
(Ptest)
Injection rate (l/min)
Time axis for injection rate and
downhole pressure measurement
manually synchronized (best fit).
Time (mins)
500
400
300
200
100
0
120
80
40
0
-40
-80
0
20
40
60
80
100
120


DH4 minifrac 12. aug. 2009
First 35 mins.
Note:
Curve bends upwards, also in periods with constant rate
Downhole pressure (Ptest)
Well work-over
Injection rate (l/min)
Time (mins)
500
400
300
200
100
0
0
120
80
40
0
-40
-80

Simulation model and pre-analysis comments:

Based on Jan Tveranger's geo-model.
All cells are 20 x 20 x 1 m
Area covered: 1 x 1 km with DH4 in center

Porosity and permeabilities almost layer-constant
Fractures modeled as high-permeability cells.

From previous figure:
The fall-off (shut-in) periods have been sufficiently and very well analysed by Pressure Analysis (Leif Larsen).
The Simulation model can (hopefully) add understanding by studying the entire test – especially focusing on build-up periods.

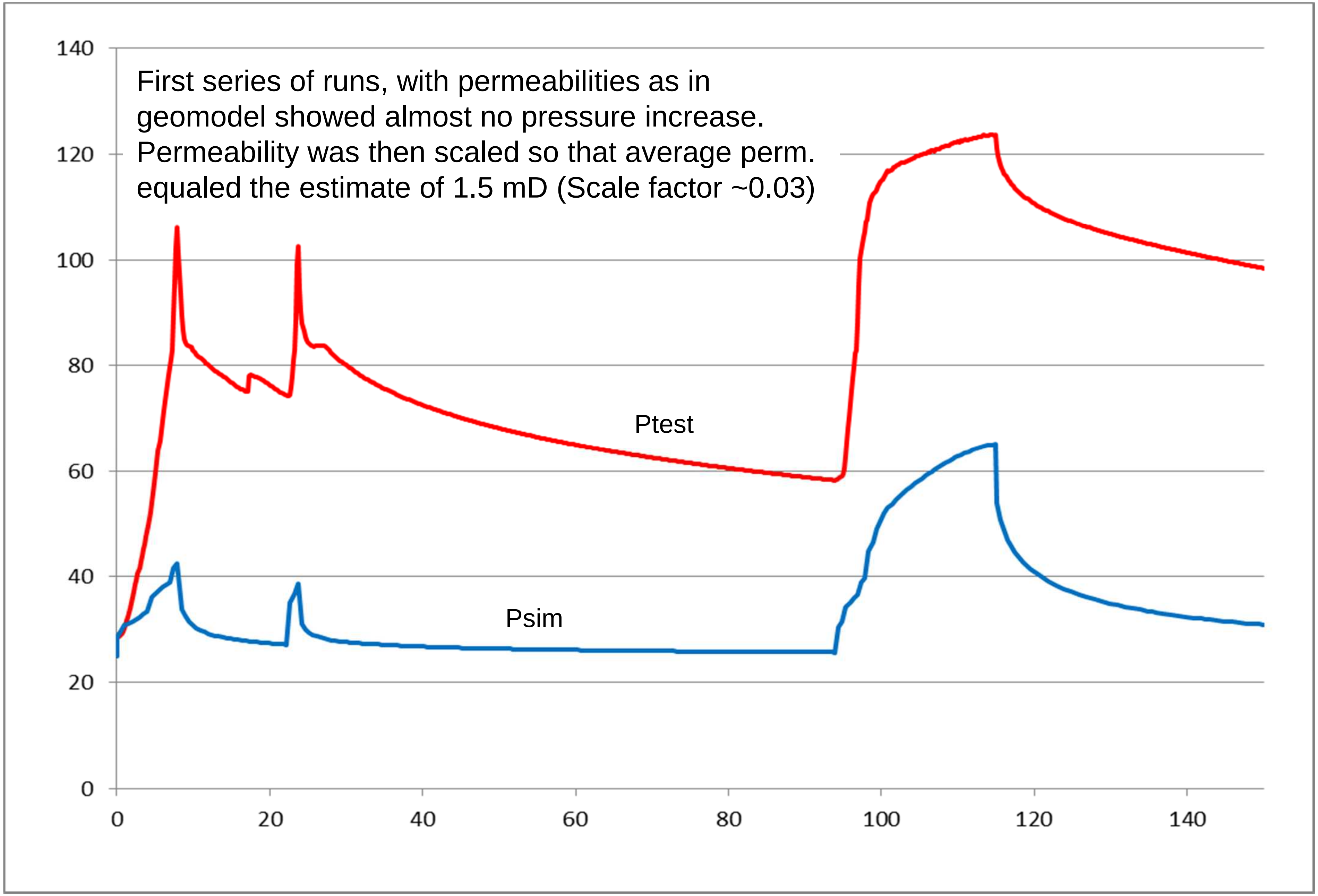
It quickly became clear that exact and detailed rate history is needed to do this. Original plan was to include the entire test, however the challenges encountered and scientific curiosity resulted in a focus on the first 7 minutes (initial build-up)

Note that in this period the curve bends upwards even during constant rate injection – in contrast to expectations from "typical curve" (earlier slide). Two "acceptable" explanations to this:

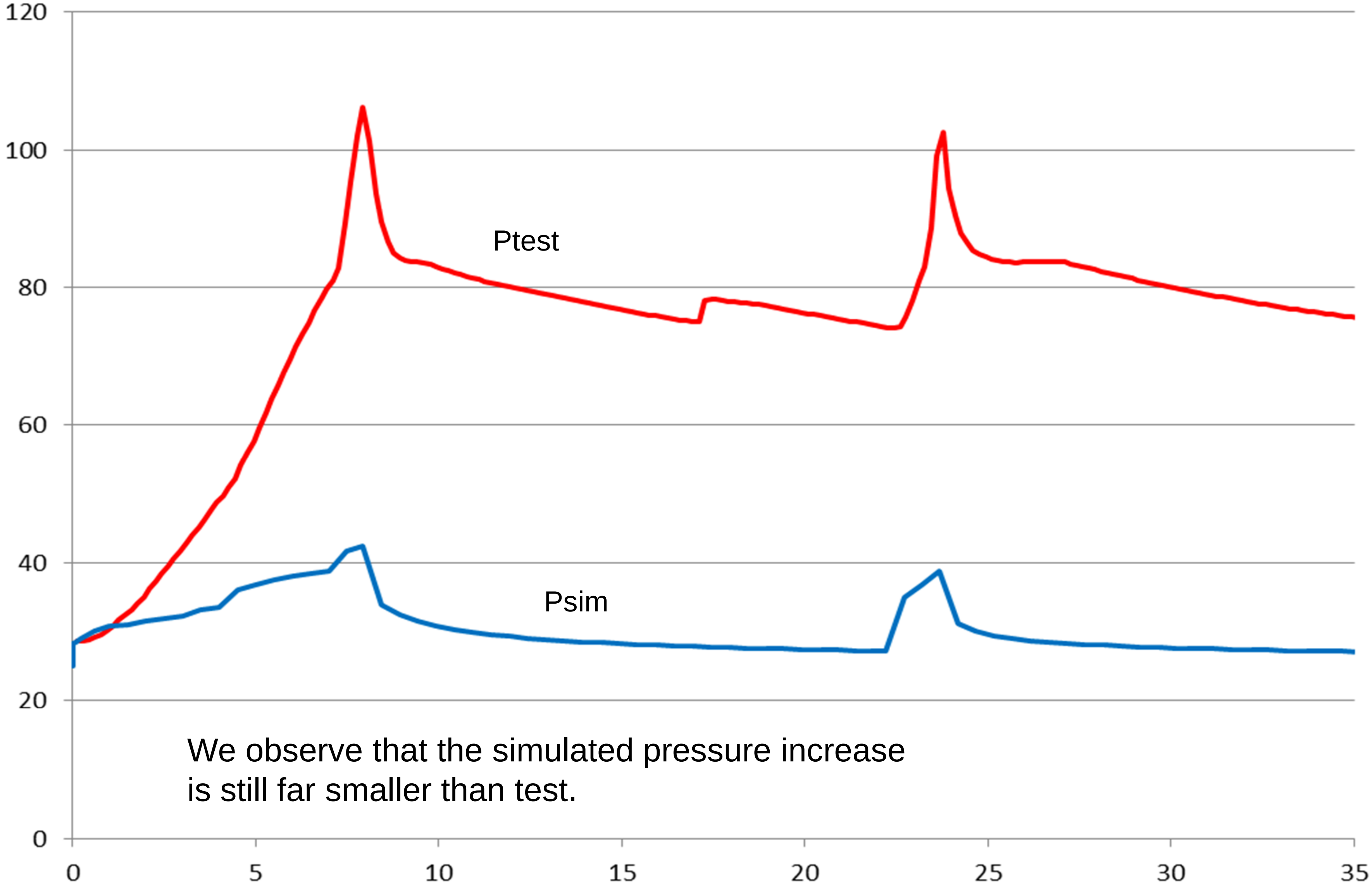
1) Fractures are plugged during injection (!) 2) Injection flow hits near-well barrier (has to be very near, as this happens during the first minute.

At the start of fall-off, pressure drop is small compared to increase during build-up. Difficult (impossible) to match in simulation model – fracture closure?

Base run: Using Leif Larsen's estimate <K> = 1.5 mD

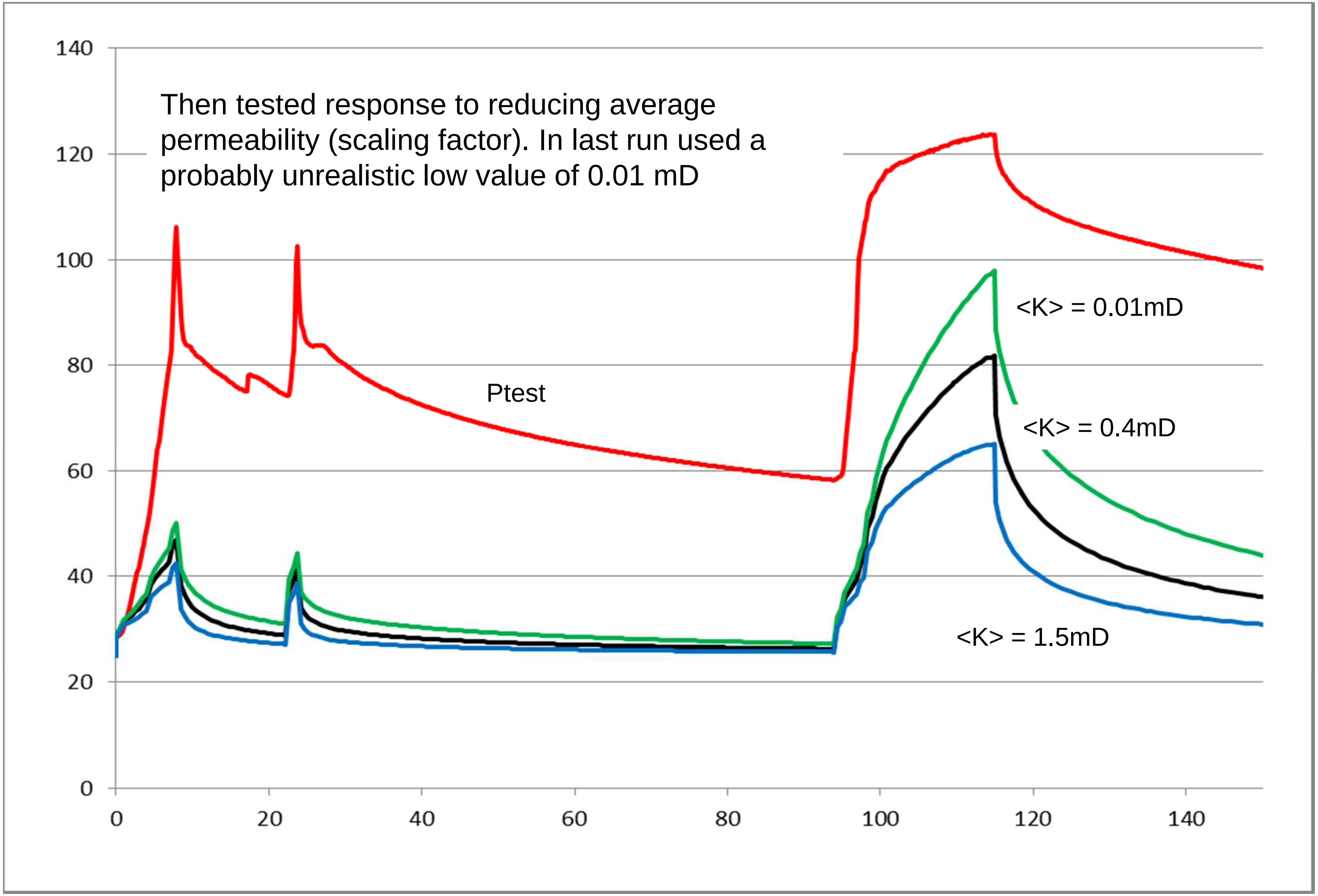


Base run: First 35 mins

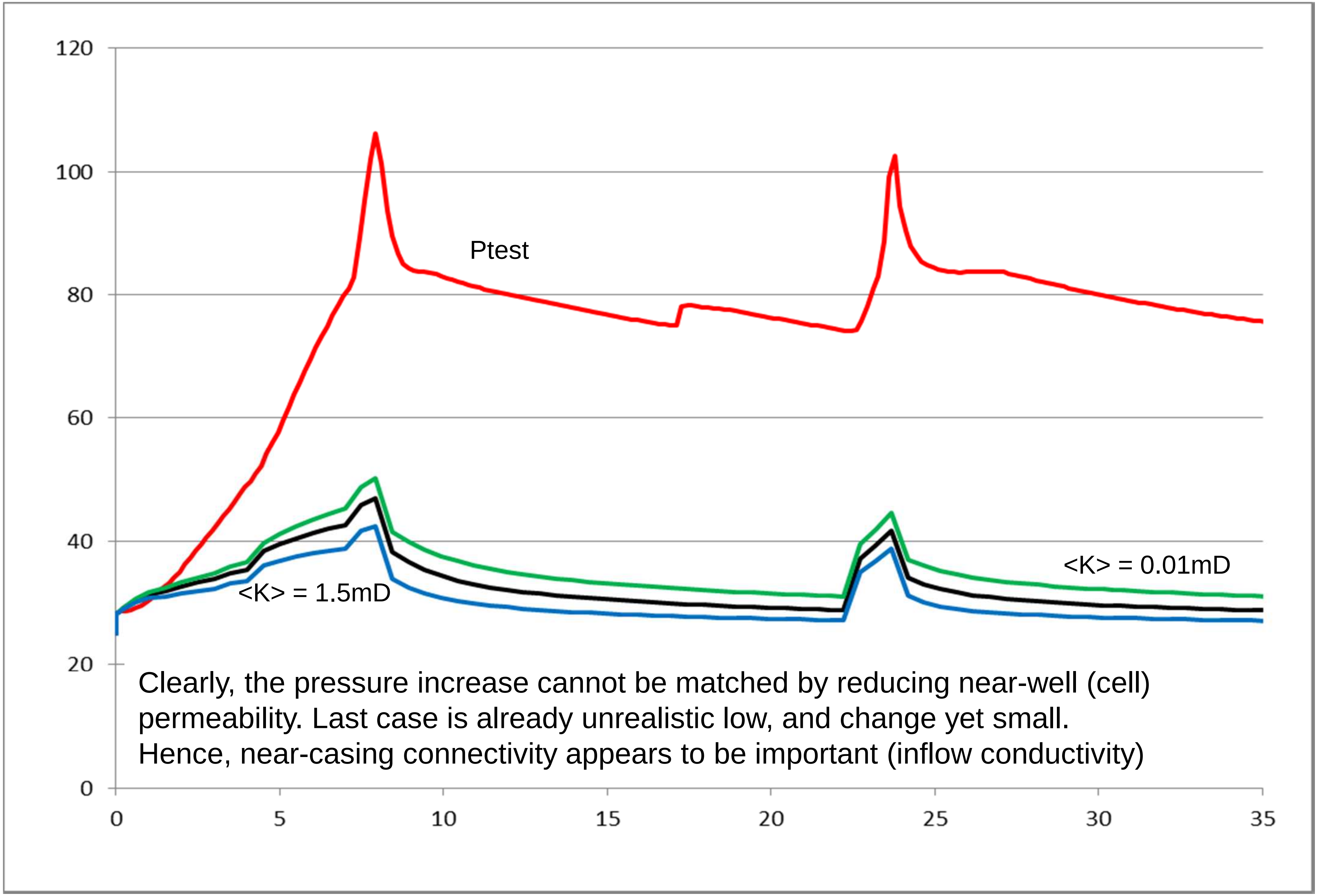


We observe that the simulated pressure increase
is still far smaller than test.

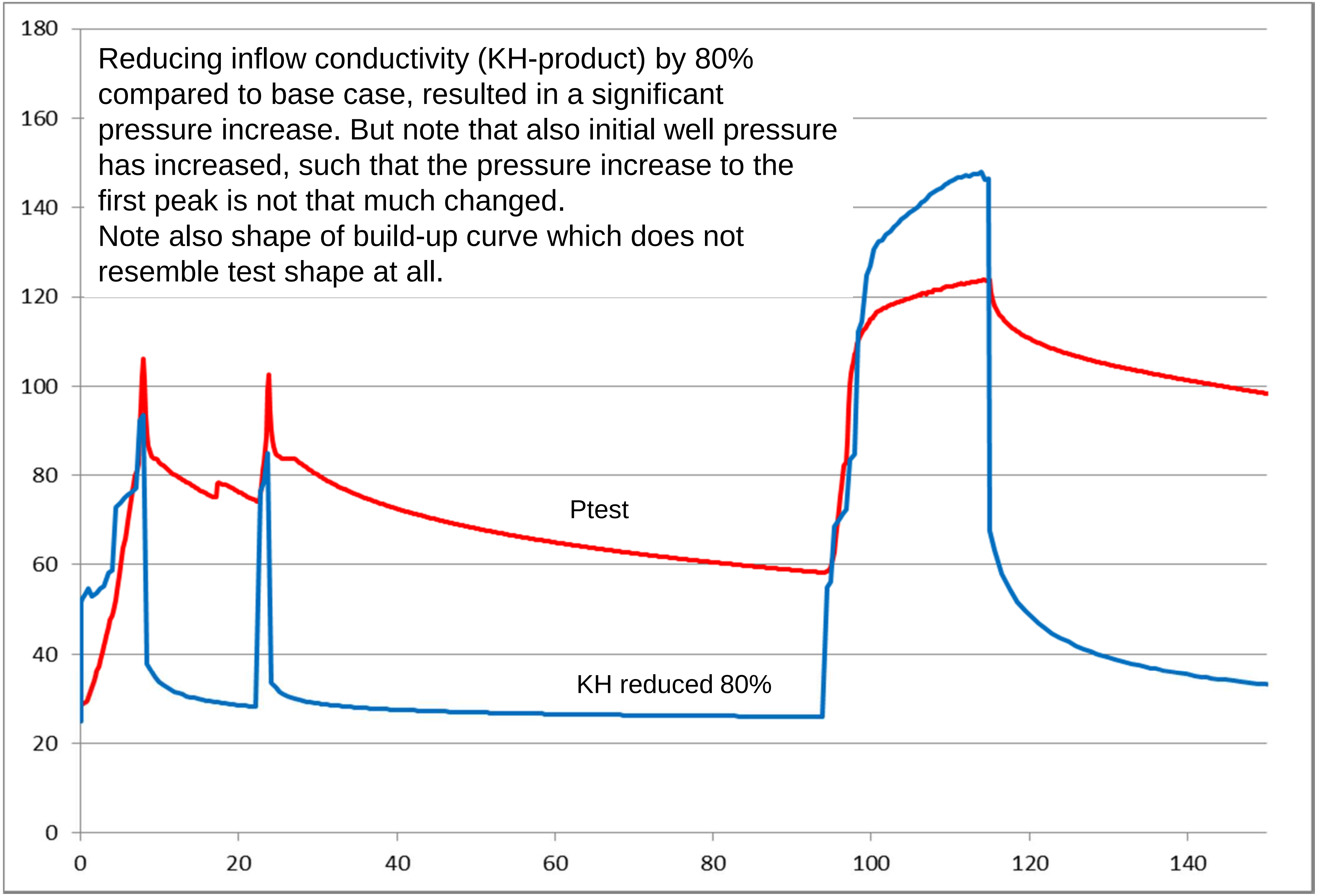
Sensitivity 1: Varying <K>



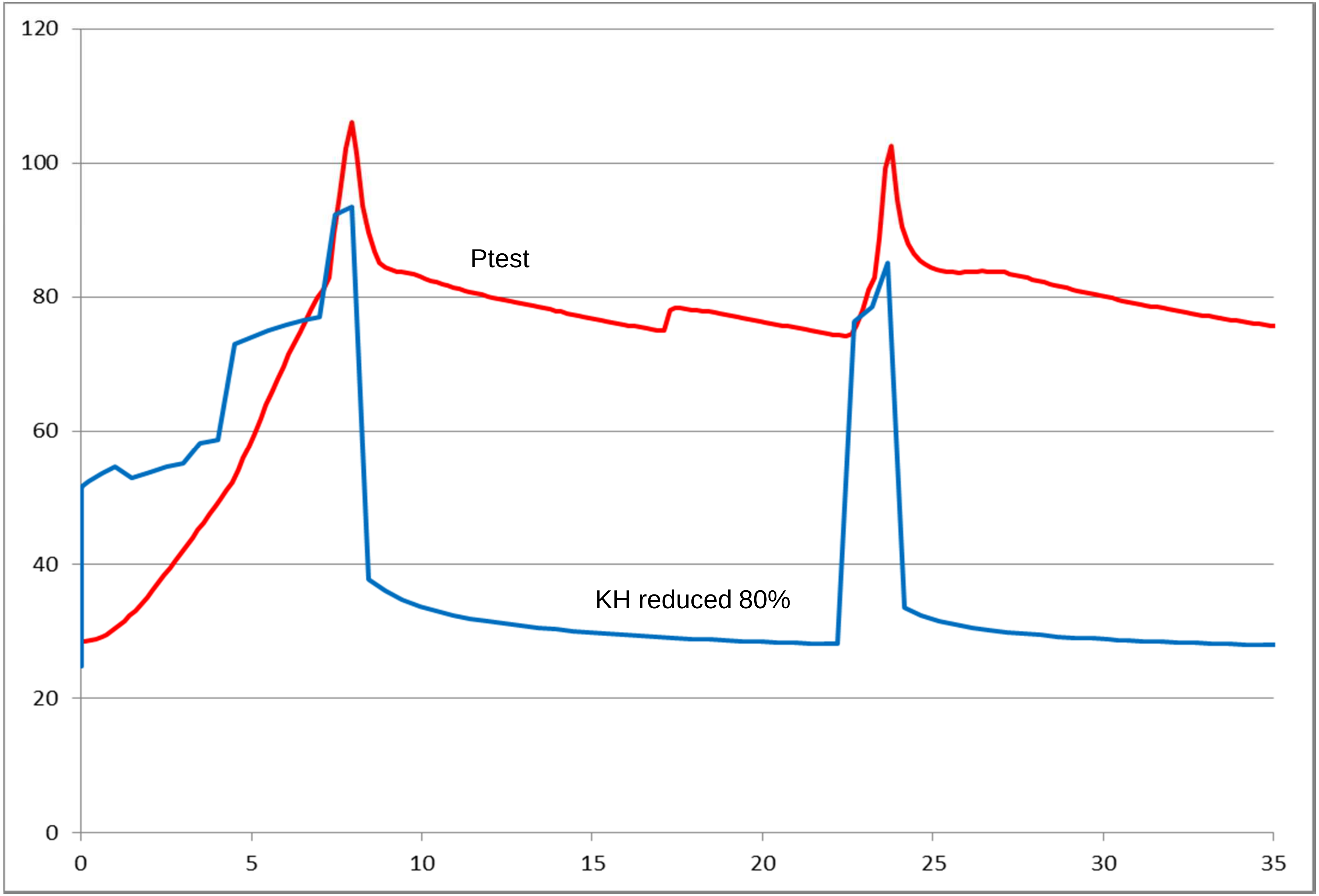
Sensitivity 1: Varying <K>, first 35 mins



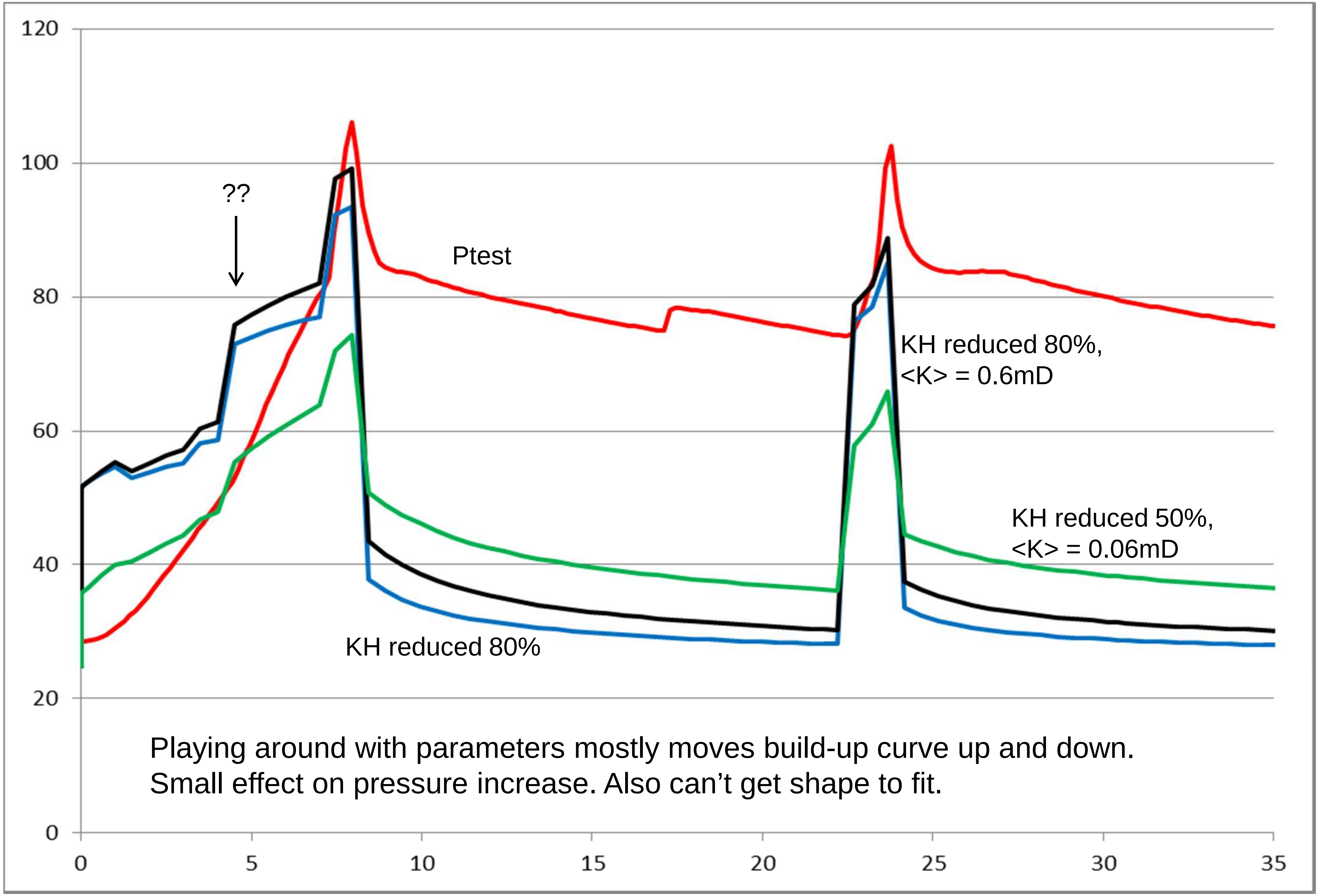
Sensitivity 2: Varying near-casing (outflow) conductivity



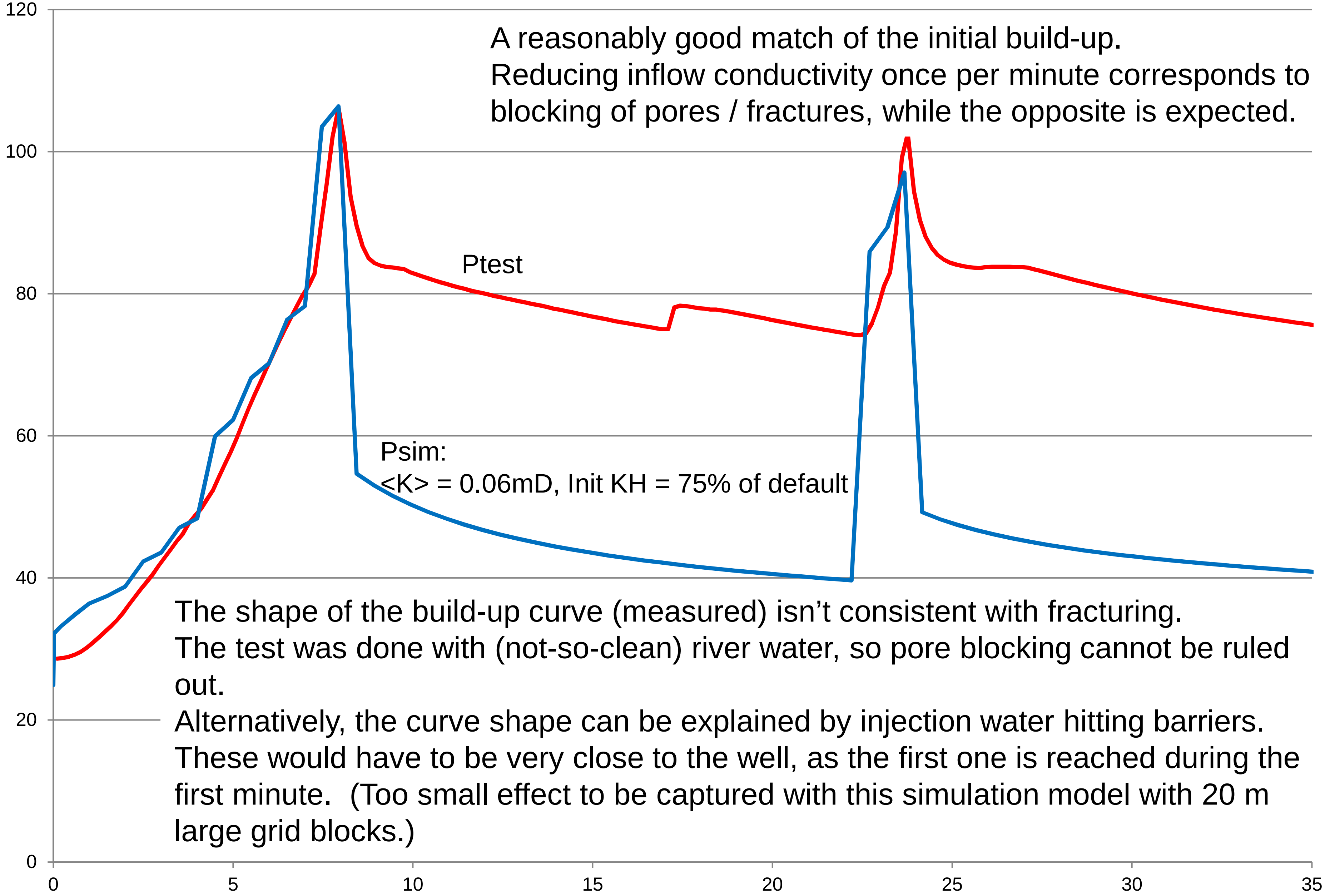
Sensitivity 2: First 35 mins



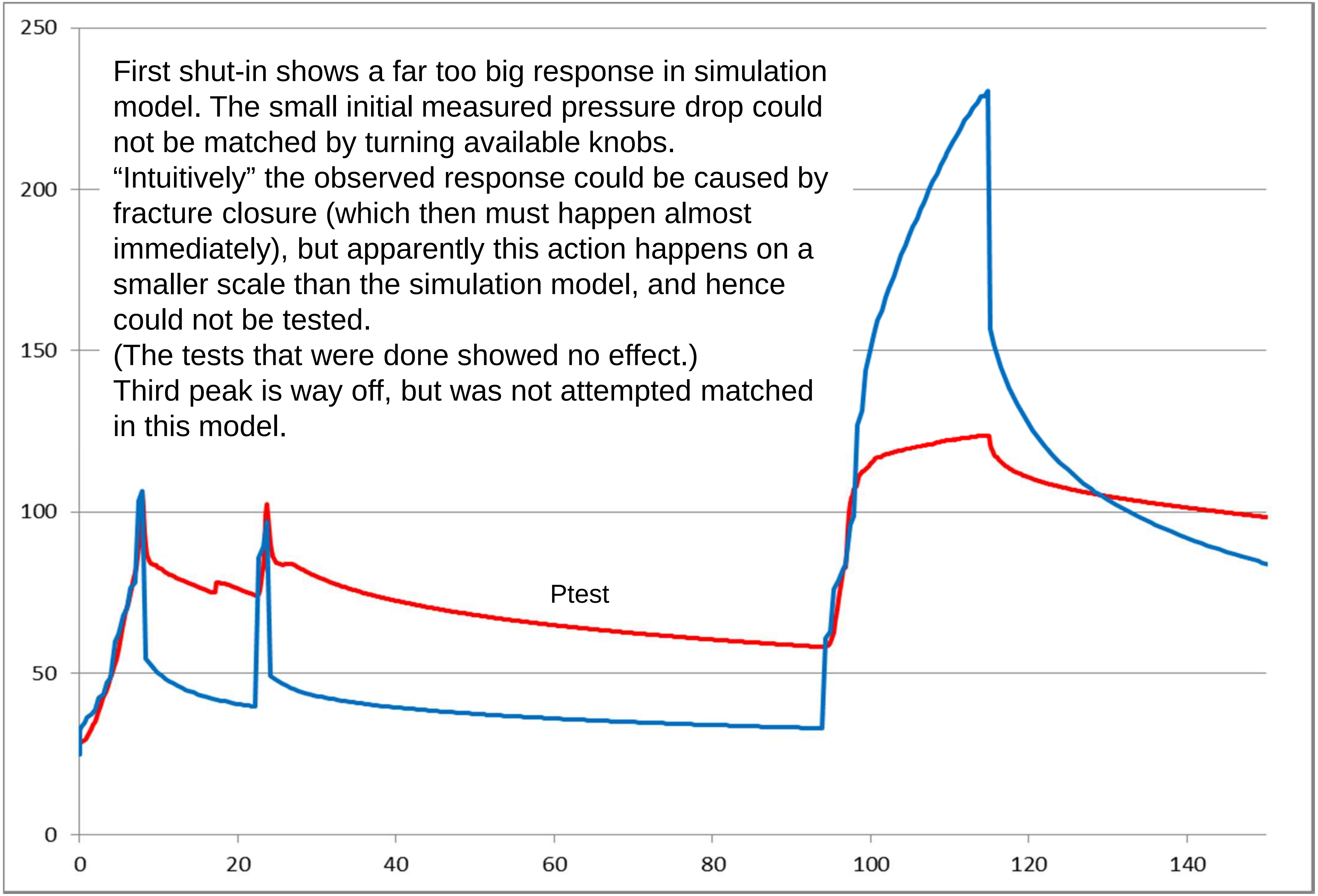
Sensitivity 2A: Some variatons on a theme



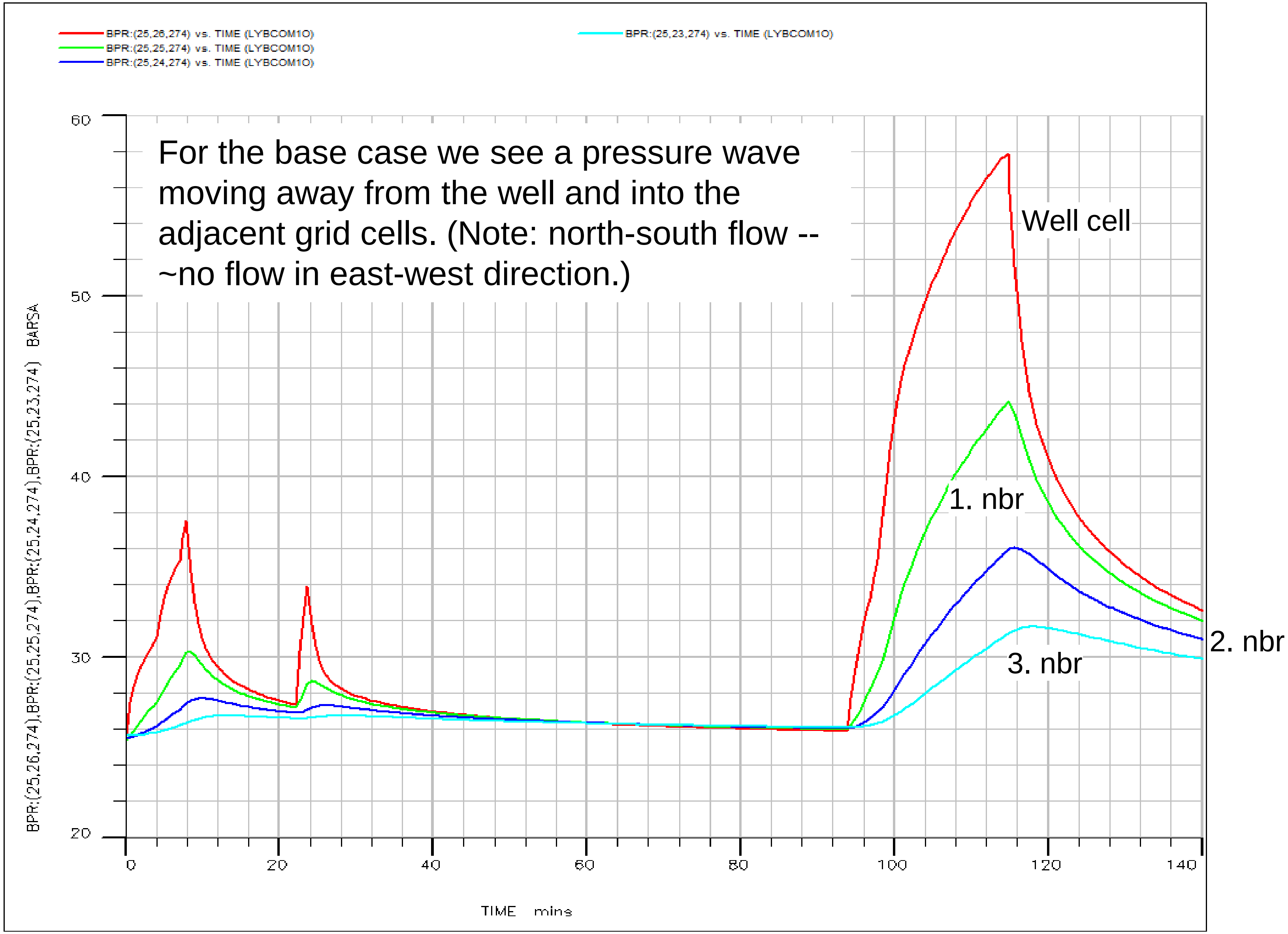
Sensitivity 3: Dynamic near-casing conductivity
KH reduced by 20% every minute (in first build-up)



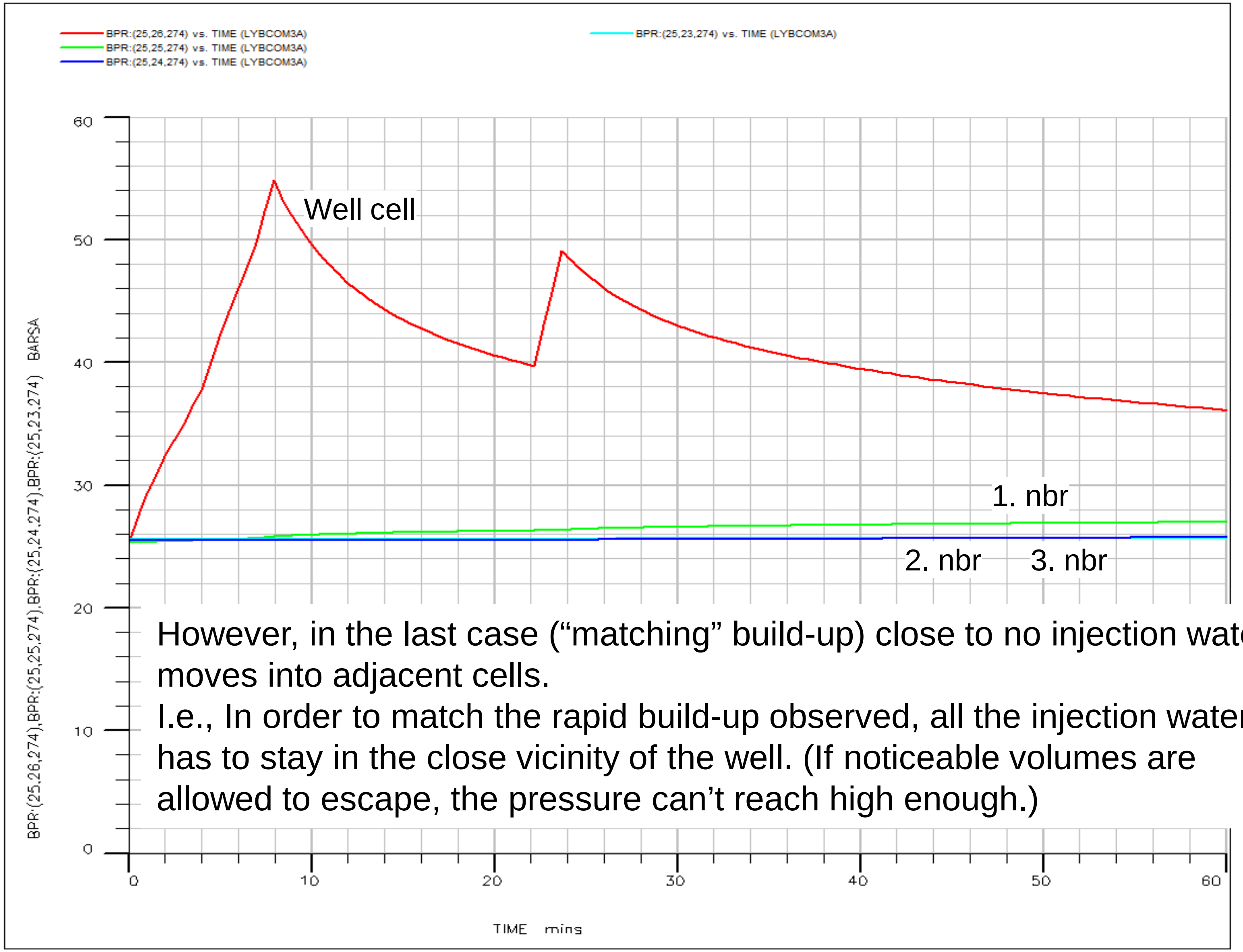
Sensitivity 3: 140 mins



Fluid flux out of well cell (pressure in neighbour cells)
Base case



Fluid flux out of well cell (pressure in neighbour cells)
Sensitivity 3



However, in the last case (“matching” build-up) close to no injection water moves into adjacent cells.

I.e., In order to match the rapid build-up observed, all the injection water has to stay in the close vicinity of the well. (If noticeable volumes are allowed to escape, the pressure can’t reach high enough.)

Points:

1. Pressure increase is very rapid
2. Initial BHP may be irrelevant, but requires relatively high perm to match
3. Cannot match pressure increase by only reducing near-well perm, necessary to also reduce near-casing connectivity
4. Cannot match shape of curve without reducing Kh during injection (?)
   Strong indication of barriers in near-well area (closer than cell size)
   (Can also speculatively be explained by «dirty» injection water)
5. Biggest challenge: The small pressure drop at shut-in – simulation model consistently computes a much larger pressure drop (may not be real….)
   a. Strong indication of fracture closure at shut-in
   b. But – to match initial part of curve, near-well perm had to be set so low that there's almost no flux out of near-well area, hence almost no fluid available to ”flow back”.
   c. Test with barriers (almost and completely isolating) around well cell had almost no effect.
   d. If we stick to the fracture closure hypothesis, the action appears to happen at a scale smaller than cell sizes, i.e. fracture lenghts shorter than 20m; barriers closer to well than 20m.
      (Not tested, but conclusions inevitable….)
6. Should do more studies with high-resolution model concentrating on near-well area?