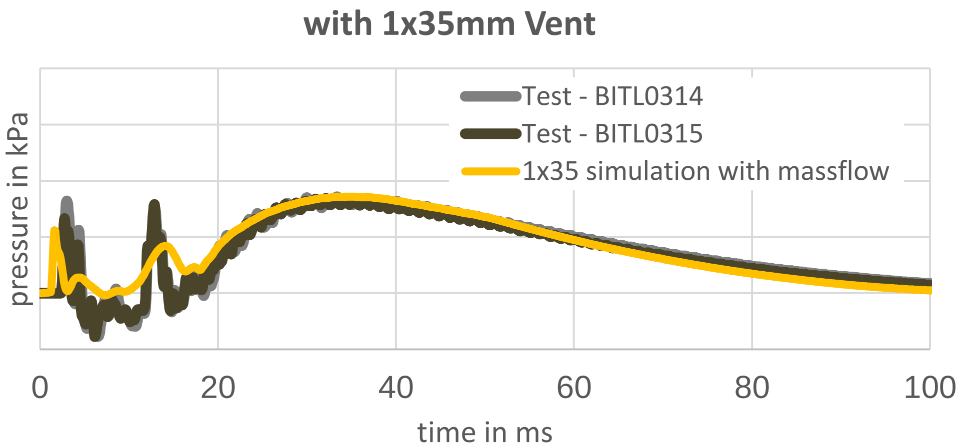
Simulation of coldgas inflators while taking the Joule – Thomson – Effect into account

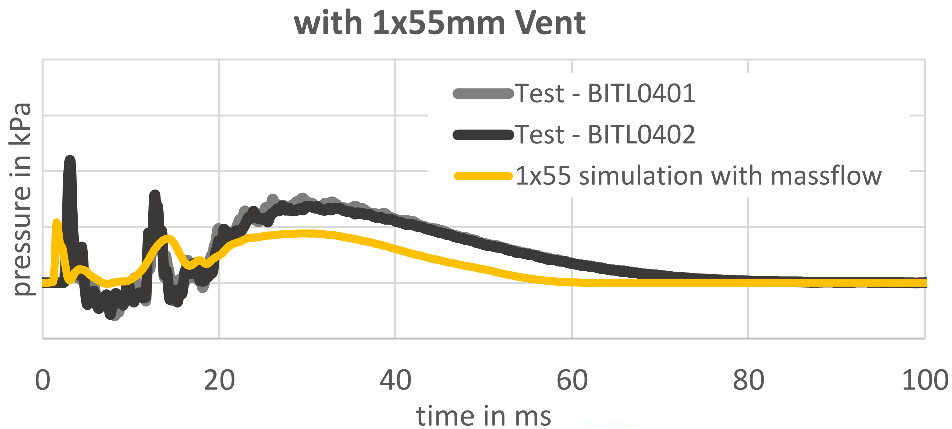
Tilo Laufer - Takata AG Berlin, 10th October 2016

outline

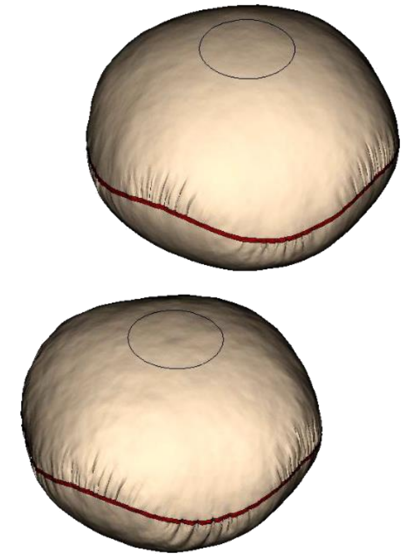
- problem definition
- conventional inflator model
- direct inflator simulation using the CP-Method
    - the Joule – Thomson – Effect
    - results of the tank test
    - final results in alternative system model
    - conclusion

- conventional inflator modelling:
  - Inflator mass-flow and temperature derived from tank test
- Takata's standardized inflation test

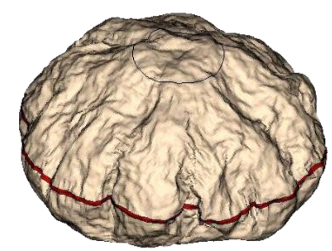


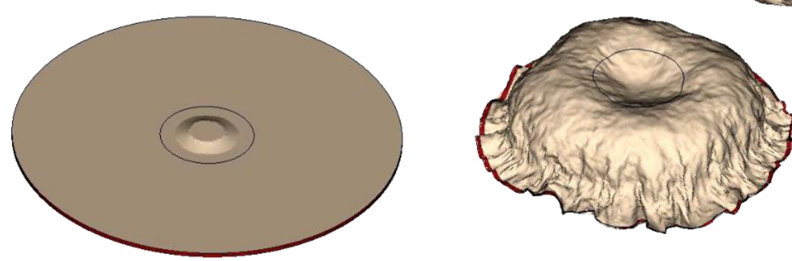


- Airbag simulation is a Fluid-Structure-Interaction (FSI) problem
- full FEA simulation coupled with CFD simulation is often to complex
    - Very long computing times
- Wang and Nefske [1] offered simplified approach to model the fluid behavior:



$$\frac{\mathrm{d}}{\mathrm{d}t}(mu)_{\mathrm{CV}} = \sum \dot{m}_{\mathrm{i}} h_{\mathrm{i}} - \sum \dot{m}_{\mathrm{O}} h_{\mathrm{O}} - \dot{W}_{\mathrm{CV}} - \dot{Q}_{\mathrm{CV}}$$

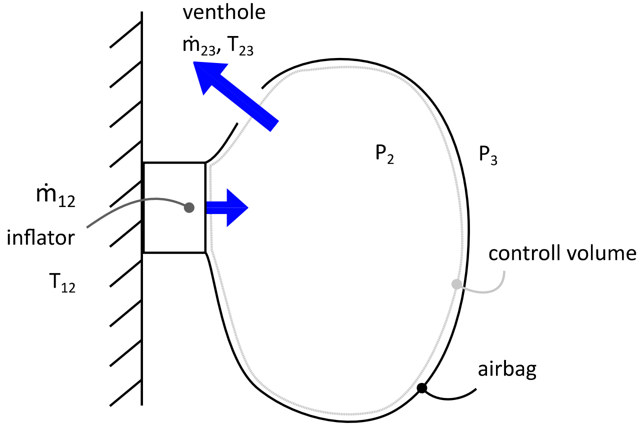




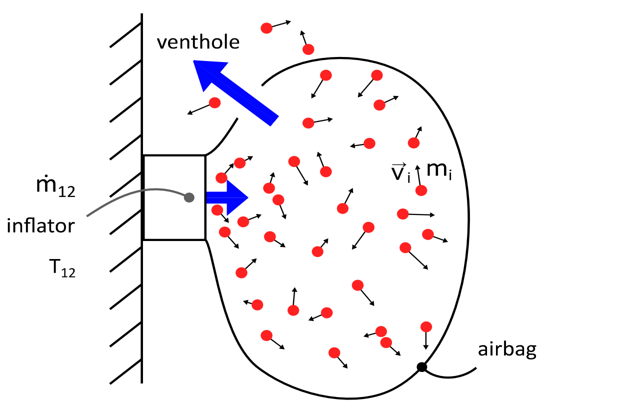
[1] Wang, J.T. and Nefske, D.J.: "A new cal3d airbag inflation model", SAE Technical Paper, 1988

- With the beginning of the 21st century NHTSA introduced the out of position requirement
- This lead to the need of a more accurate modeling of the fluid domain
    - LS-Dyna introduced the Corpuscular-Particle-Method (CPM)
    - With an acceptable increase of computation time the airbag deployment improved a lot
- But the CPM still needs a prescribed mass flow and temperature curve
    - By default derived from a tank test
    - The tank test brings by default a lot of assumptions in to the model

UPM

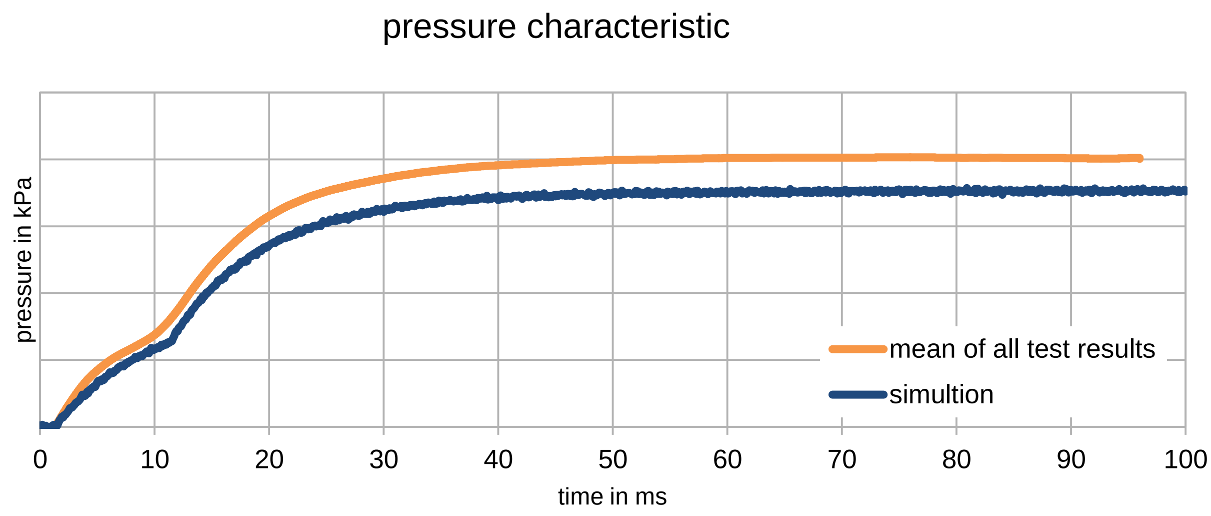


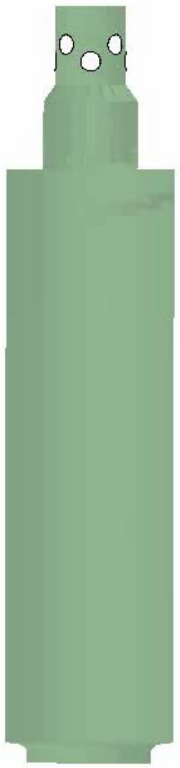
CPM



direct inflator simulation using the CP-Method

- Idea:
  - Direct modeling of cold gas inflators
  - Prefill the inflator with the correct mass, at the right pressure
  - Test the proper inflator output by simulating the tank test



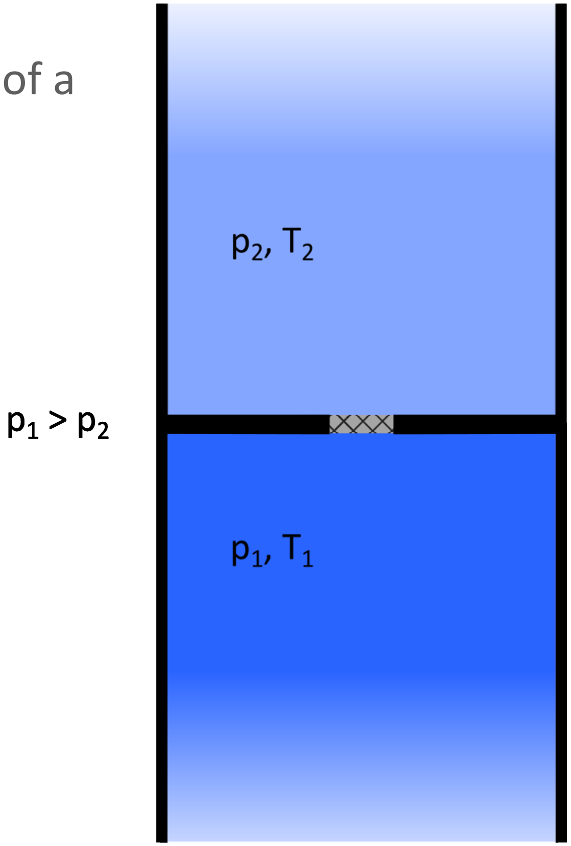


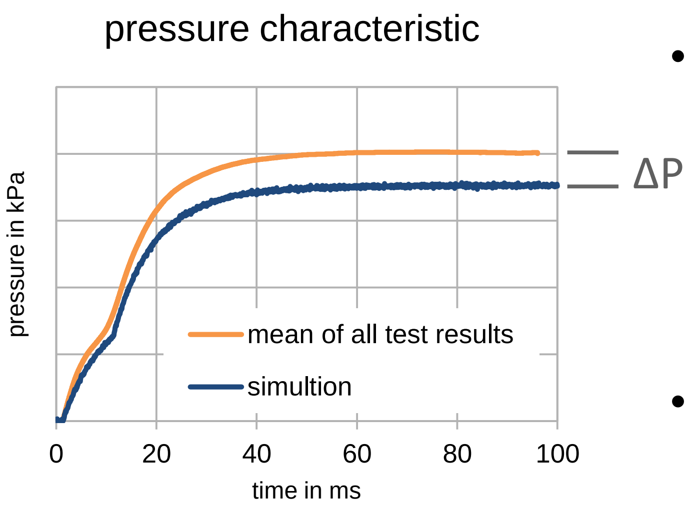
- The Joule-Thomson-Effect describes the temperature change of a fluid during a throttling process

$$\mu_{\mathrm{JT}} = \left(\frac{\partial T}{\partial p}\right)_H$$

- if $\mu_{\mathrm{JT}} > 0$: the fluid will cool down at a throttling process
- if $\mu_{\mathrm{JT}} < 0$: the fluid will heat up at a throttling process

$$\mu_{\mathrm{JT}} = \mu_{\mathrm{JT}}(p, T)$$





- Difference between test and simulation:
  - The inflator output in simulation is lower then in test
  - Reason: missing of Joule-Thomson-Effect
- JT-Effect describes the temperature change of a real gas or liquid during a adiabatic throttling process

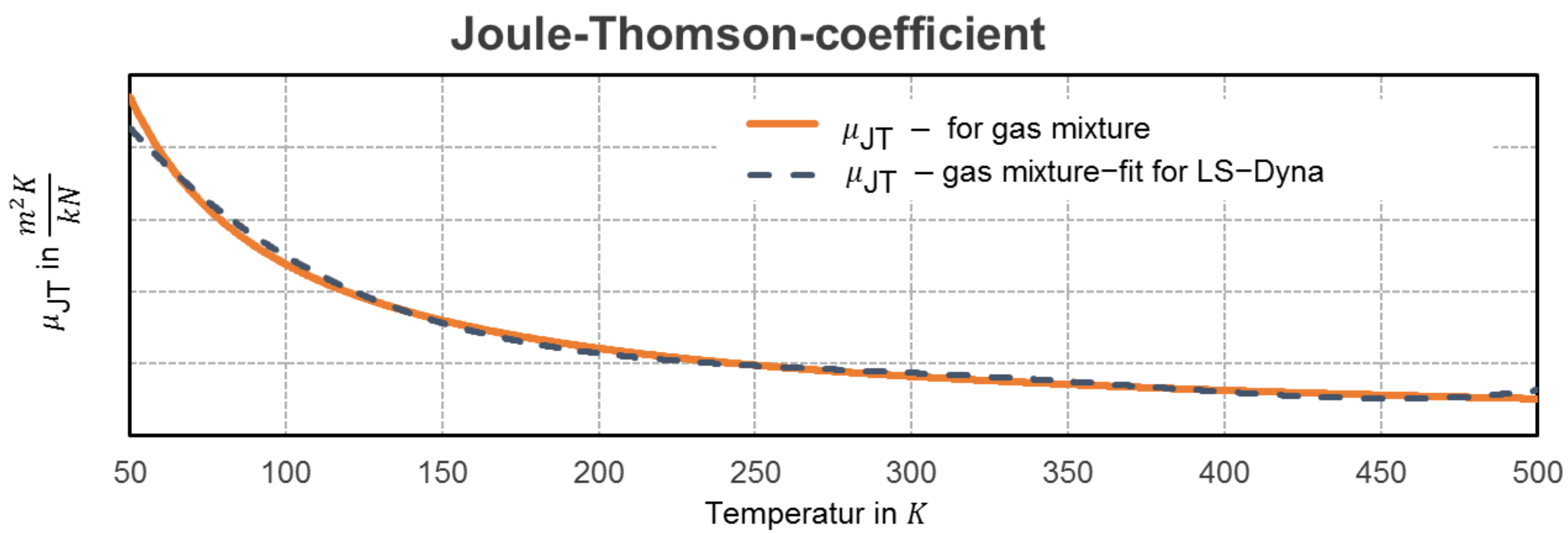
$$\mu_{\mathrm{JT}}(T) = \frac{b - {}^{2a}/_{RT}}{C_{\mathrm{p}}(T)} = \frac{b - {}^{2a}/_{RT}}{C_{\mathrm{p0}} + C_{\mathrm{p1}}T + C_{\mathrm{p2}}T^2 + C_{\mathrm{p3}}T^3}$$

- Real gas (Van der Waals equation)
  - a - cohesion pressure
  - b - co-volume

- Calculate Joule-Thomson-coefficient:
  - Using the van-der-Waals coefficients from the table [2]
  - Approximate the Joule-Thomson-coefficient with polynomial of order 4

[2] O. Babel.: "Joule-thomson-effekt", internet, 2014

Name of gas	a in Nm^4 / $kmol^2$	b in $m^3/kmol$
carbon dioxide	365585,65	0,0428
nitrogen	136777,05	0,0386
hydrogen	24645,79	0,0267
helium	3468,81	0,0238
air	135467,72	0,0365



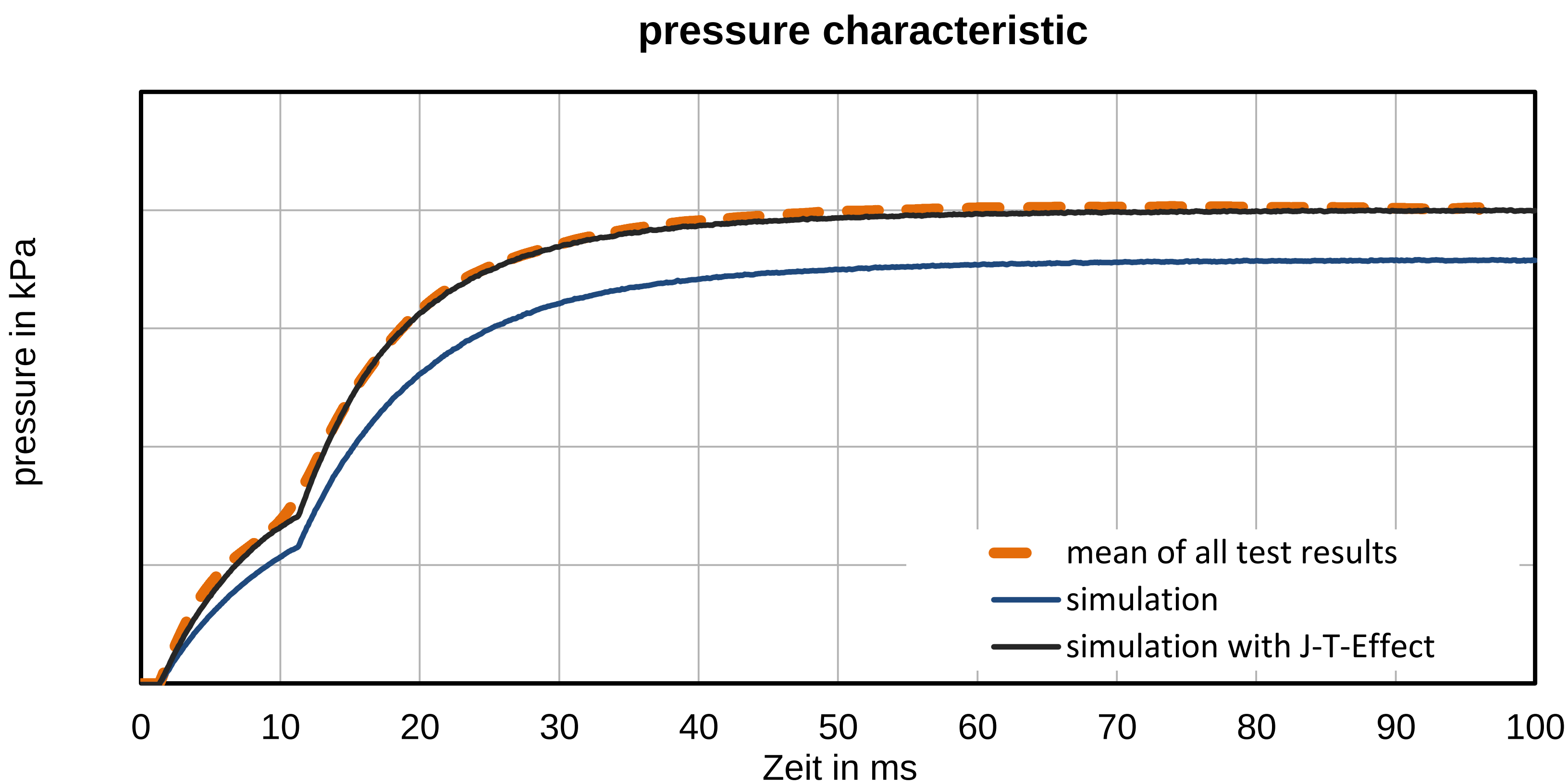
- How to model the Joule-Thomson-Effect in LS-Dyna
  - Two new Keywords required
  - First (**`*DEFINE_CPM_VENT`**) is referenced in Card 8 of the Airbag Particle keyword

```
*DEFINE_CPM_VENT
$:    label        c23     lctc23     lcpc23      enh_v       ppop      c23up
      1020&C23_VENT           1120                    1                    1.0
$:       jt       ids1  ->  ids2      iopt1
          2       1010      1012
```

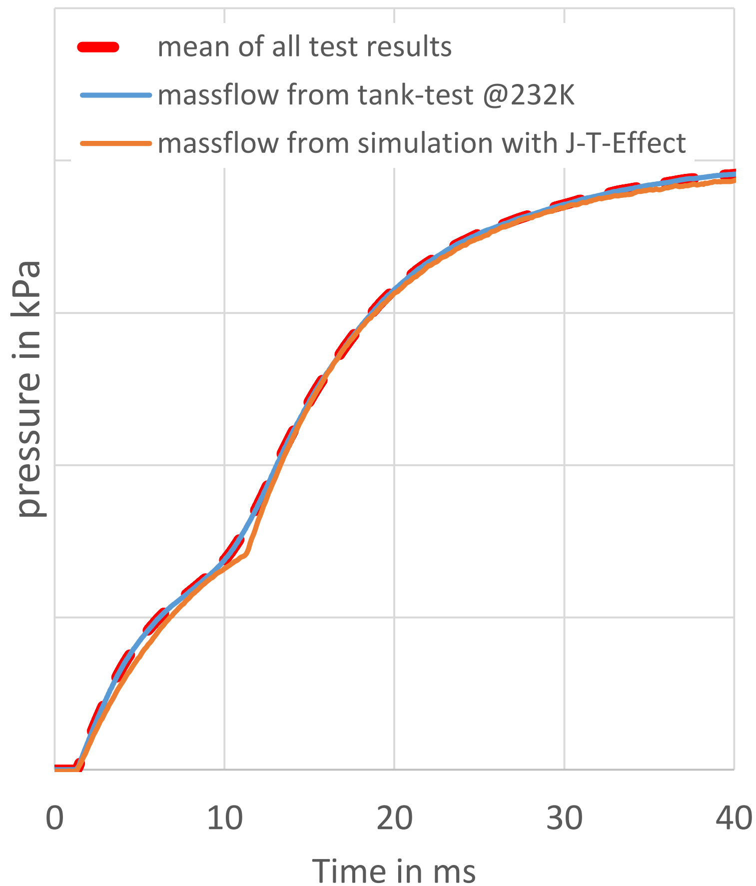
  - Second (**`*DEFINE_CPM_GAS_PROPERTIES`**) is referenced in Card 9 and 11 of the Airbag Particle keyword

```
*DEFINE_CPM_GAS_PROPERTIES
$         ID        Xmm        Cp0        Cp1        Cp2        Cp3        Cp4
        1301 0.0040026       20.8          0          0          0          0
$     mu_t0      mu_t1      mu_t2      mu_t3      mu_t4     Chm_ID       Vini
   111.809   -13.3453 0.0617413-1.2798e-49.72665e-8
```

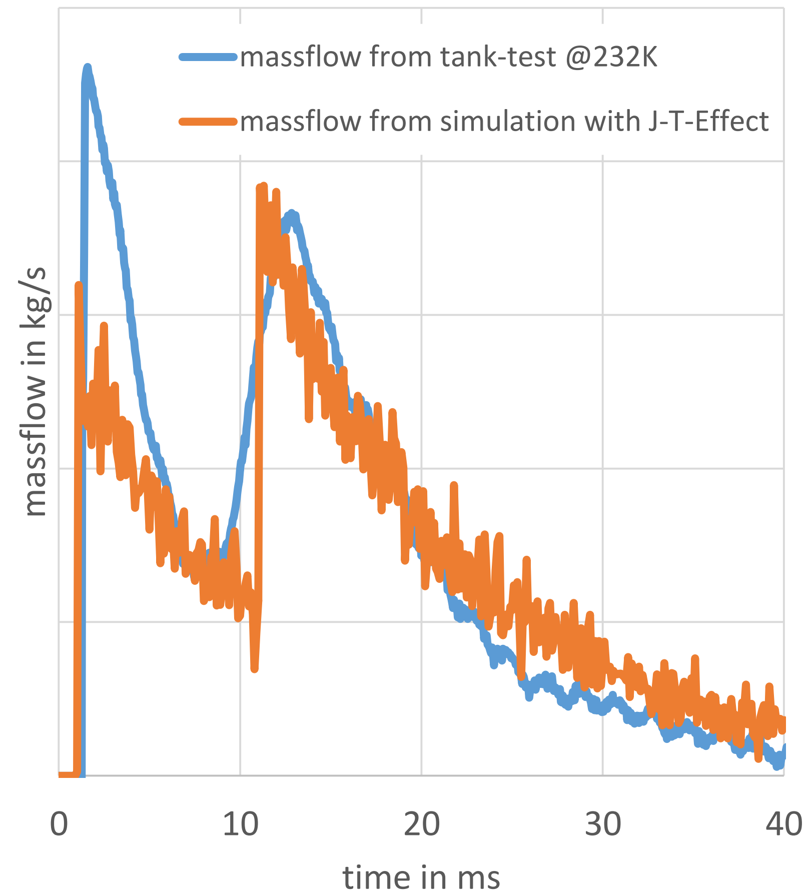
- Results of tank test simulation:
  - The Joule-Thomson-Effect closed the pressure gap
  - good correlation between test and simulation



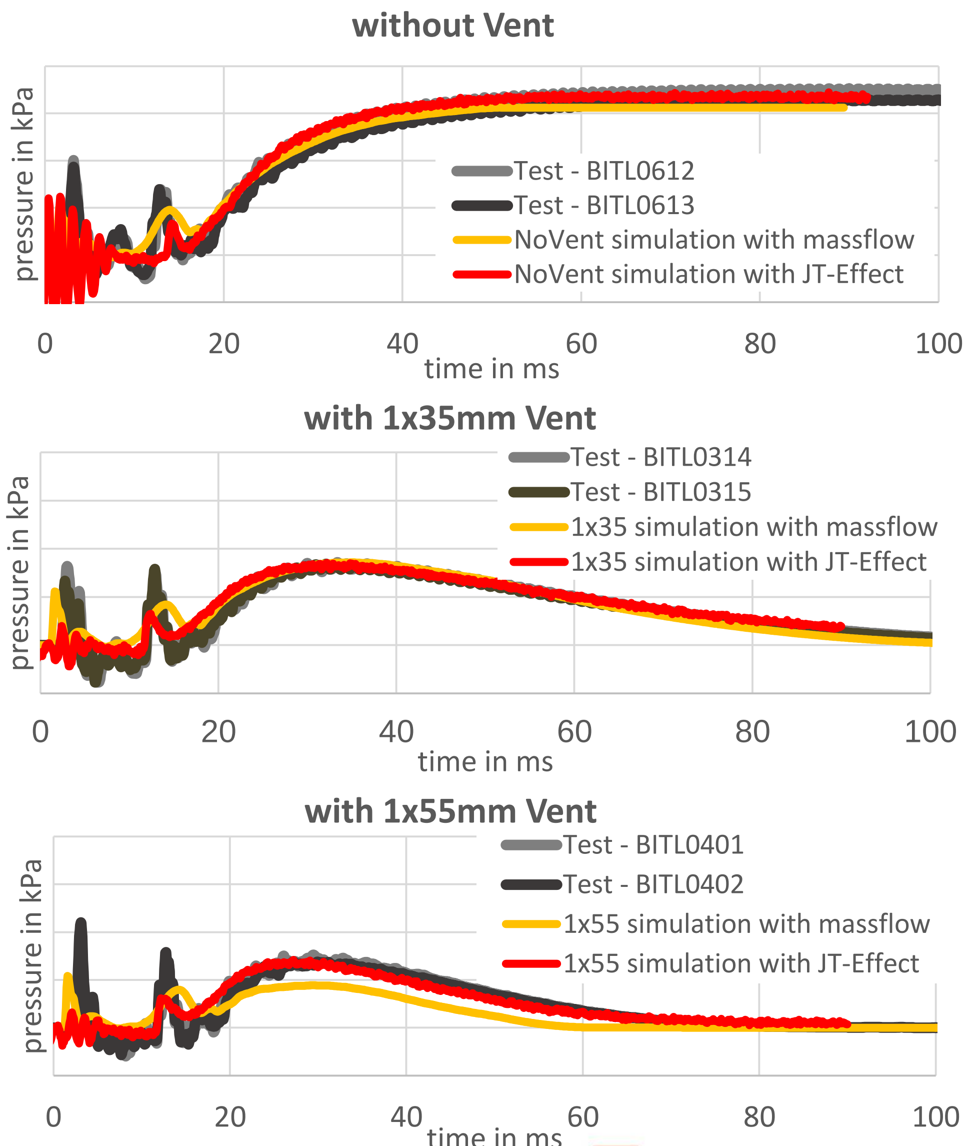
Tank-Test pressure comparison



massflow comparison



- Using the direct cold gas inflator modeling to simulate various system load-cases
  - System load-cases are represented by Takata's standardized inflation test with various vent sizes



- With LS-Dyna CP-Method it is possible to simulate cold-gas-inflators without tank-test assumptions
- The treatment of the Joule-Thomson-Effect is possible for more accurate results

- Open points
  - compare LS-Dyna Versions, currently: `mpp.s.R7.1.2.95028.95028_dmp_sp`
  - Vary number of CPM-particles, currently: 100.000 particle
  - Analyze pressure dependency in Joule-Thomson-Coefficients, currently: $\mu_{\mathrm{JT}} = \mu_{\mathrm{JT}}(T)$

TAKATA

Thank you for your attention

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