Accelerated Burning of Gun Propellants Caused by Pressure Oscillations Within the Perforations of Propellant Grains

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New Orleans, LA, U.S.A.

Contents

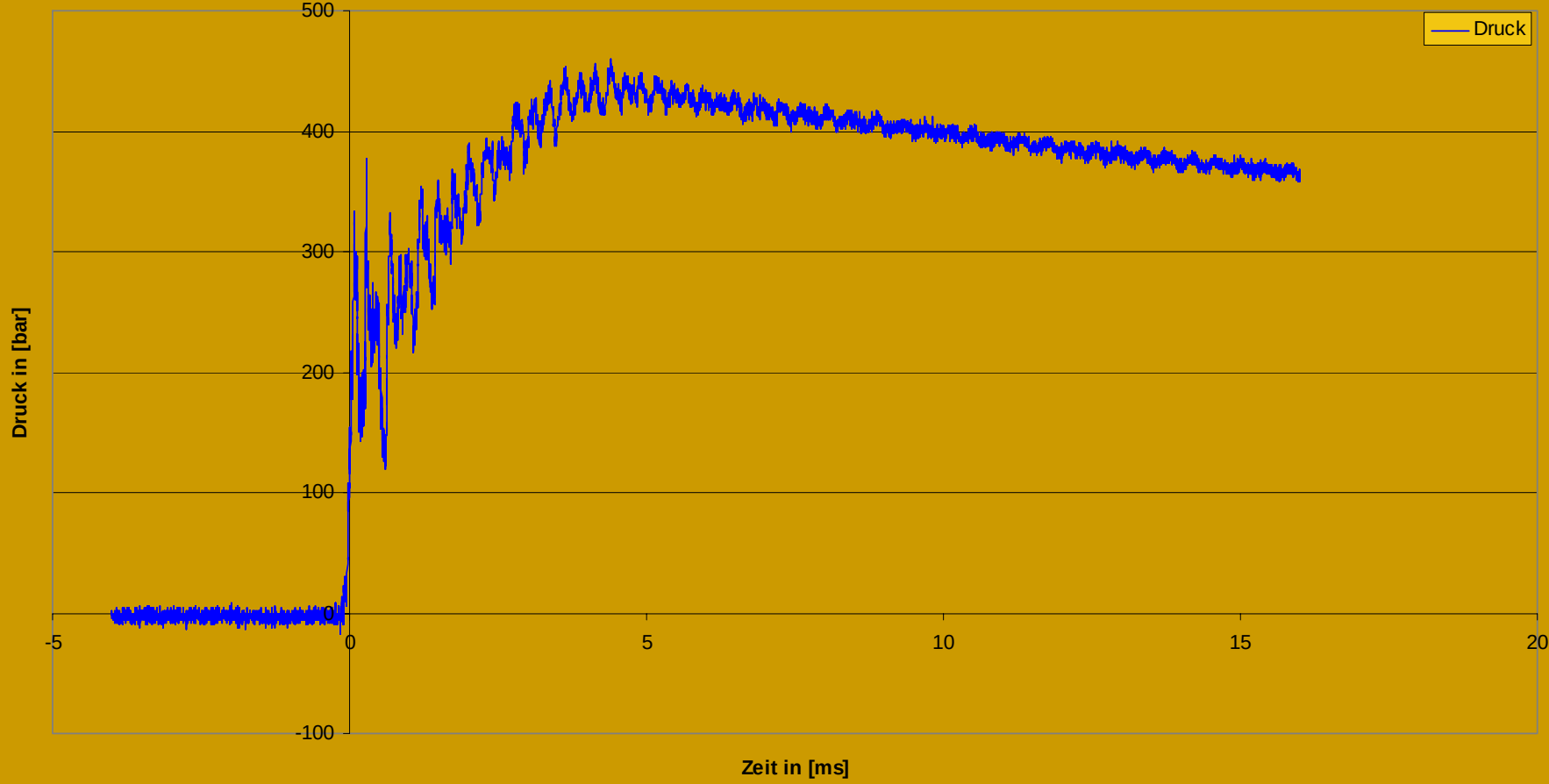
1. Pressure oscillations in holes of propellant grains

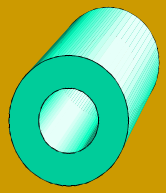
2. Connections between pressure oscillations, accelerated burning and temperature behaviour

3. Working hypothesis explaining the effect of accelerated burning caused by pressure ocillations

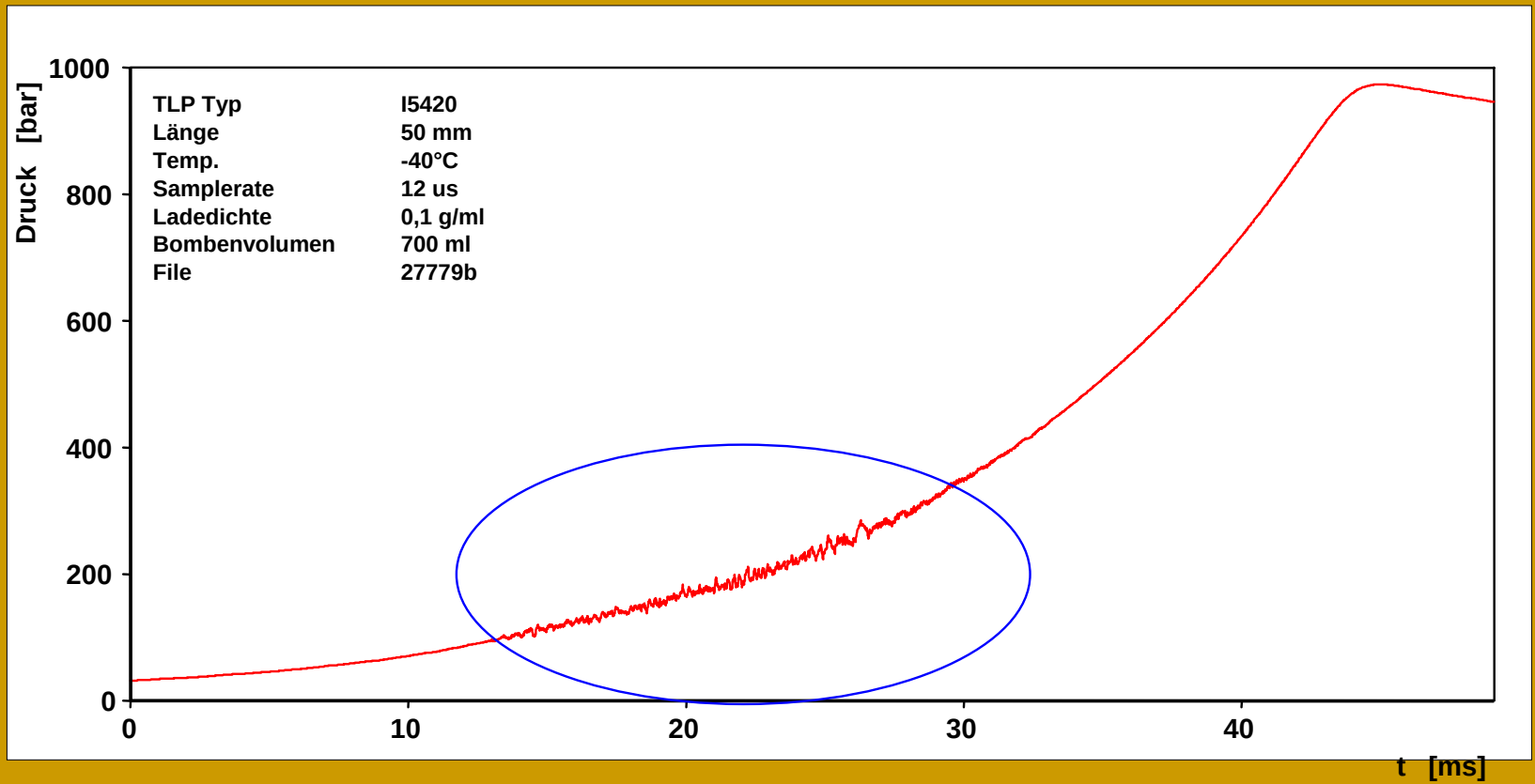
4. Conclusions

Example for Vieille-oscillations in a closed vessel
WTD 91 January 2007



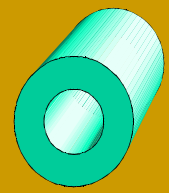


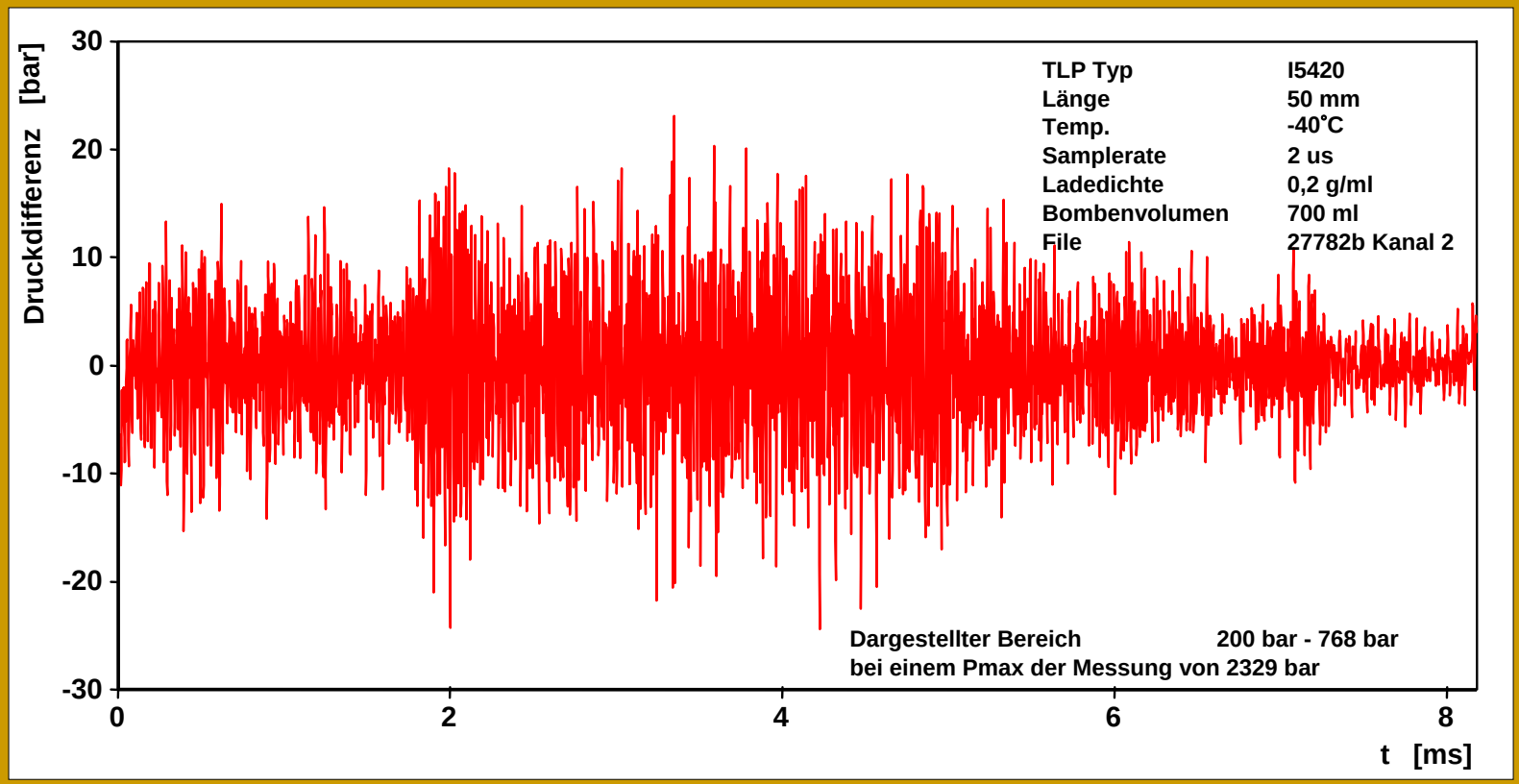
Oscillations superimposing the rise of pressure



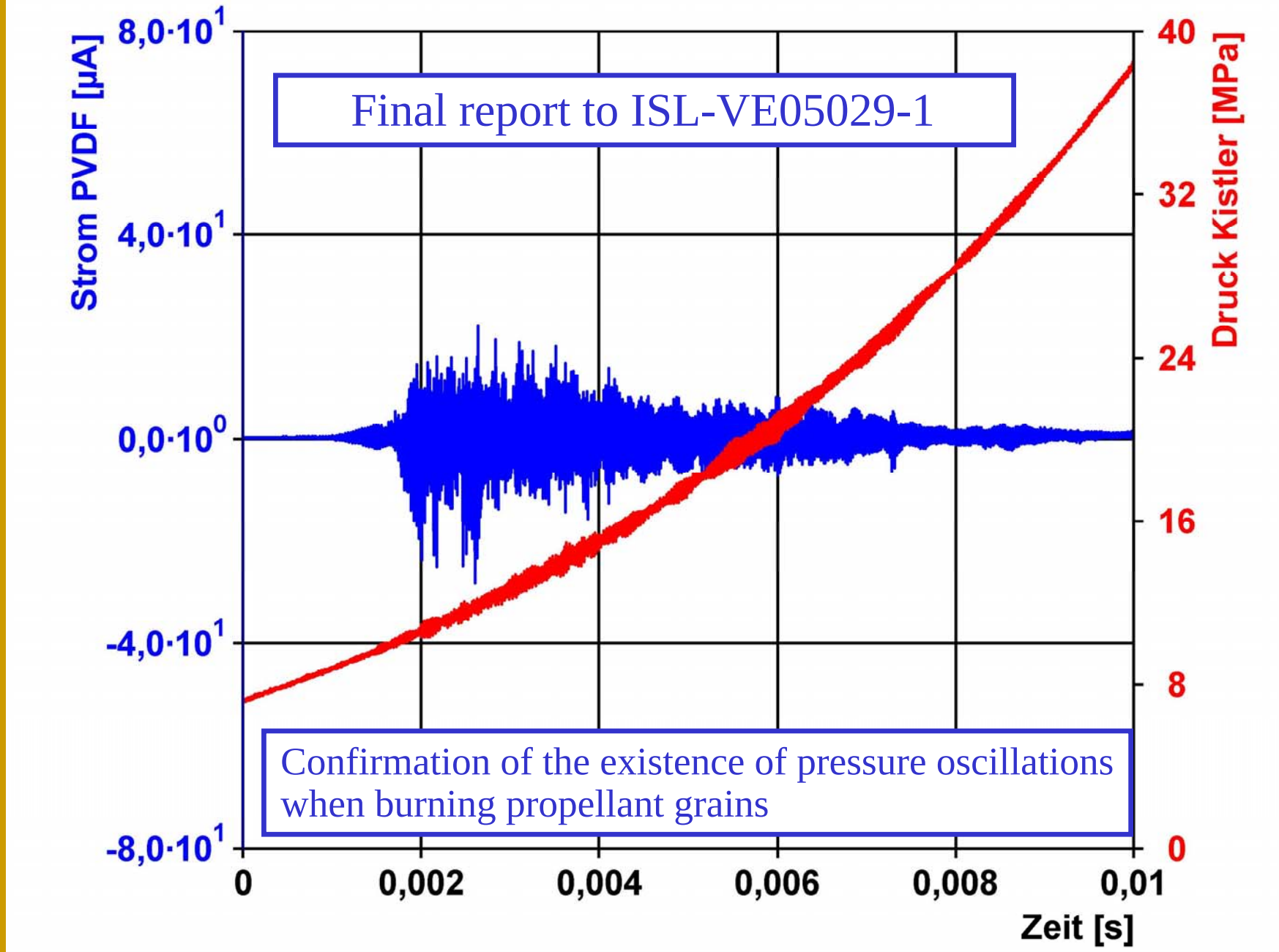
Pressure / time curve resulting from burning a tube propellant in a closed vessel. The oscillations are found in the encircled range.

Pressure oscillations when burning a tubular propellant



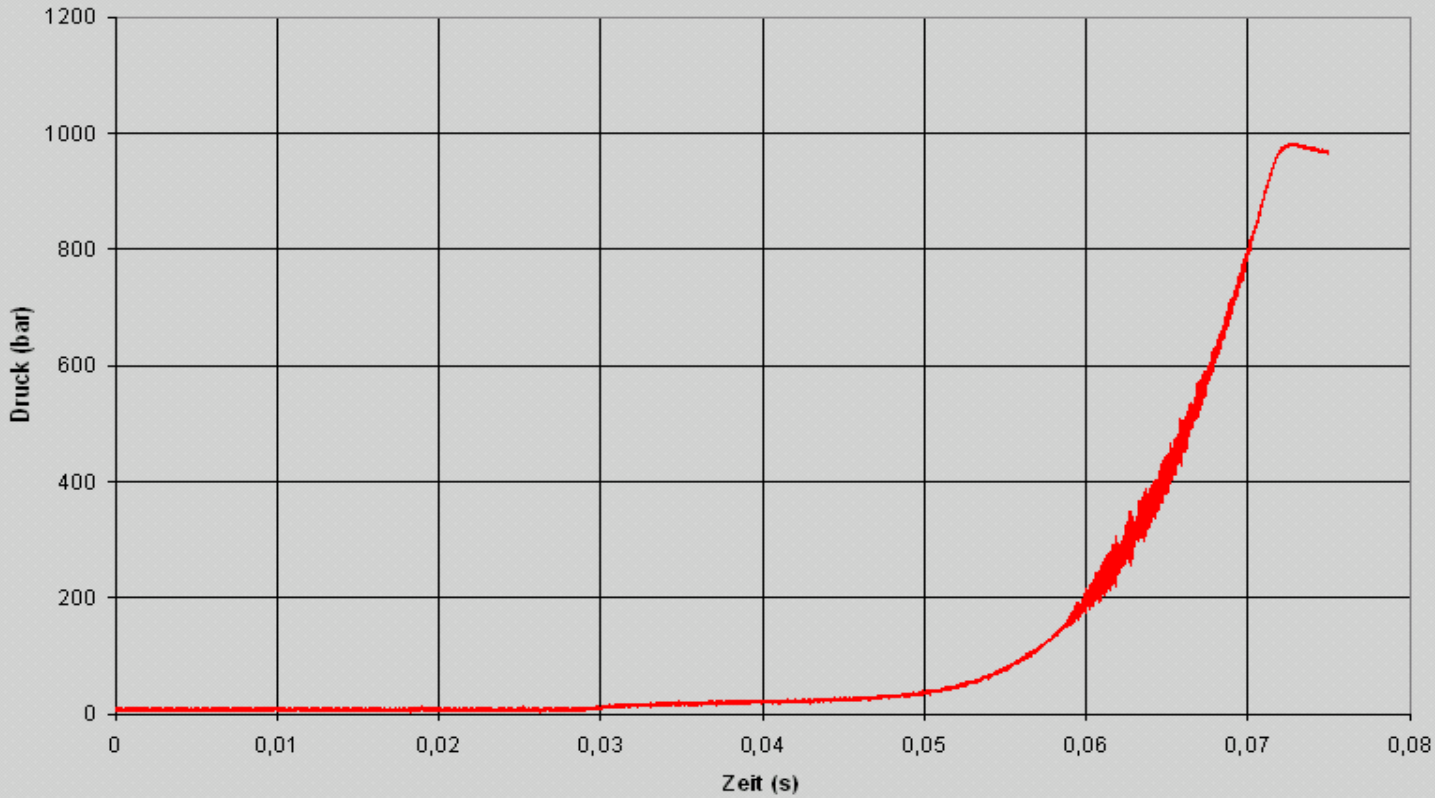


The picture was achieved by subtracting the original p / t - curve from the smoothed p / t - curve.


Final report to ISL-VE05029-1
Confirmation of the existence of pressure oscillations when burning propellant grains
Strom PVDF [µA]
8,0·10^1
4,0·10^1
0,0·10^0
-4,0·10^1
-8,0·10^1
Druck Kistler [MPa]
40
32
24
16
8
0
0
0,002
0,004
0,006
0,008
0,01
Zeit [s]

Prüfpulver C/S 2100/1; 0.1 g/cm^3; -40°C

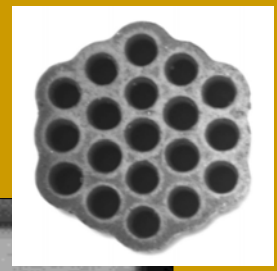
DIEHL
BGT Defence



Confirmation of the existence of pressure oscillations when burning propellant grains

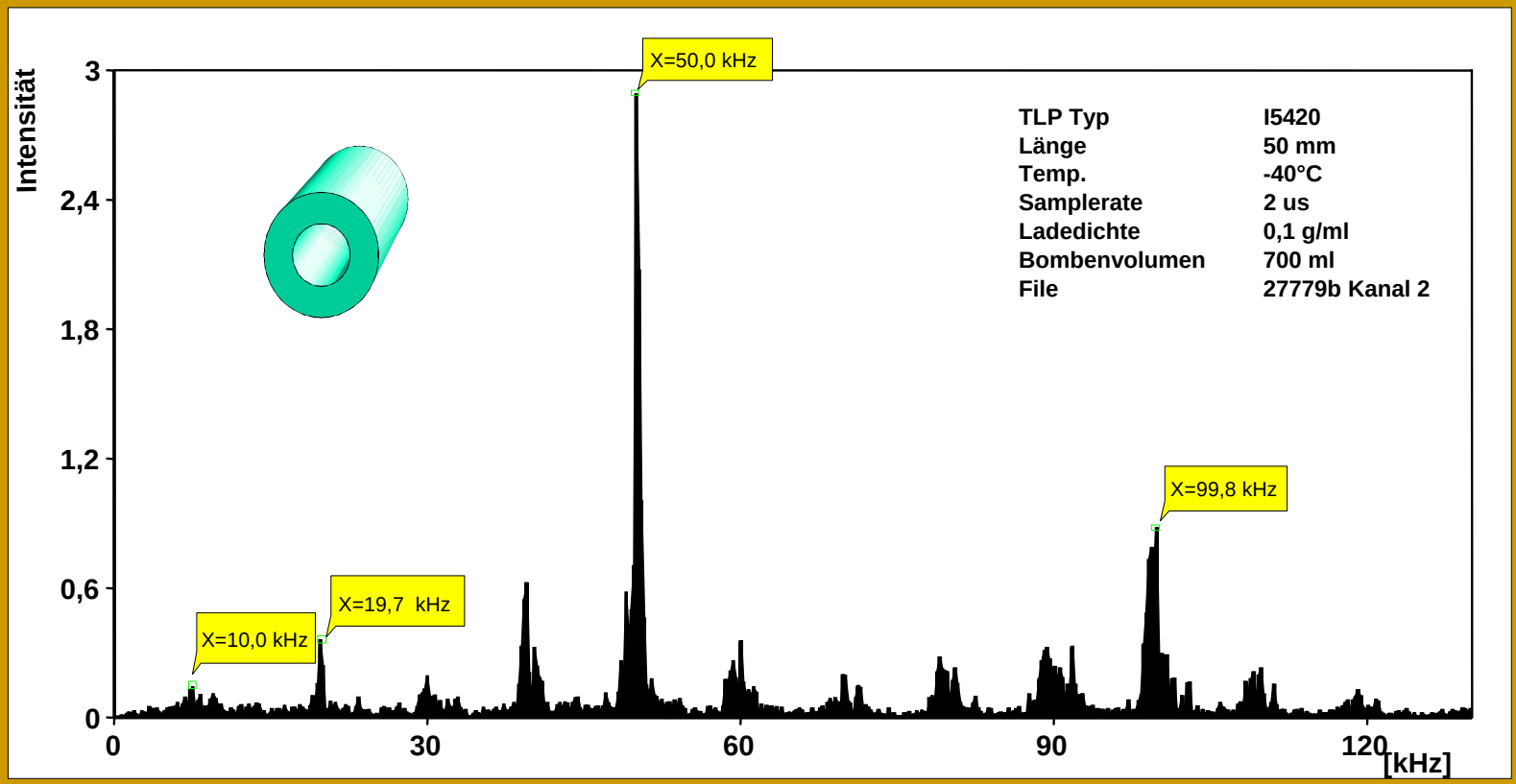
Copyright

Abnormal (wavelike) erosions in the holes



The picture shows a sectional view of a triple-base 19-hole-propellant grain after interrupted burning at - 46°C (- 51°F). The wavelike erosions indicate the occurrence of standing waves in the holes.

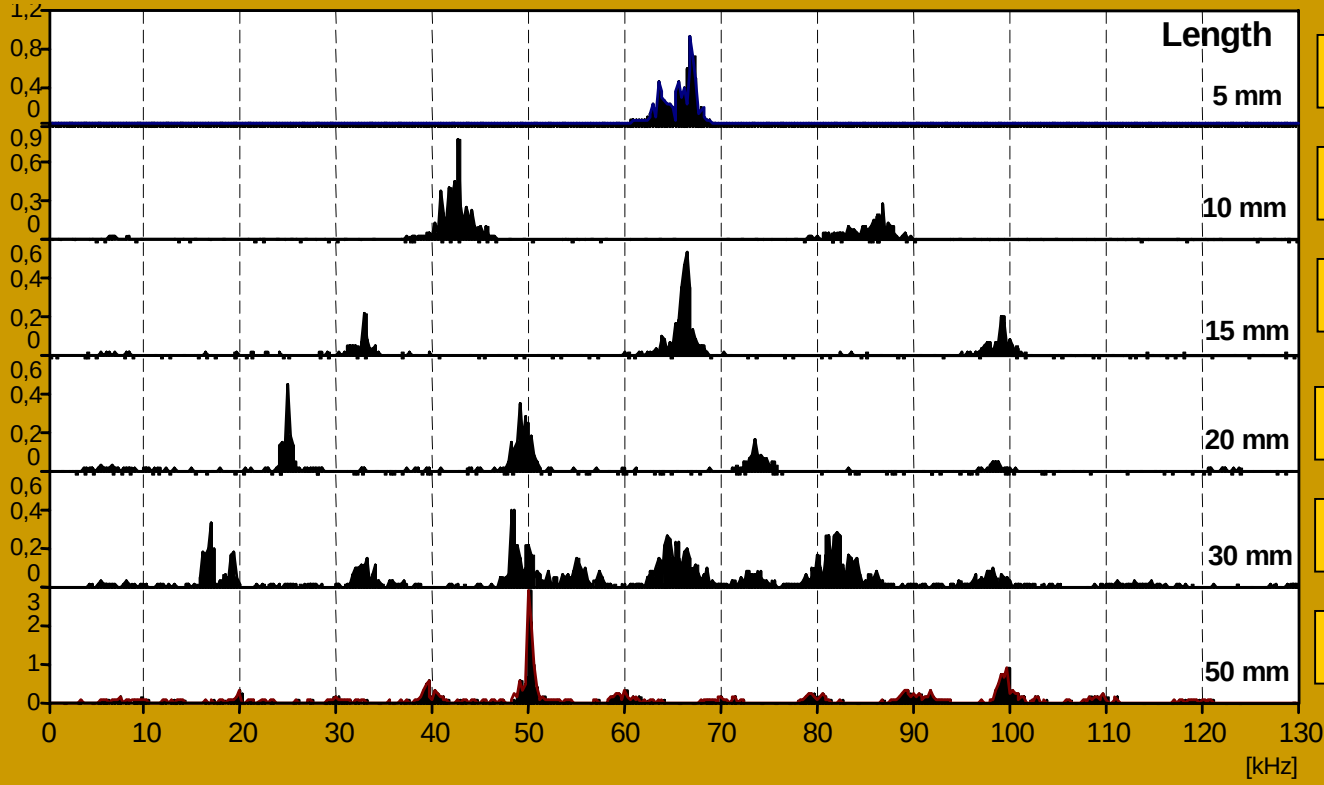
Frequency spectrum of a tubular propellant with a length of 50 mm

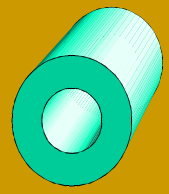


Characteristic maxima of frequencies associated with the fundamental frequency (10 kHz)

Frequency spectra of tubular propellants with different lenghts

(Loading density = 0.1 g/ccm)





5 mm

10 mm

15 mm

20mm

30 mm

50 mm

The shift of the frequencies proves that the oscillations are connected with the tube lengths.

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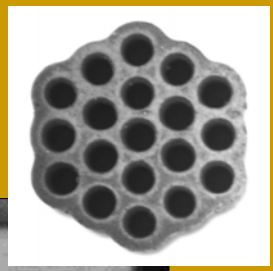
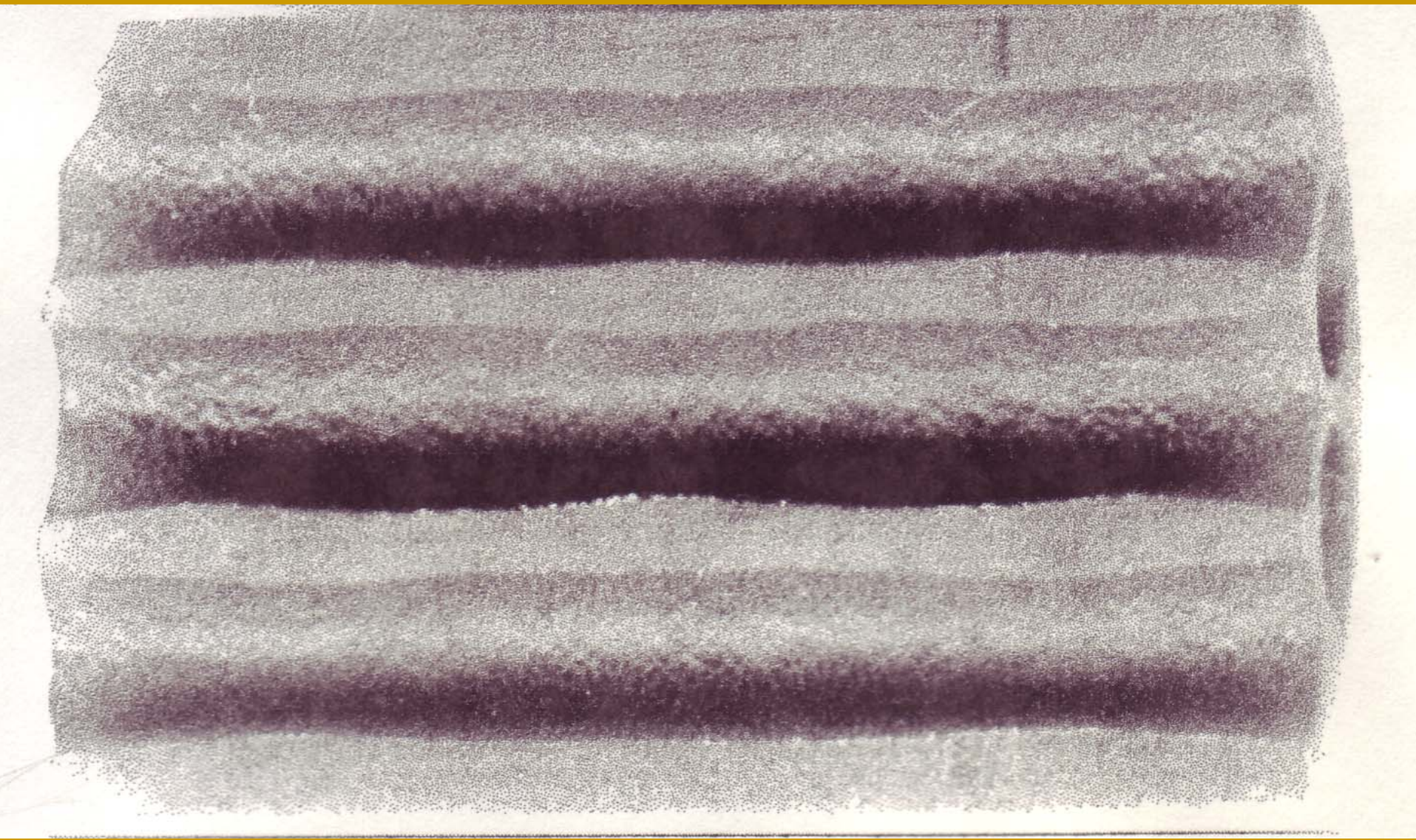


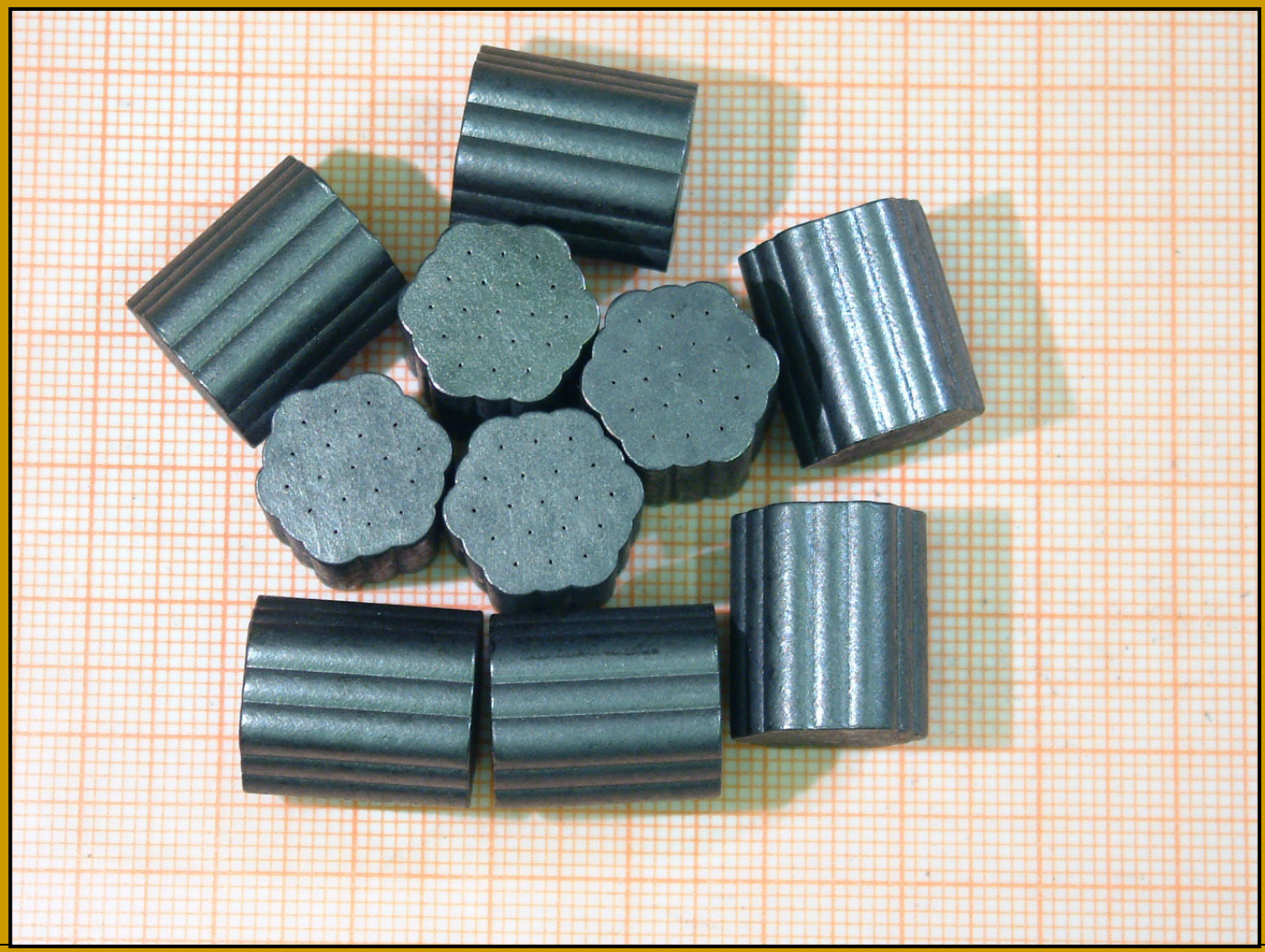
The picture shows a sectional view of a triple-base 19-hole-propellant grain after interrupted burning at - 46°C (- 51°F). The wavelike erosions indicate the occurrence of standing waves in the holes.

Abnormal (wavelike) erosions in the holes

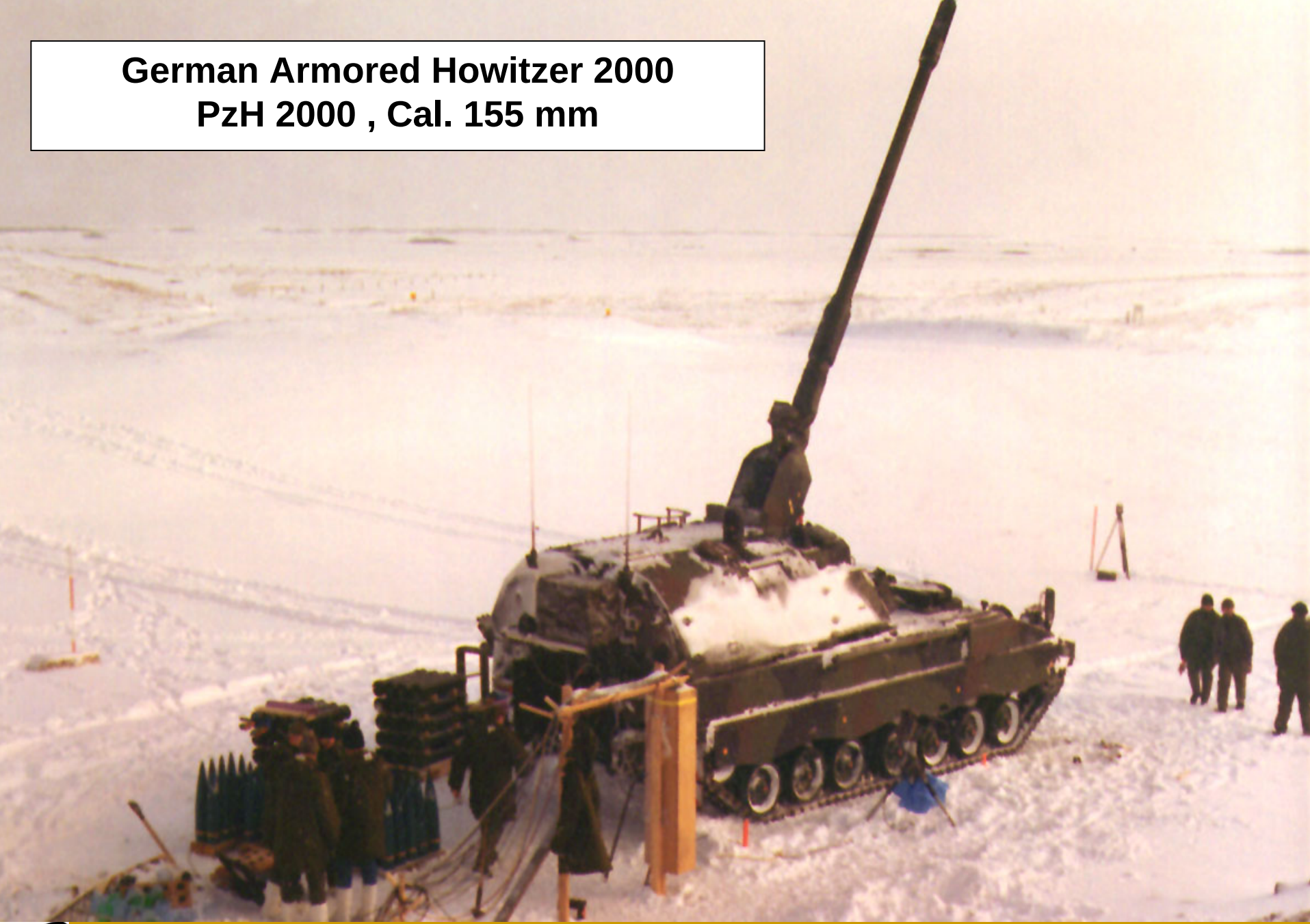


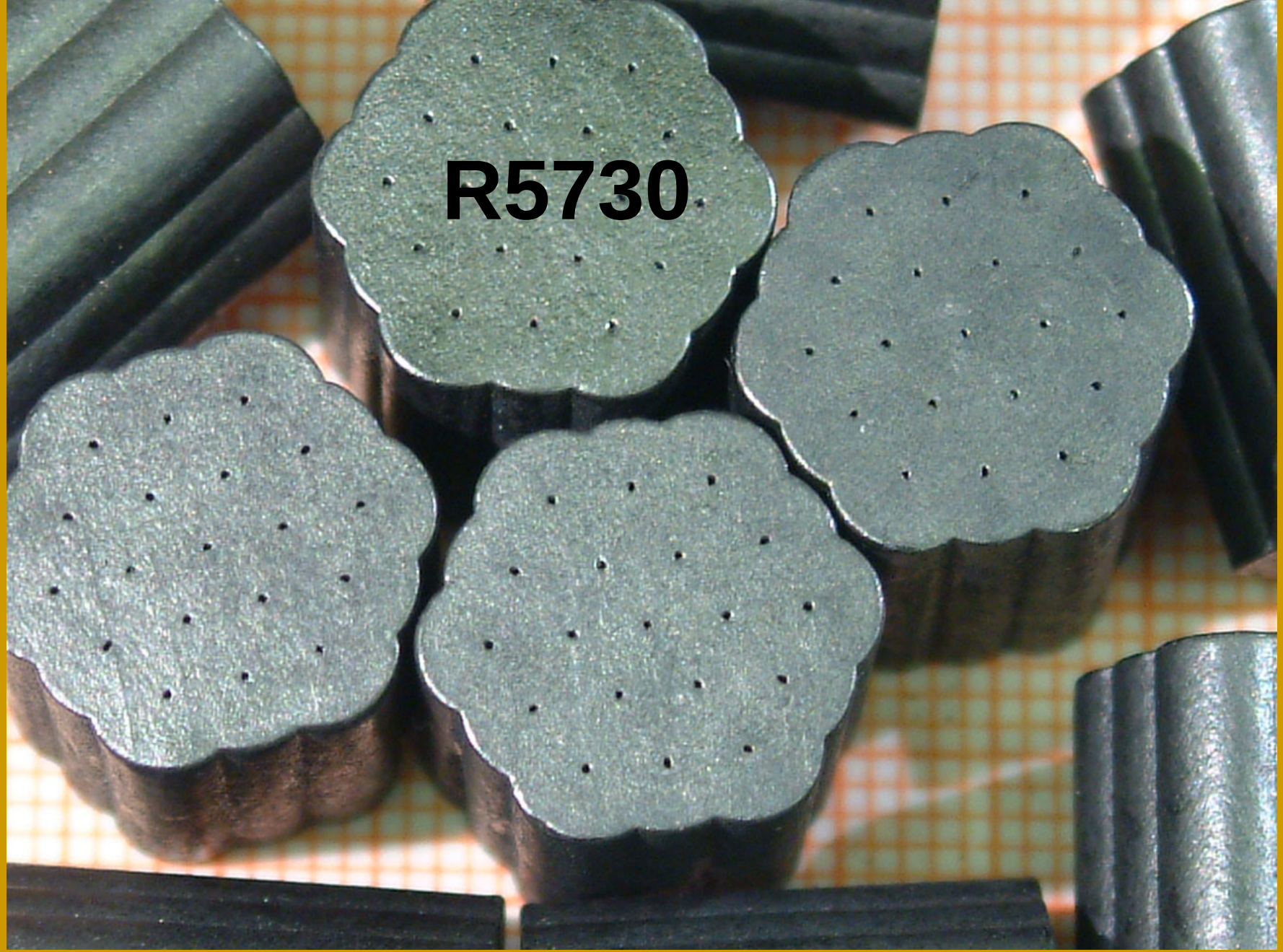
Double-base 7-hole-propellant grain after interrupted burning at - 40°C (- 40°F).

19-hole-triple-base-propellant R5730

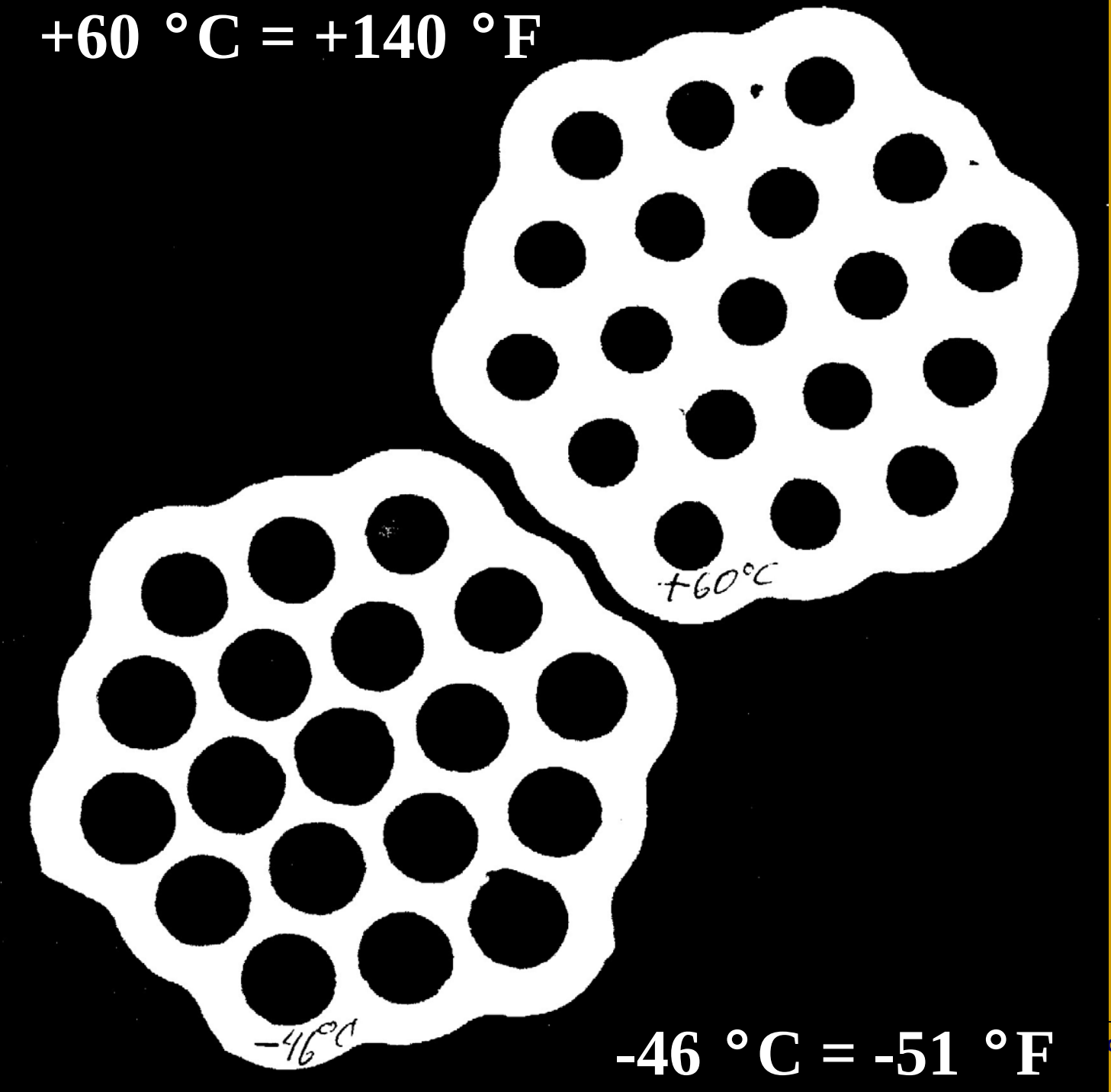


German Armored Howitzer 2000
PzH 2000 , Cal. 155 mm

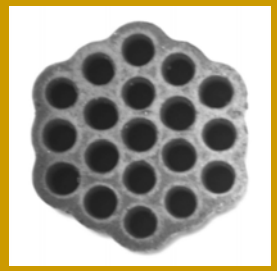



R5730

+60 °C = +140 °F



-46 °C = -51 °F



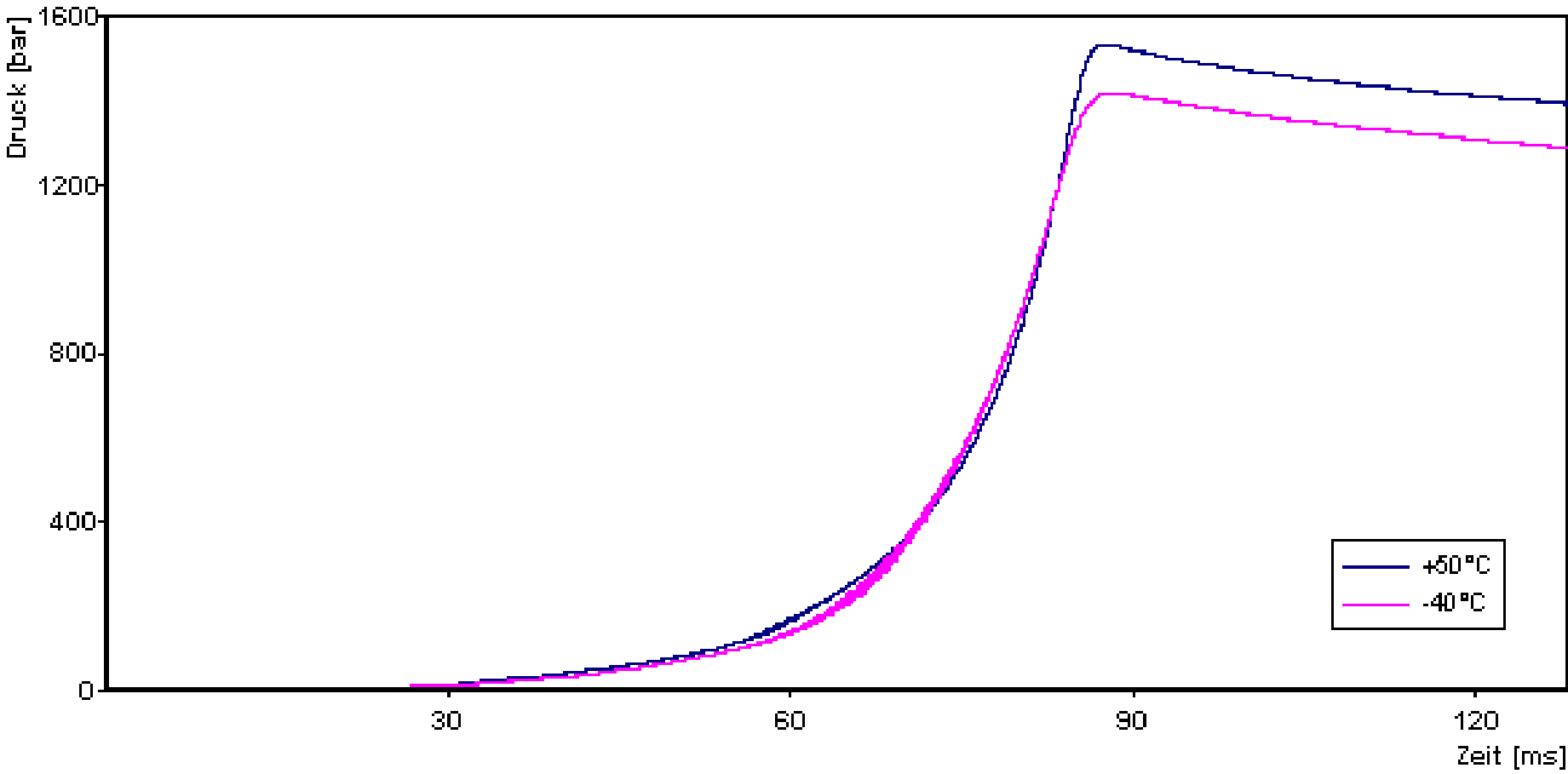
R5730

after

Inter-rupted burning

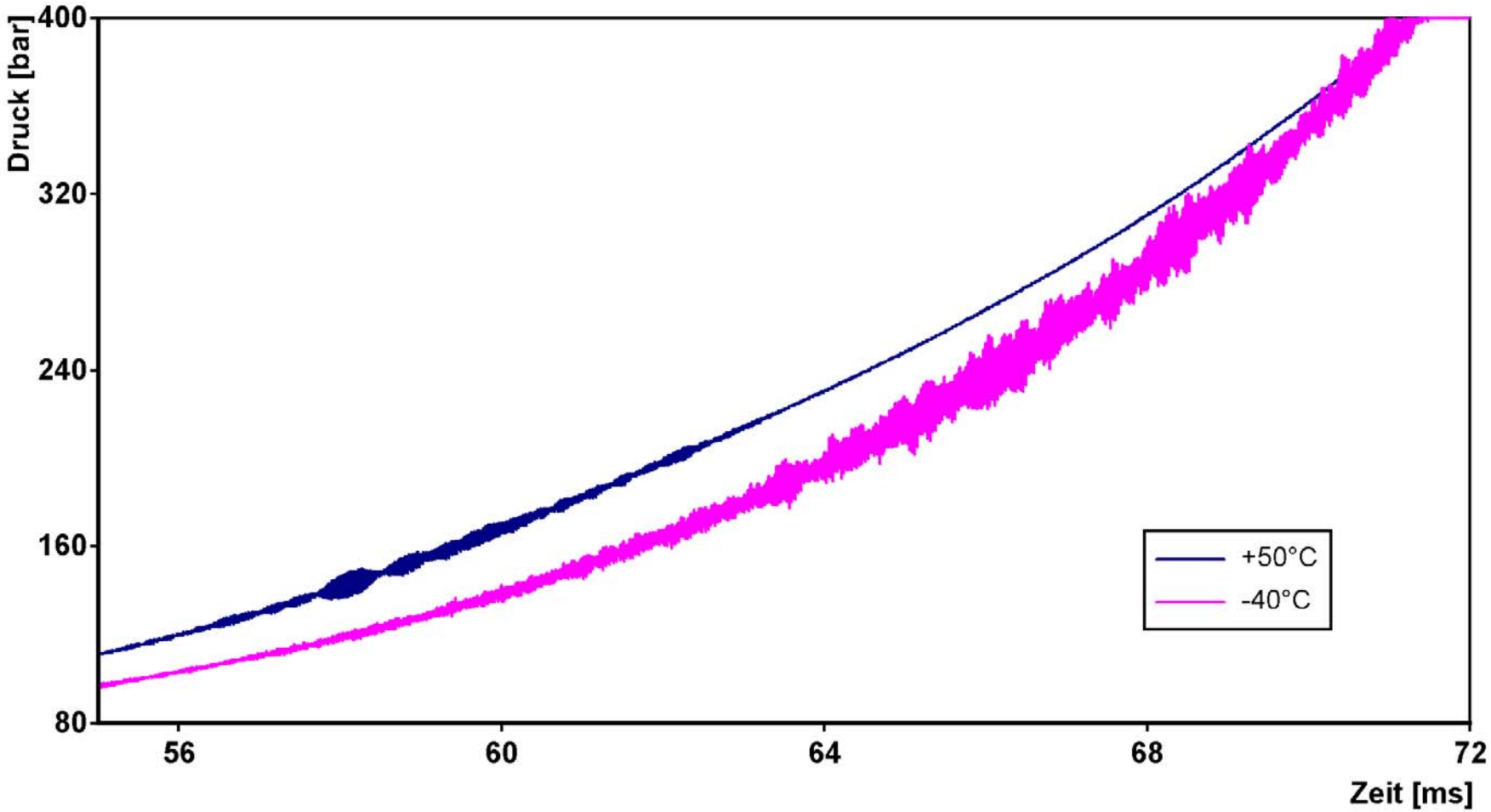
Pressure - time curves of the propellant R5730 in a closed vessel at – 40 (- 40°F) and +50°C (+122°F)

Both curves are temporally superimposed to improve the comparability. The cold propellant (-40°C) shows intense oscillations. The warm one (+50°C) shows only weak and short-time oscillations.



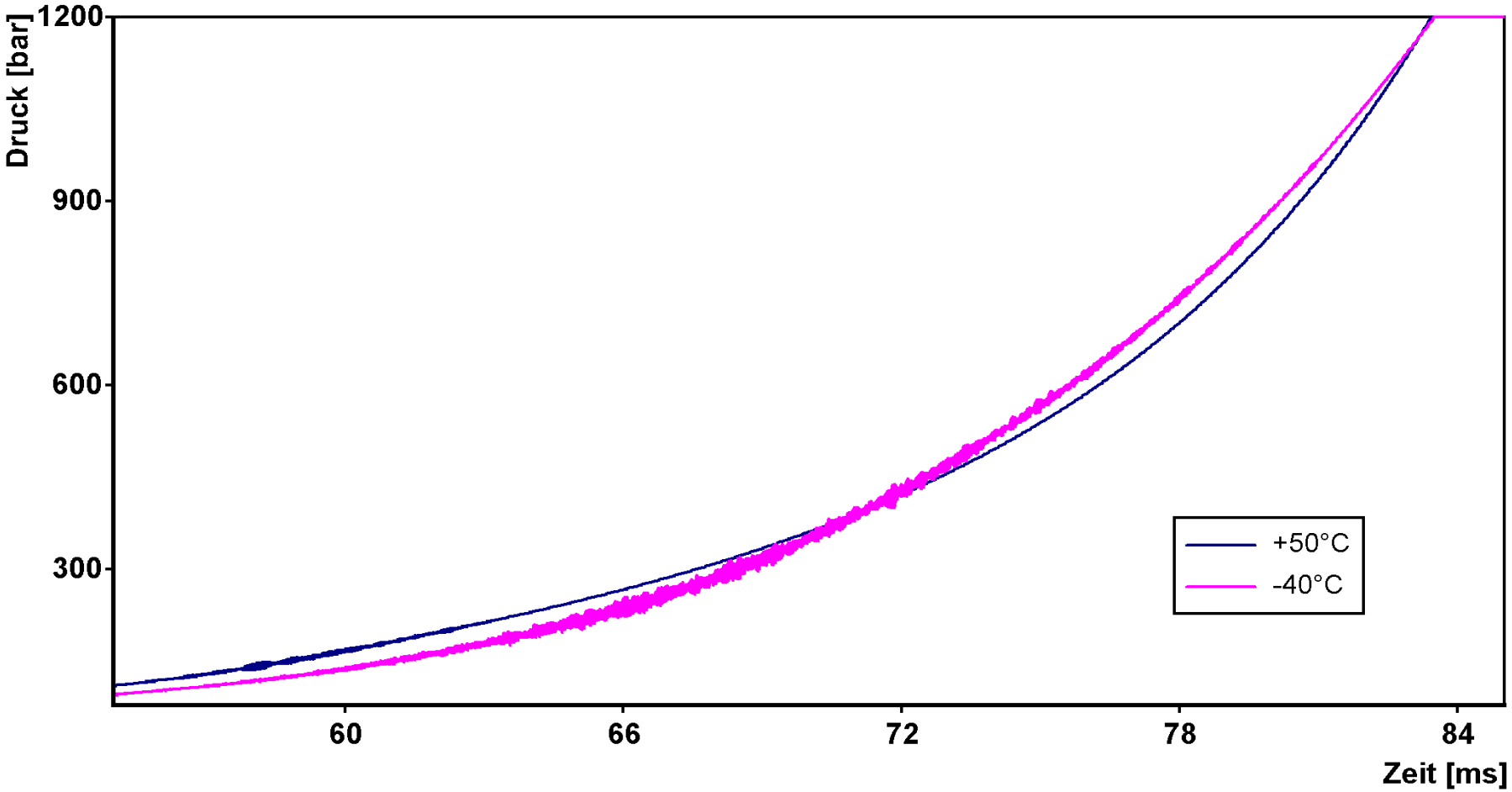
Pressure - time curves of the propellant R5730 in a closed vessel at – 40 (- 40°F) and +50°C (+122°F)

Furthermore the cold propellant shows increasing oscillations for a while connected with accelerated burning and overtakes the warm propellant during burning.



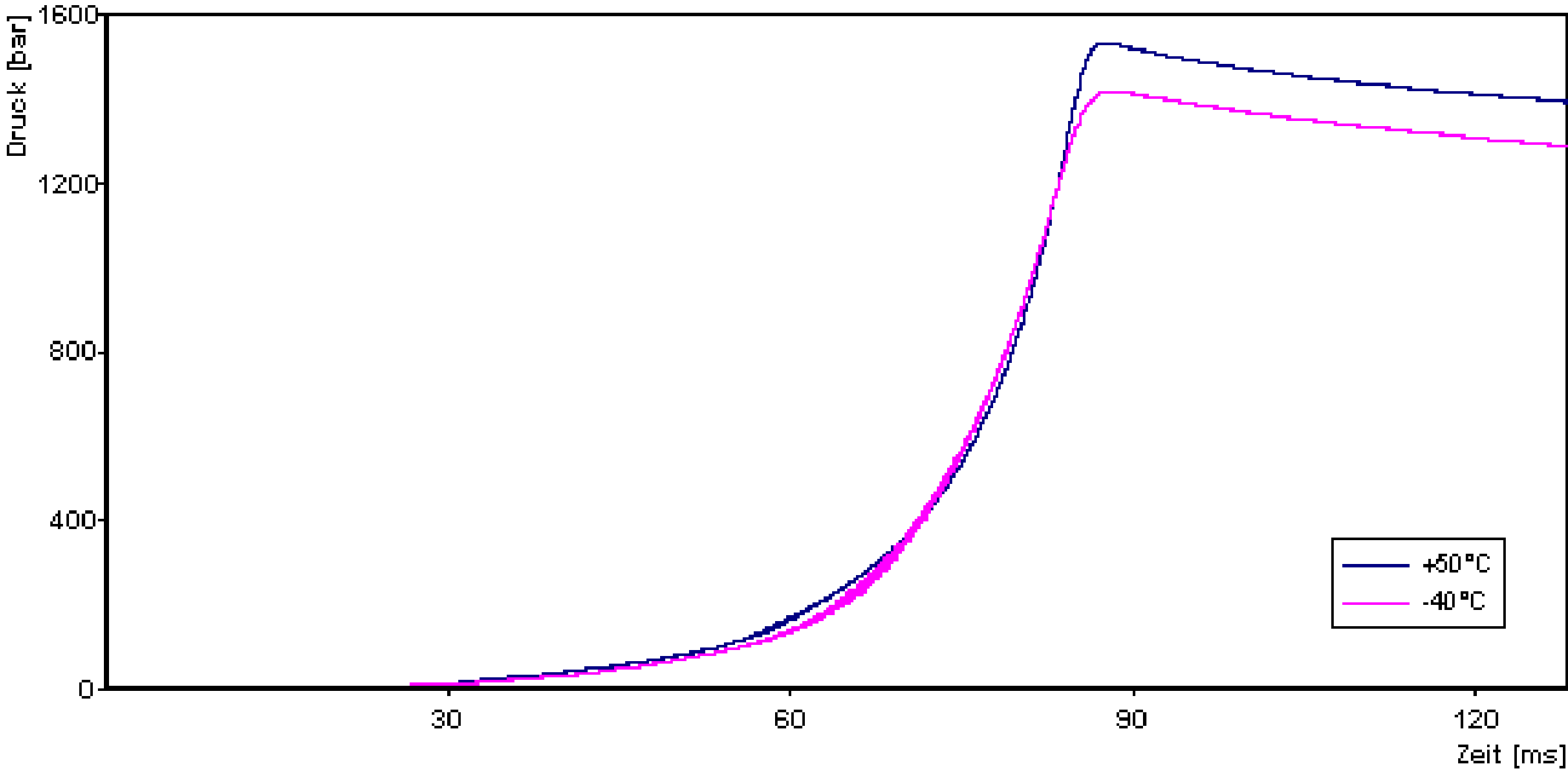
Pressure - time curves of the propellant R5730 in a closed vessel at – 40 (- 40°F) and +50°C (+122°F)

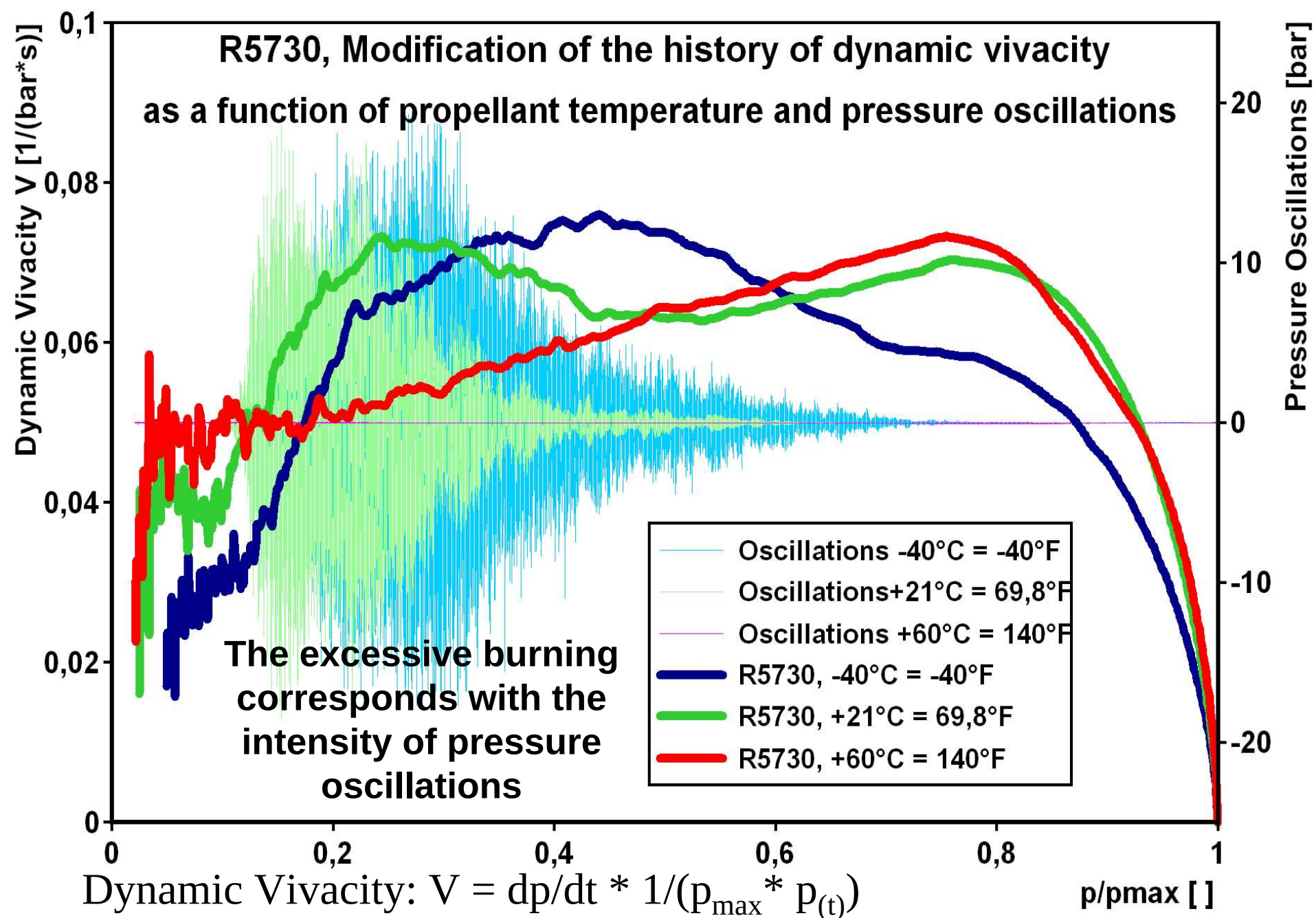
Having overtaken - the oscillations of the cold propellant die away and the burning rate rises slower. The burning rate of the warm propellant rises faster and overtakes the cold one again.



Pressure - time curves of the propellant R5730 in a closed vessel at – 40 (- 40°F) and +50°C (+122°F)

Finally the warm propellant reaches a higher maximum pressure than the cold propellant.





Dynamic Vivacity: $V = dp/dt * 1/(p_{max} * p_{(t)})$

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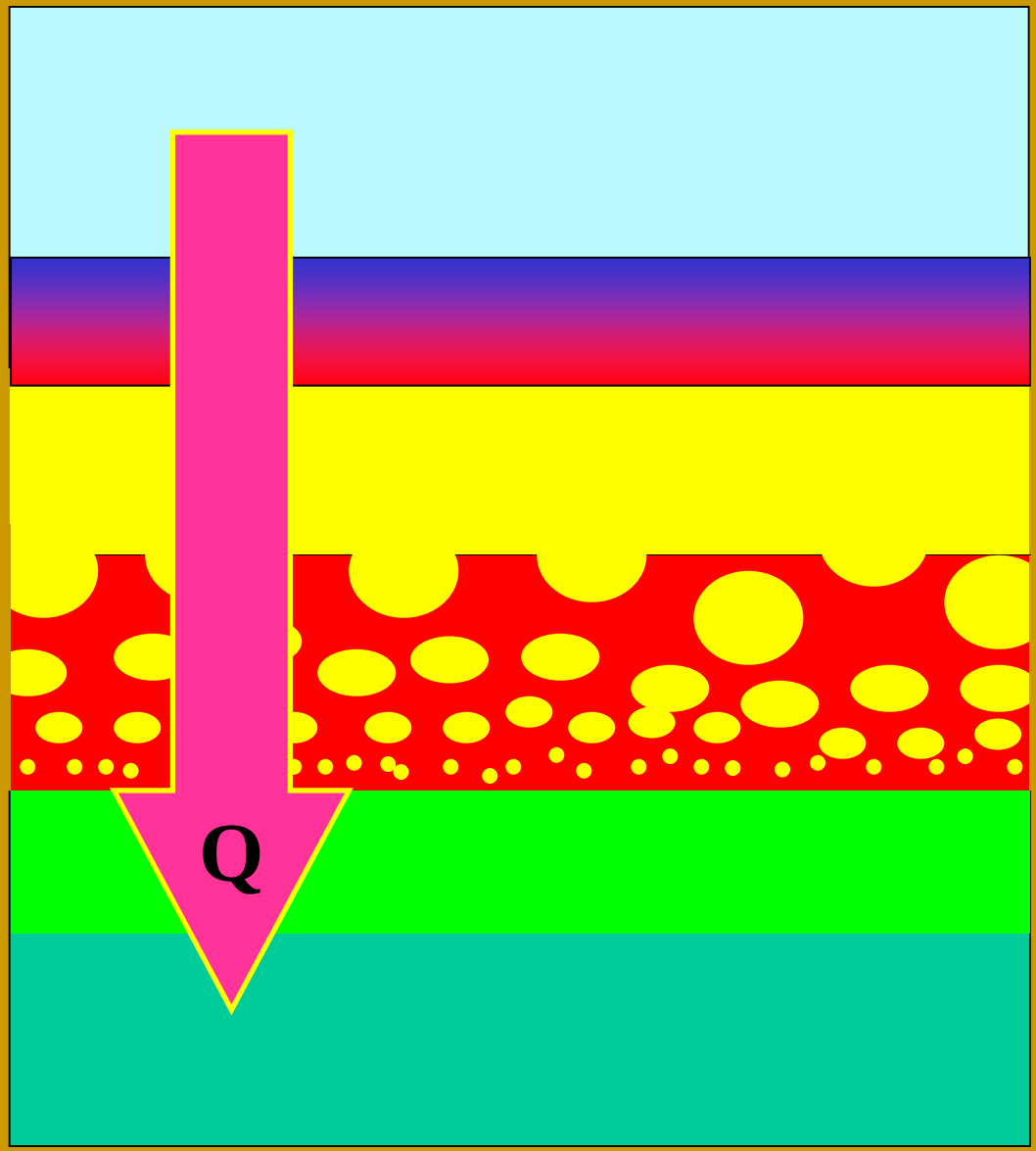


Flue Gas

Flame Zone

Gas Phase Reaction Zone

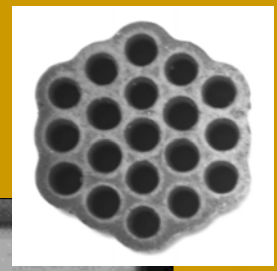
Foam/Liquid Reaction Zone with bubbles – two phases

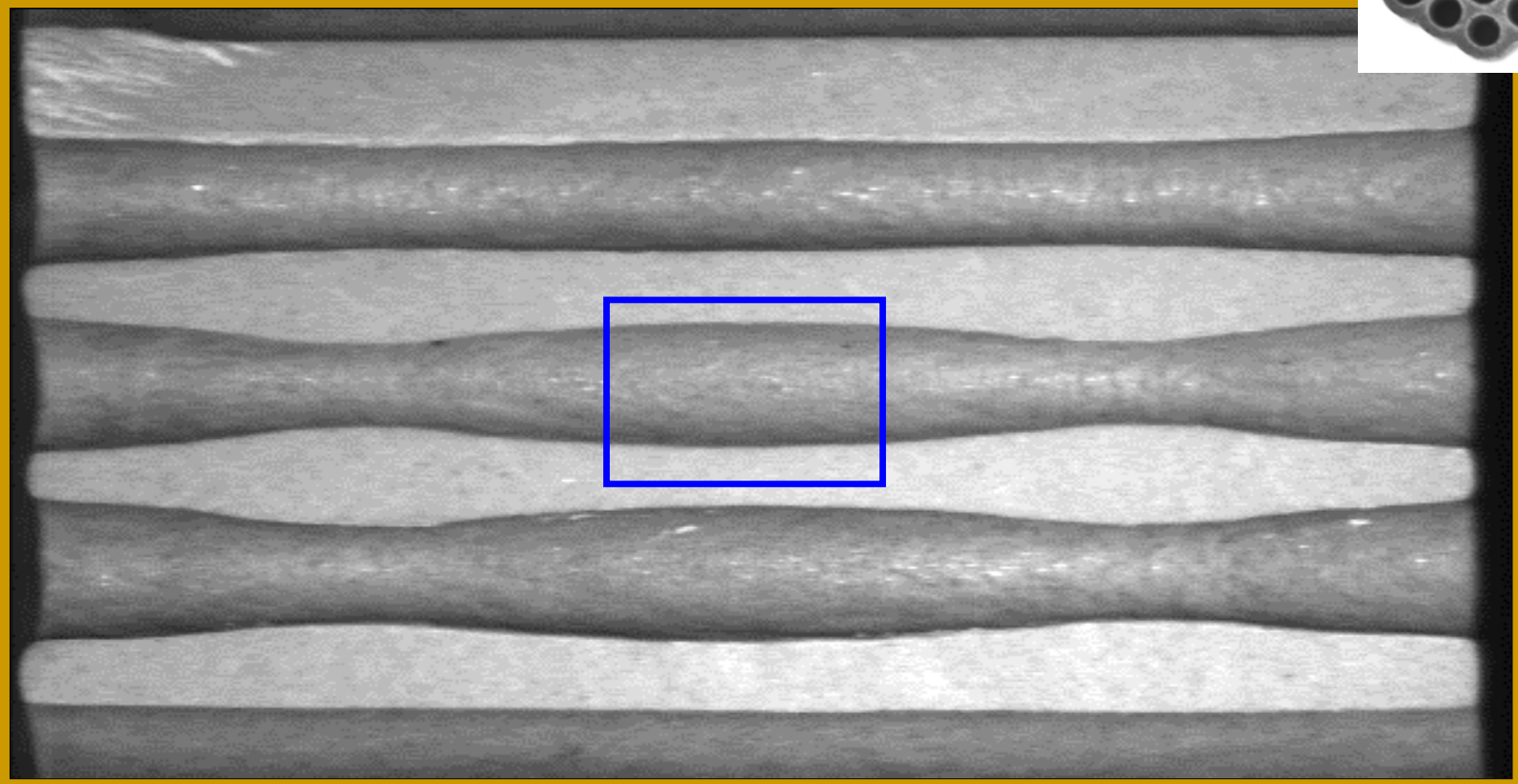
Heating Zone (solid)

Unburned Propellant

Simple model of a burning propellant surface

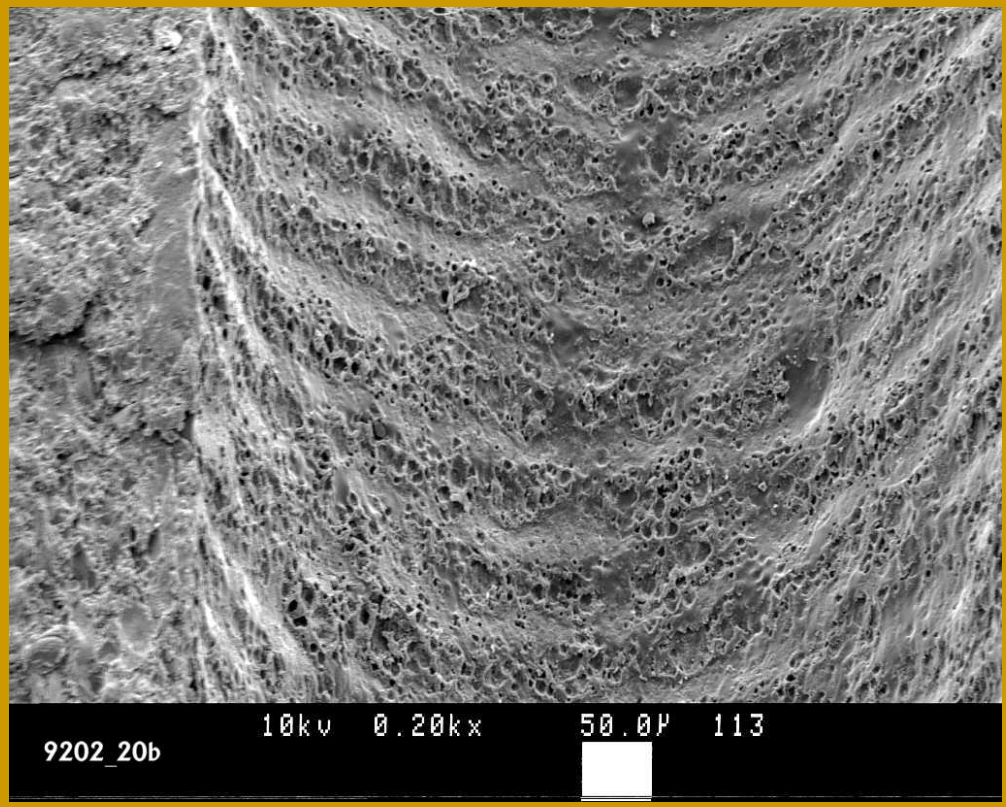
Abnormal (wavelike) erosions in the holes

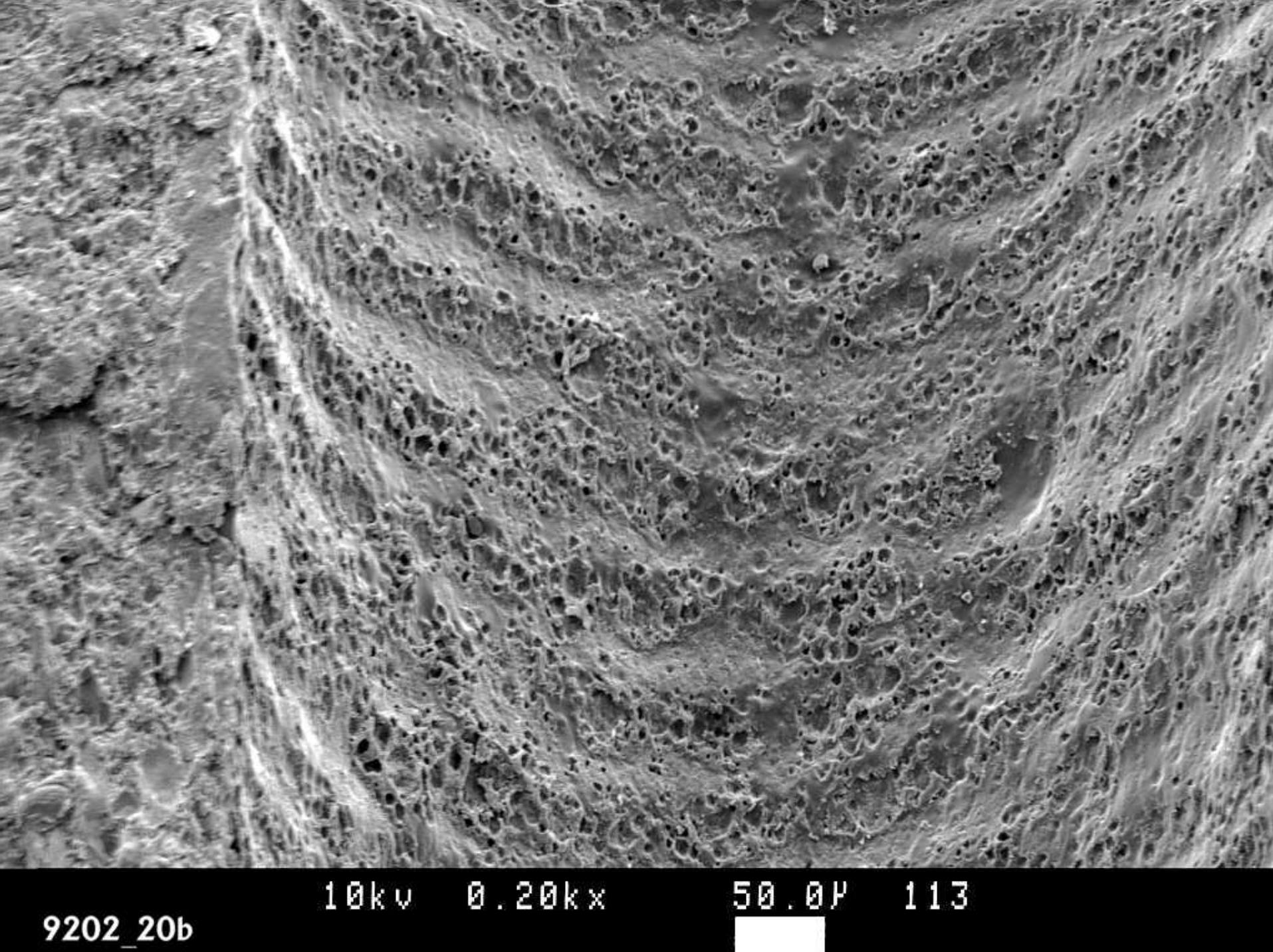




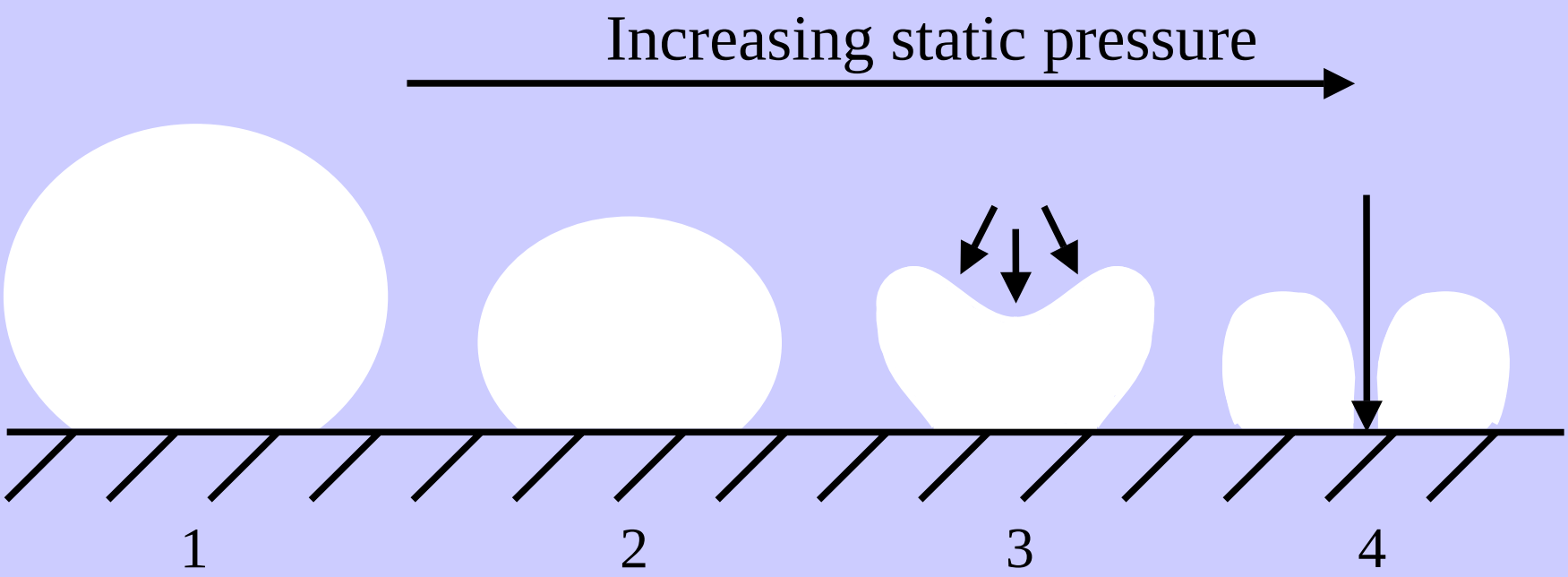
The picture shows a sectional view of a triple-base 19-hole-propellant grain after interrupted burning at - 46°C (- 51°F). The wavelike erosions indicate the occurrence of standing waves in the holes.

Wavelike erosion on the surface of a hole after interrupted burning, $T_{propellant}$ = 20°C (= 68°F), magnification: 200 times, sample 92/02

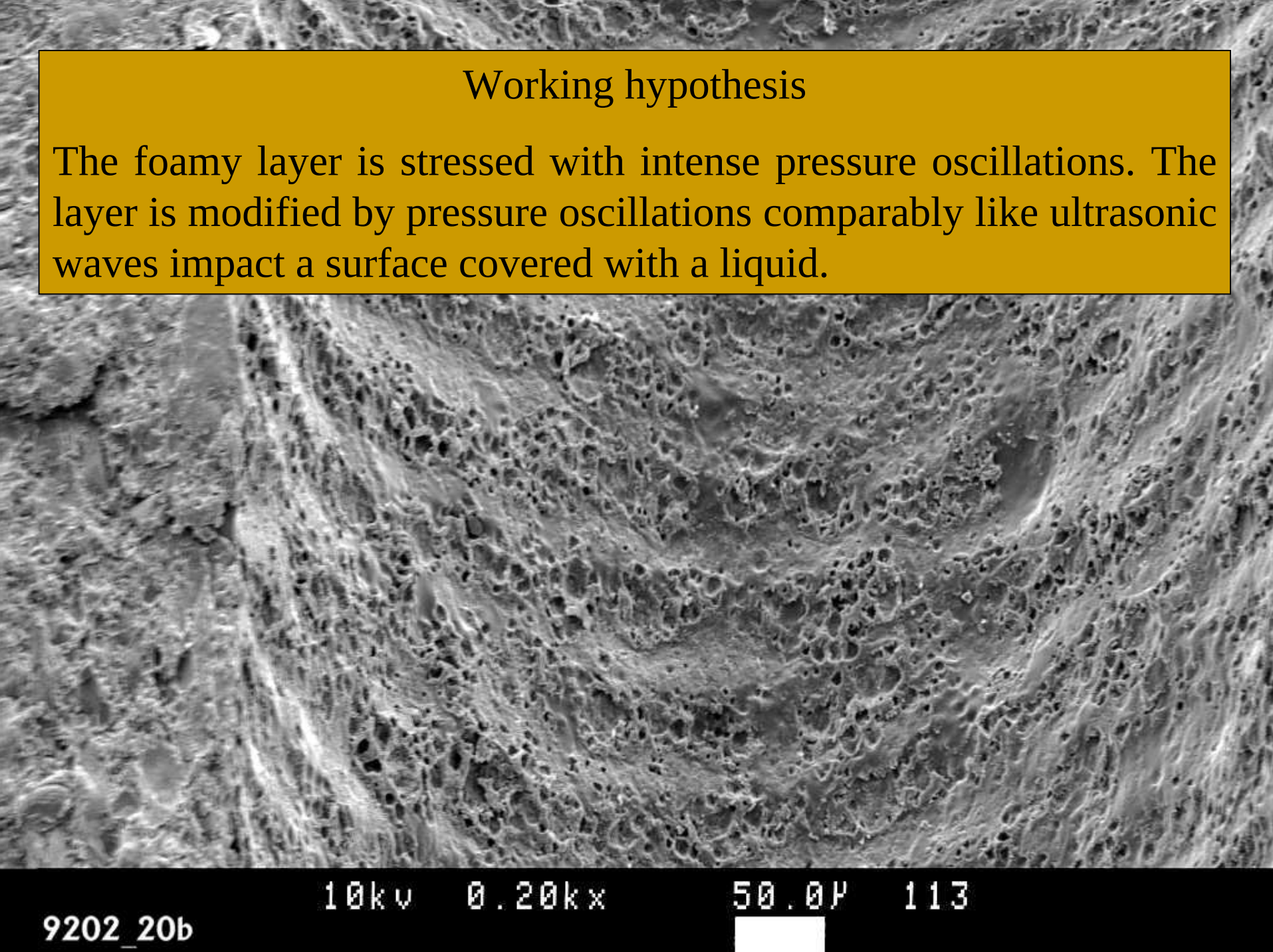


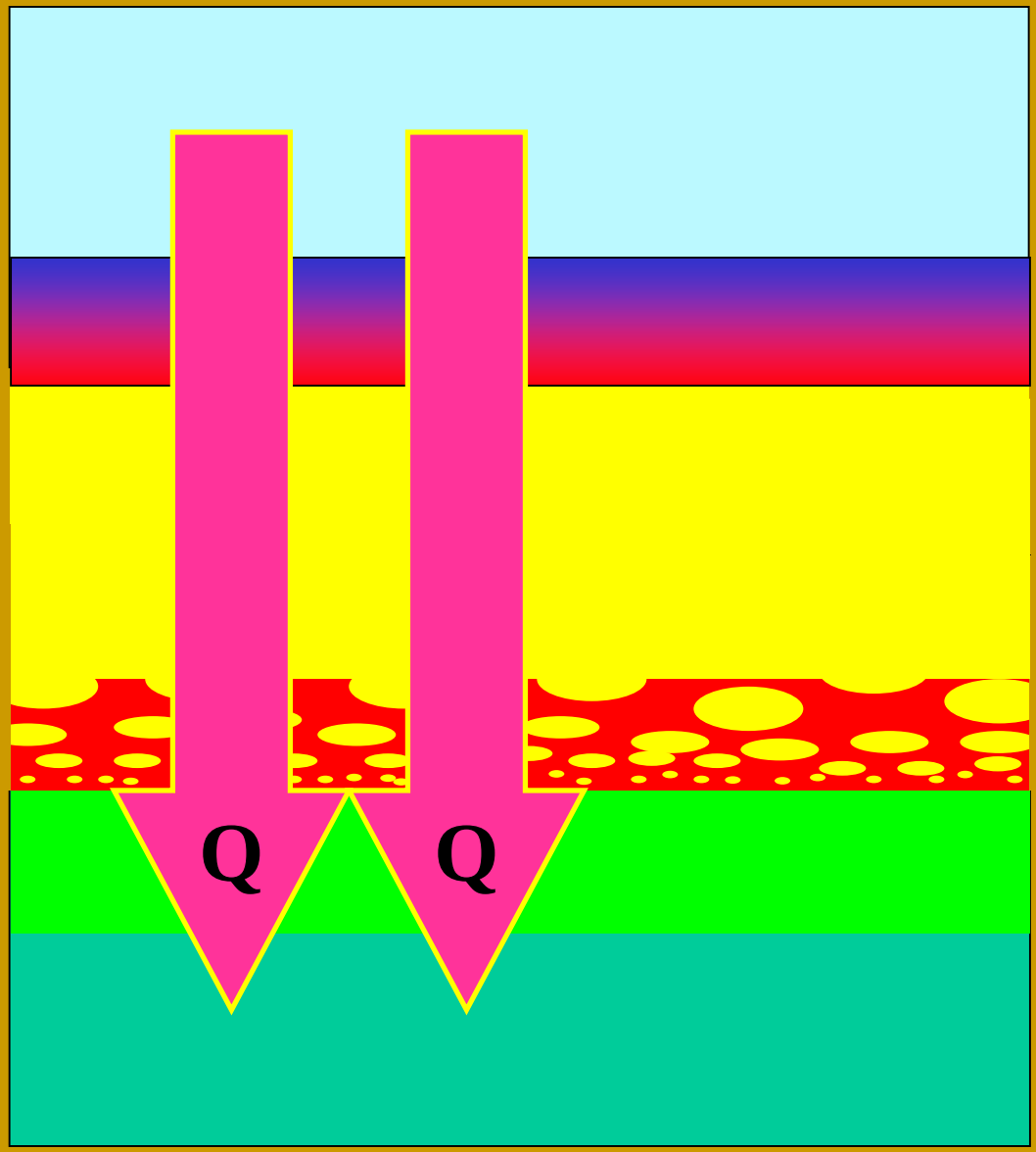

10kv 0.20kx 50.0µ 113
9202_20b

Ultrasound generates cavitation bubbles in liquids



Cavitation bubble imploding close to a fixed surface generating a jet (4) of the surrounding liquid.


Working hypothesis
The foamy layer is stressed with intense pressure oscillations. The layer is modified by pressure oscillations comparably like ultrasonic waves impact a surface covered with a liquid.
10kv 0.20kx 50.0µ 113
9202_20b



Flue Gas

Flame Zone

Gas Phase Reaction Zone

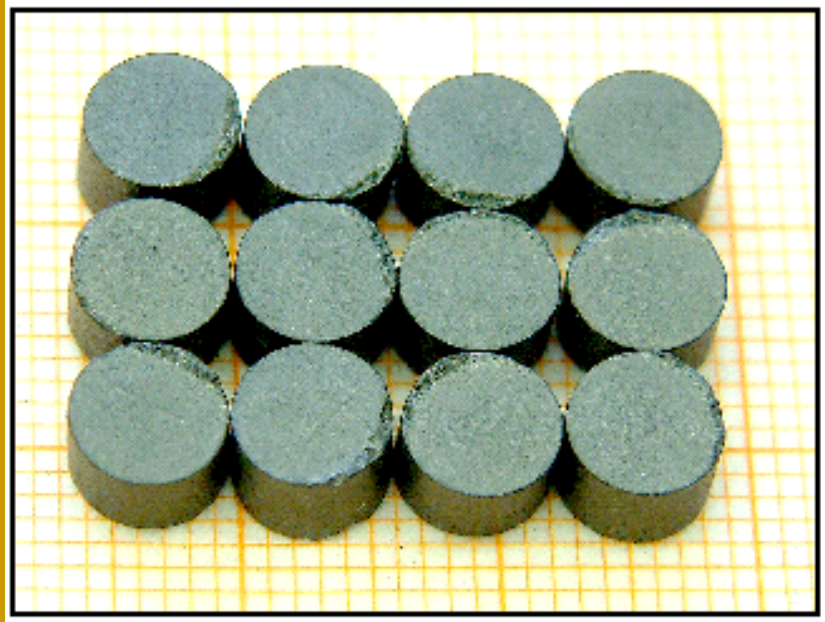
Foam/Liquid Reaction Zone with bubbles – two phases

Heating Zone (solid)

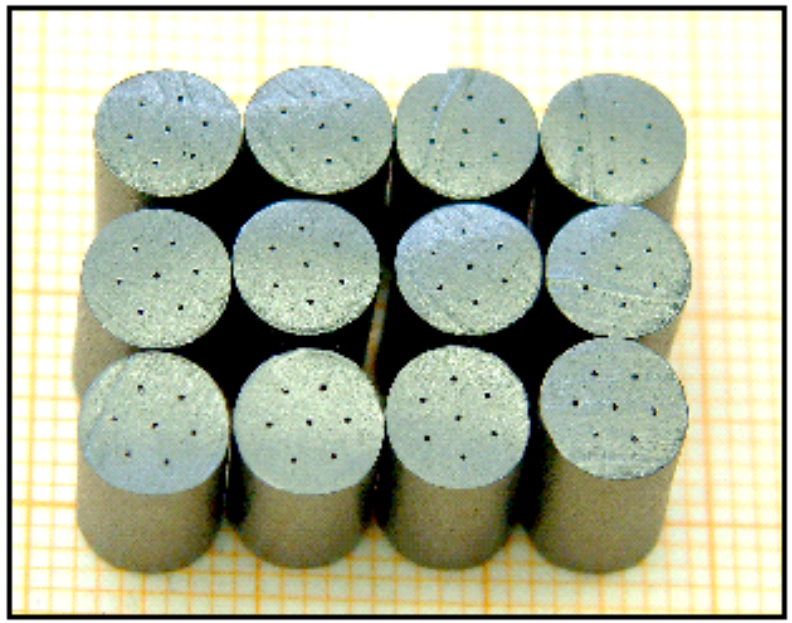
Unburned Propellant

The intense oscillations cause a reduced foam / liquid zone and an increased heat flux.

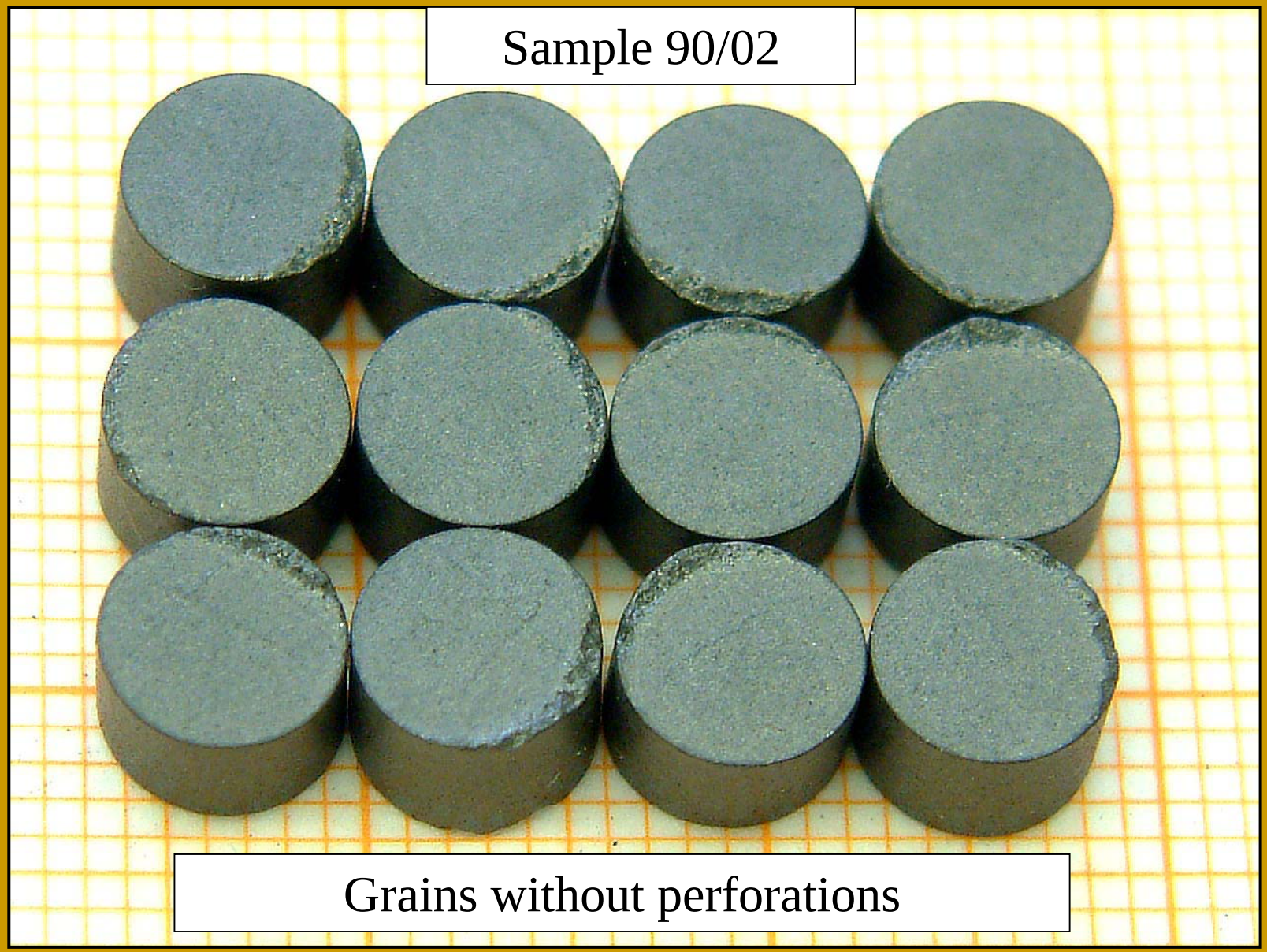
Relationship between pressure oscillations and accelerated burning using a triple-base propellant with and without perforations



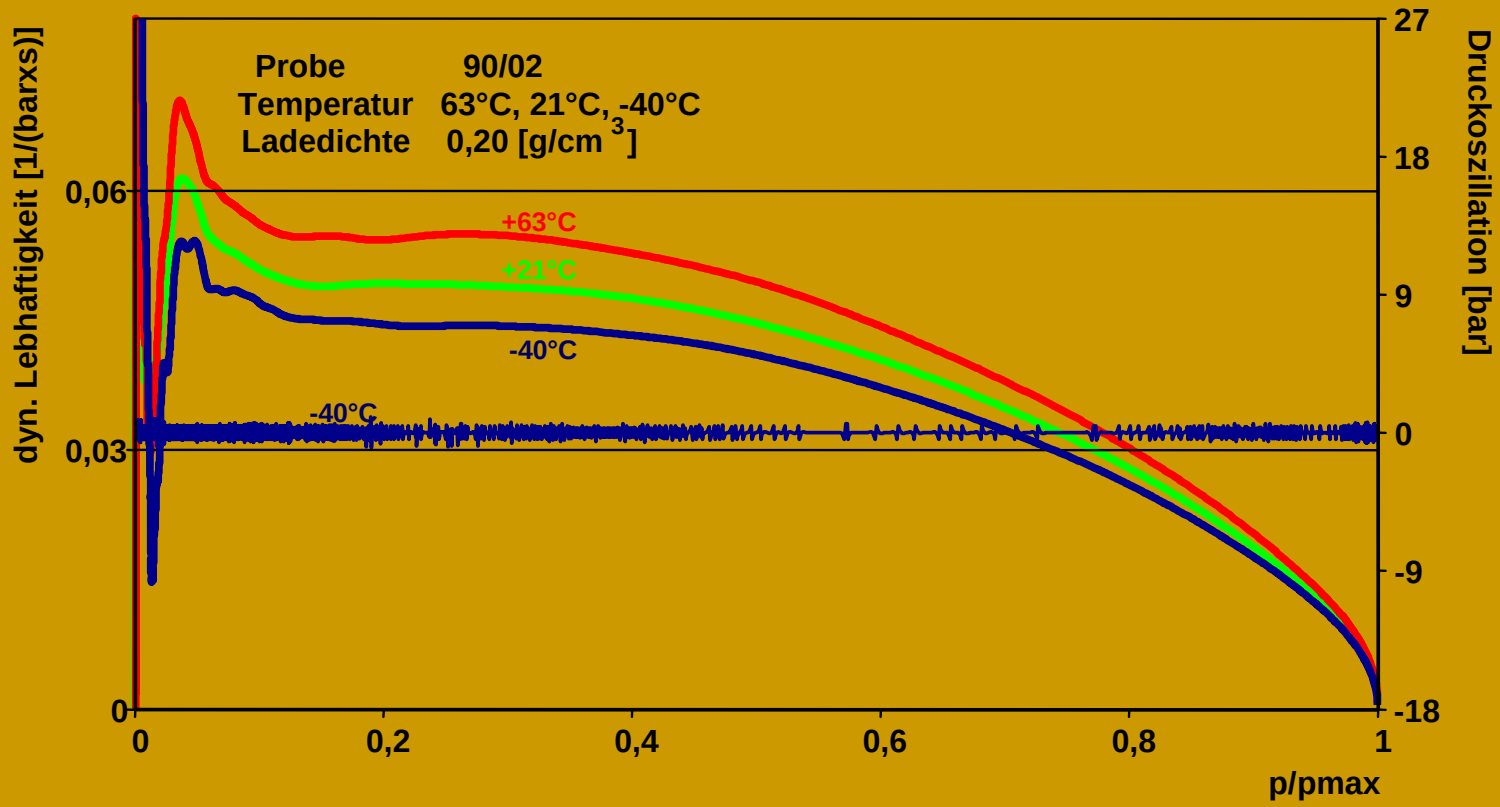
Grains without perforations



Grains with perforations


Sample 90/02
Grains without perforations

Dependency of dynamic vivacity on temperature, non-perforated propellant.

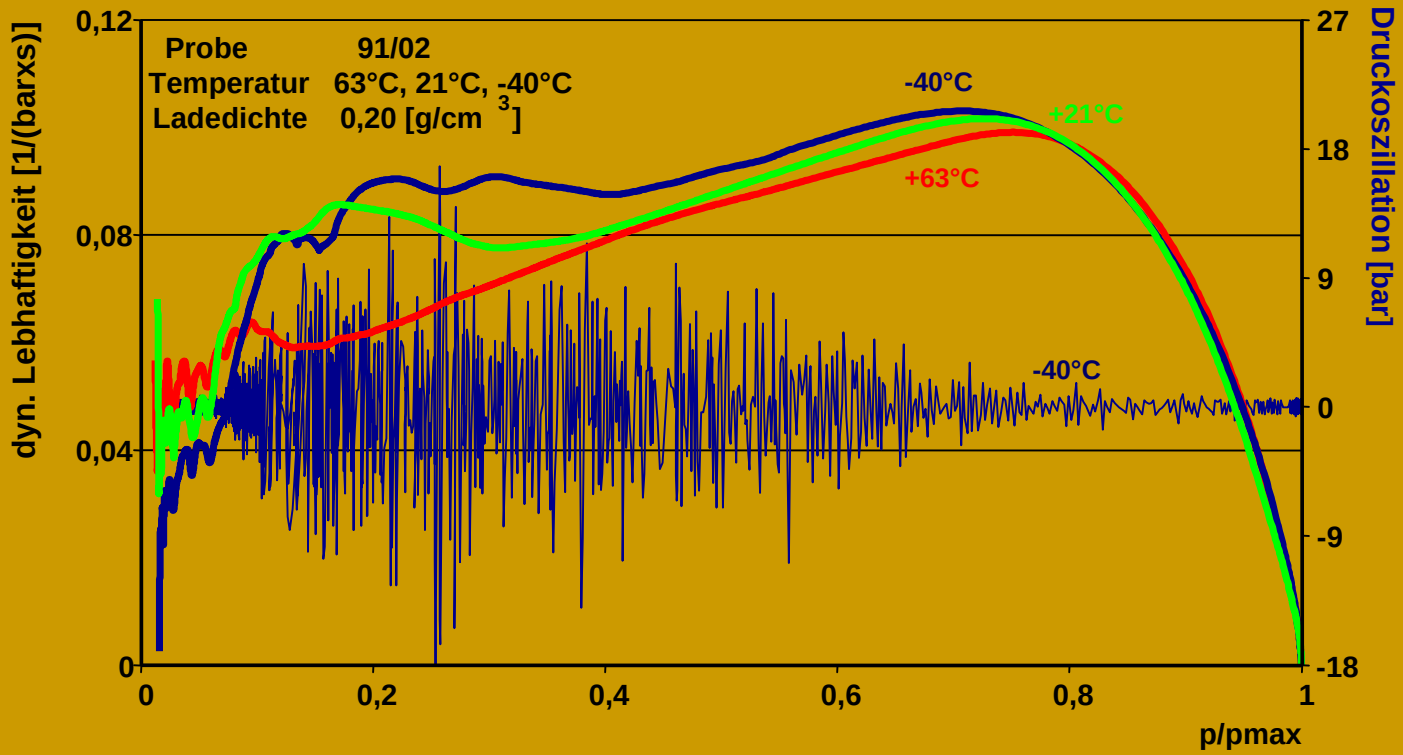


From +63 (+145°F) to –40°C (- 40°F) the vivacity of the non-perforated propellant decreases with temperature. No noteworthy oscillations can be observed.

Sample 91/02

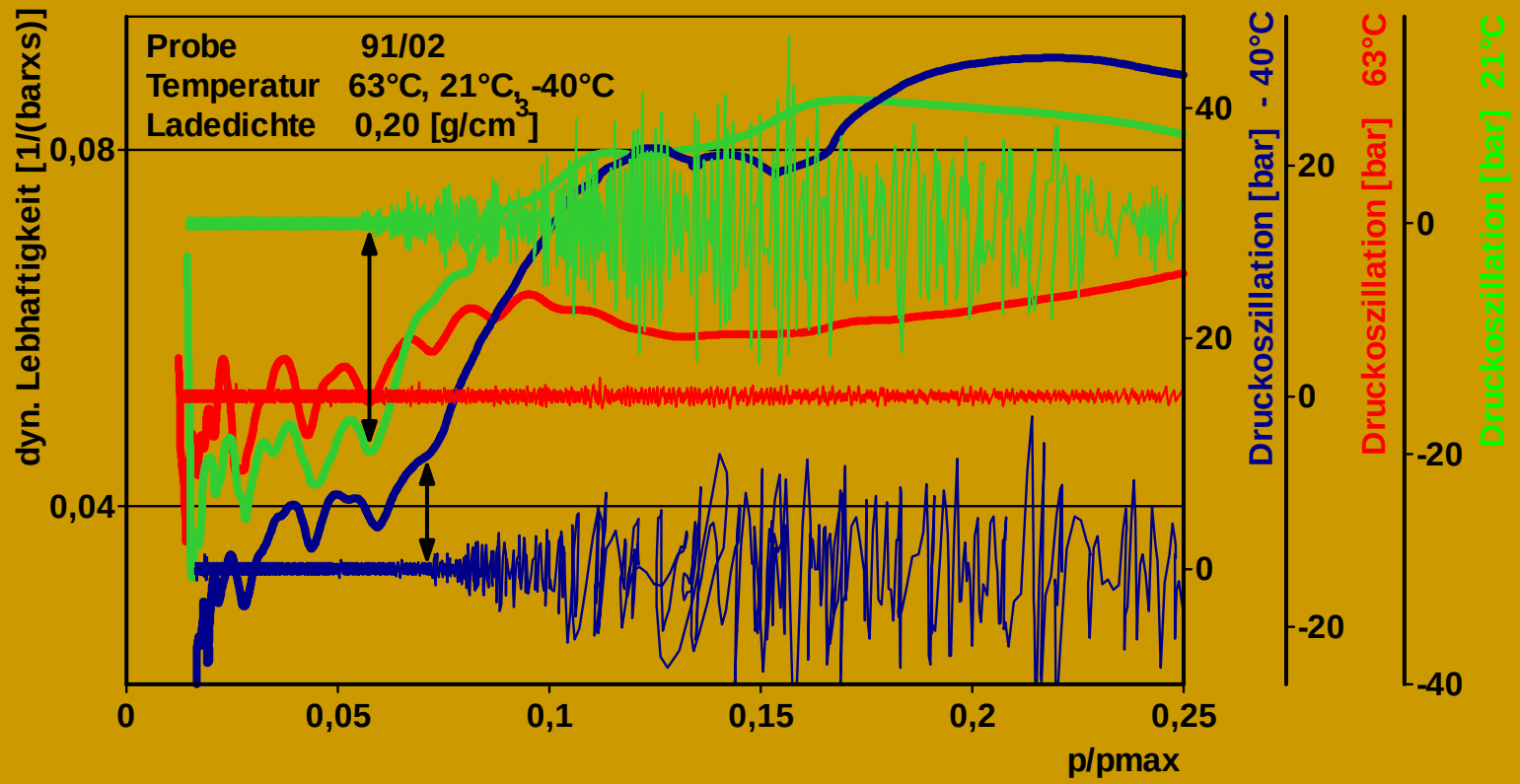
Grains with perforations

Dependency of dynamic vivacity on temperature, perforated propellant.



Reversal of the temperature behaviour for the perforated propellant within the temperature range from +63 (+145°F) to - 40°C (- 40°F). The vivacity of the perforated propellant increases with temperature. The excessive burning corresponds with the intensity of pressure oscillations.

Expanded p/p_{max}- scale of the initial range of the dynamic vivacities with graphic depiction of the related pressure oscillations at different temperatures



At +63°C: only weak oscillations - regular behaviour of the dynamic vivacity

At +21°C: intense oscillations - increased dyn. viv. compared to the +63°C-curve

At –40°C: intense oscillations - significant increase of the dynamic vivacity

Conclusions

- During combustion of perforated propellant grains in closed vessels a special form of pressure oscillations is generated independent from the known Vieille-oscillations.
- These oscillations have been proven at several institutes (WTD 91, ISL, Diehl).
- The oscillations often result in accelerated burning and modify the surfaces of the perforations.
- Working hypothesis: The pressure oscillations modify the two phases reaction zone and cause a reduced foam layer and an increased heat flux.

Aim of the work

Presently ammunition with temperature independent muzzle velocity is under development.

This work is a foundation for understanding one of the principle burning mechanism of propellants used for this ammunition. Pressure oscillations in the holes of perforated propellant grains are able to increase the burning rate at low temperatures (over) compensating the reduced burning rate of the energetic material at low temperatures.

Technical Test Center for Weapons and Ammunition – WTD 91 - Meppen

Bundeswehr