UMassAmherst

Suppression of Clogging in Cold Spray Nozzles

Jacobo Morère, David P. Schmidt,
Piotr Liebersbach, James J. Watkins

CSAT 2018
Worcester Polytechnic Institute
June 19-20th

CSAT Cold Spray Action Team

UMassAmherst

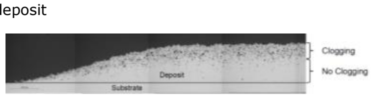
OUTLINE

1. Clogging. Causes and how to prevent it
2. Joule-Thomson effect
3. Development of the prototype
4. Testing the prototype
5. Results
6. Next steps

UMassAmherst

Our enemy: clogging

- One of the biggest issues in Cold Spray
- Expensive problem (time + money)
    - Replacing the nozzle
    - Short operation times
    - Low quality of the deposit



- We know little about the exact causes of clogging

UMassAmherst

What we know about the clogging

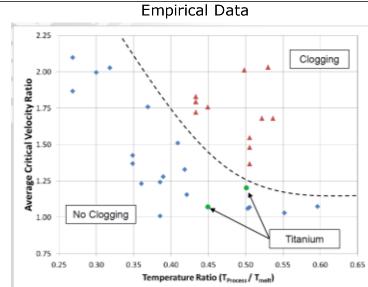
KNOWN SUSPECTS:

Low-melting point particles

Preheated particles

High temperature of the nozzle wall

Empirical Data

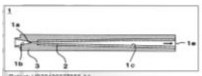


Matt Siopis. Study of Nozzle Clogging During Cold Spray. **CSAT 2017**

UMassAmherst

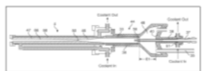
Strategies to prevent the clogging (I)

Nozzle material and geometry



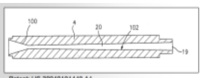
Patent: US20130327856 A1
Nozzle for cold spray allowing for greatly improved long-term sustained usage over the prior art, without the occurrence of nozzle clogging.

Glass: Quartz or Borosilicate



Patent: US20130087633 A1
An improved cold spray gun apparatus and system, which prevents nozzle clogging and erosion of the nozzle material.

Biphenyl tetracarboxilic dianhydride (BPDA), low expansion glass, or silicon nitride.



Patent: US 20040191449 A1
Clogging of the passageway in the supersonic nozzle (4) is prevented by forming at least the diverging section (102) from polybenzimidazole.

Polybenzimidazole (PBI)

Department of Polymer Science and Engineering 5

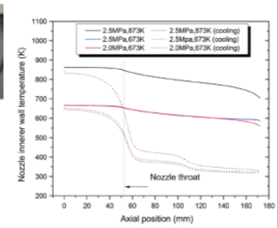
UMassAmherst

Strategies to prevent the clogging (II)

Cooling of the nozzle wall

Water cooling device

X. Wang, B. Zhang, J. Lv, S. Yin Investigation on the Clogging Behavior and Additional Wall Cooling for the Axial-Injection Cold Spray Nozzle, Journal of Thermal Spray Technology 24 (2015) 697-701.



Reduces nozzle wall temperature

Delays nozzle clogging when used.

Department of Polymer Science and Engineering 6

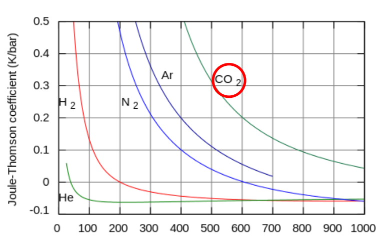
UMassAmherst

Strategies to prevent the clogging (III)

Active cooling of Cold-Spray nozzles by compressed CO_2 expansion

Joule-Thomson effect

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

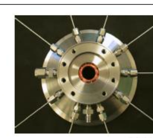


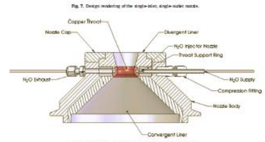
Department of Polymer Science and Engineering 7

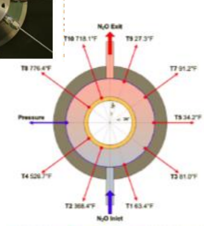
UMassAmherst

Development of the prototype (I)

Inspirational ideas.





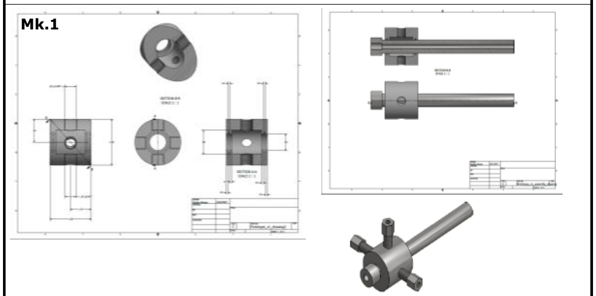


'Nitrous oxide cooling in hybrid rocket nozzles', *Progress in Aerospace Science, 46 (2010), 106-115*

Department of Polymer Science and Engineering 8

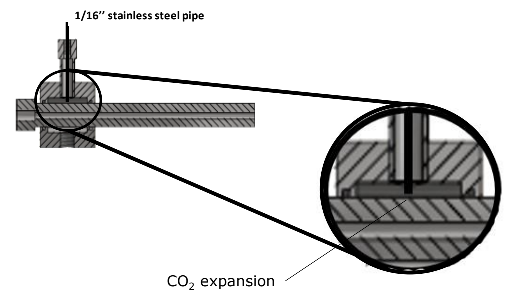
UMassAmherst

Development of the prototype (II)



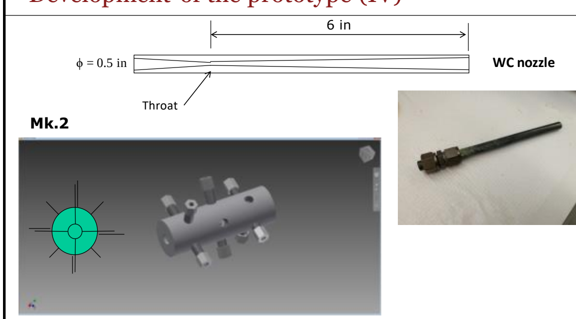
UMassAmherst

Developement of the prototype (III)



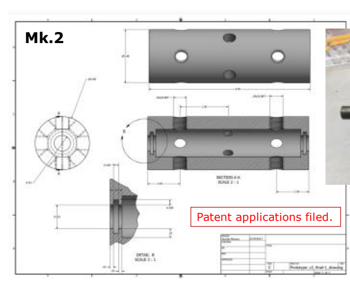
UMassAmherst

Development of the prototype (IV)



UMassAmherst

Development of the prototype (V)



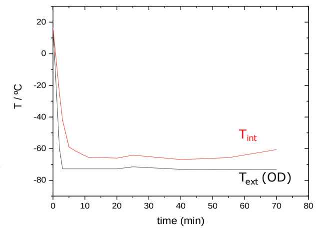
UMassAmherst

Lab testing of the prototype (I)

A couple of twin-linked high-pressure pumps pressurize the CO_2 and allow the system to run continously while connected to a CO_2 tank.

UMassAmherst

Lab testing of the prototype (II)

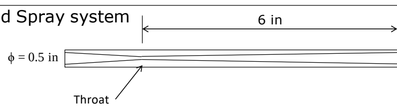


UMassAmherst

United Technologies Research Center

Cooling tests at UTRC (I)

- VRC Gen III Cold Spray system



- WC nozzle

0.058″ x 0.200″ 5° >>>> Temp. difference ID-OD 25-60ºC

- 30 bar He
- 300 – 600°C
- High purity Ni (Praxair Ni-914-3)

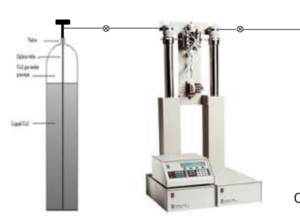
Special thanks to Matt Siopis and Aaron Nardis at UTRC

UMassAmherst

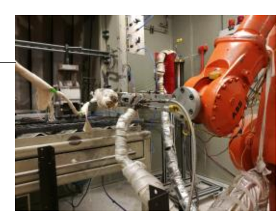
United Technologies Research Center

Cooling tests at UTRC (II)

Experimental set up



CO_2 tank (w/ syphon) High-pressure pumps



Cold Spray system + robotic arm w/ cooling dev

UMassAmherst

United Technologies Research Center

Cooling tests at UTRC (III)

Sample	Spray conditions	Cooling device	Clog	Time / min	Cooler Temp.
1	350ºC	On	No	6	81
2	400ºC	On	No	6	109
3	450ºC	On	No	14.5	187
4	500ºC	On	No	9.5	210
5	550ºC	On	No	8	255
6	600ºC	On	No	9.5	288
7	600ºC	Off	Yes	3.5	368

The device was able to cool down effectively the nozzle's outside wall at all the conditions tested and to prevent the clogging

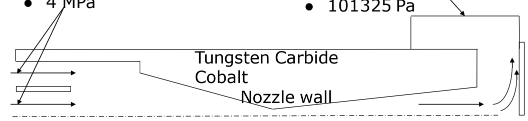
Department of Polymer Science and Engineering 17

UMassAmherst

Simulation Details

Pressure Inlets:
- 698 K
- 4 MPa

Pressure Outlet:
- 300K
- 101325 Pa



- Axisymmetric Steady State Model
- VRC nozzle used @ UTRC
  - 0.068" Throat Diameter
  - 6" Diverging Length
  - 0.2" Exit Diameter

Department of Polymer Science and Engineering 18

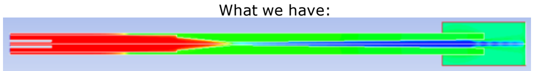
UMassAmherst

United Technologies Research Center

Cooling tests at UTRC (IV)

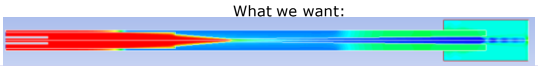
Computed Heat Transfer Rate

What we have:



- **q = 832 W**
- Inlet Temp: 698 K
- Outside Wall Temp: 421 K

What we want:



- **q = 3700 W**
- Inlet Temp: 698 K
- Outside Wall Temp: 210 K

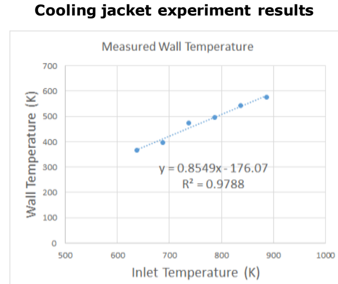
Department of Polymer Science and Engineering 19

UMassAmherst

United Technologies Research Center

Cooling tests at UTRC (V)

Cooling jacket experiment results



Department of Polymer Science and Engineering 20

UMassAmherst

Next steps (I)

- Greater flow rate
- Automatization of the system
- Increase the operation time (60 min)
- More compact pump system

Department of Polymer Science and Engineering 21

UMassAmherst

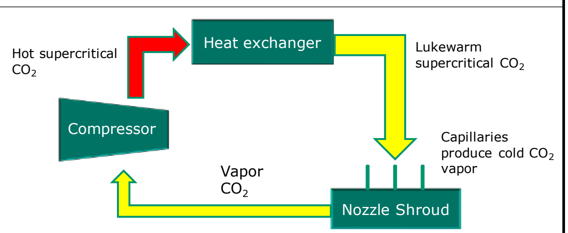
Next steps (II)

- Final design
- Reduce size
- Increase safety measures
- Flexible lines
- Recycling of CO_2

Department of Polymer Science and Engineering 22

UMassAmherst

Recycling the CO_2

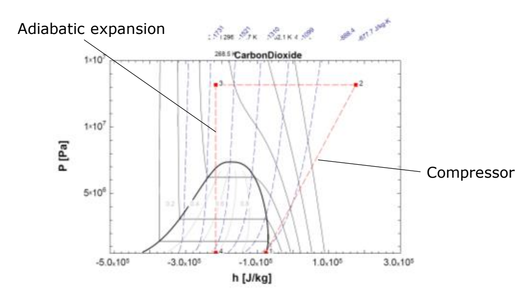


Essentially, a supercritical CO_2 refrigeration system

Department of Polymer Science and Engineering 23

UMassAmherst

CO_2 refrigeration system



Department of Polymer Science and Engineering 24

UMassAmherst

CONCLUSIONS

We have designed and fabricated a prototype of an experimental device able to cool down significantly the inner wall of the Cold Spray nozzle taking advantage of the adiabatic expansion of CO_2 in the outer wall of the nozzle to overcome the appearance of clogging.

We were able to effectively remove heat from the nozzle's outside wall using this prototype and prevent the appearance of clogging inside the nozzle.

With the cooling device we were able to cold spray systems and conditions ever reached before.