Design of Floating Thermal Spacers in an Ultra-Efficient Adiabatic Compressor

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- *Energy Storage:* Mid-Grid vs GIES
- *WindTP* System Overview
- Compressor and Expander Technology
- Floating Thermal Spacers and Thermal Gaskets
- Forces in Floating Thermal Spacers

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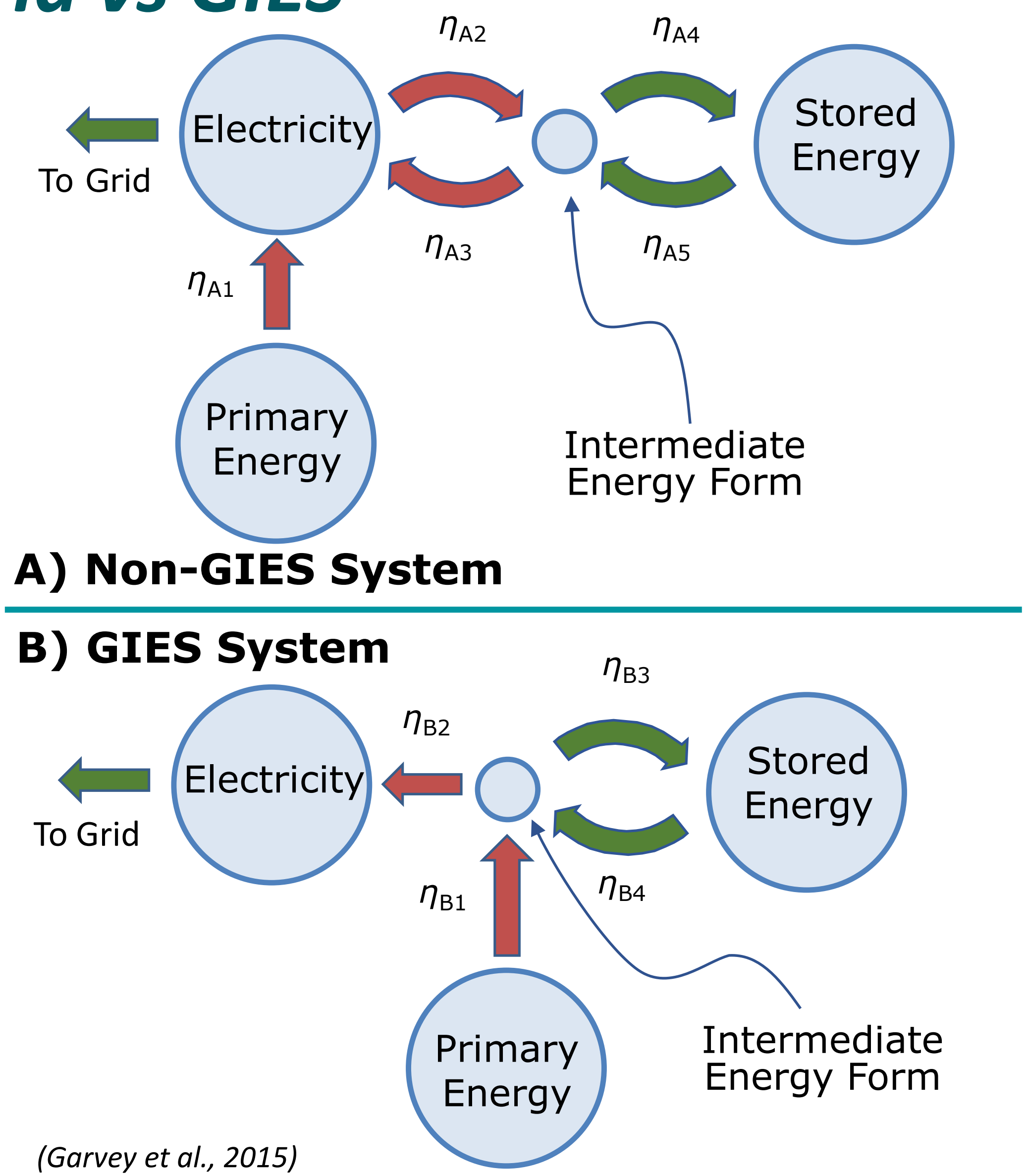
Energy Storage: Mid-Grid vs GIES

- In a highly-variable future energy mix, large quantities of energy storage will be required; possibly >320 TWh in Europe.
- Most energy storage focus is on mid-grid solutions; electricity is absorbed, stored and returned.
- However, generation-integrated energy storage (GIES) is an alternative set of solutions; energy is stored *before* being converted into electricity.
- Wind turbines with co-located battery banks are not GIES!



(Garvey et al., 2015)

Wind TP
GREEN • AFFORDABLE • DISPATCHABLE

UKES2019
UK Energy Storage Conference

For more information on GIES:

Energy Policy 86 (2015) 544–551

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ENERGY POLICY

On generation-integrated energy storage

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http://www.sciencedirect.com/science/article/pii/S0301421515300458

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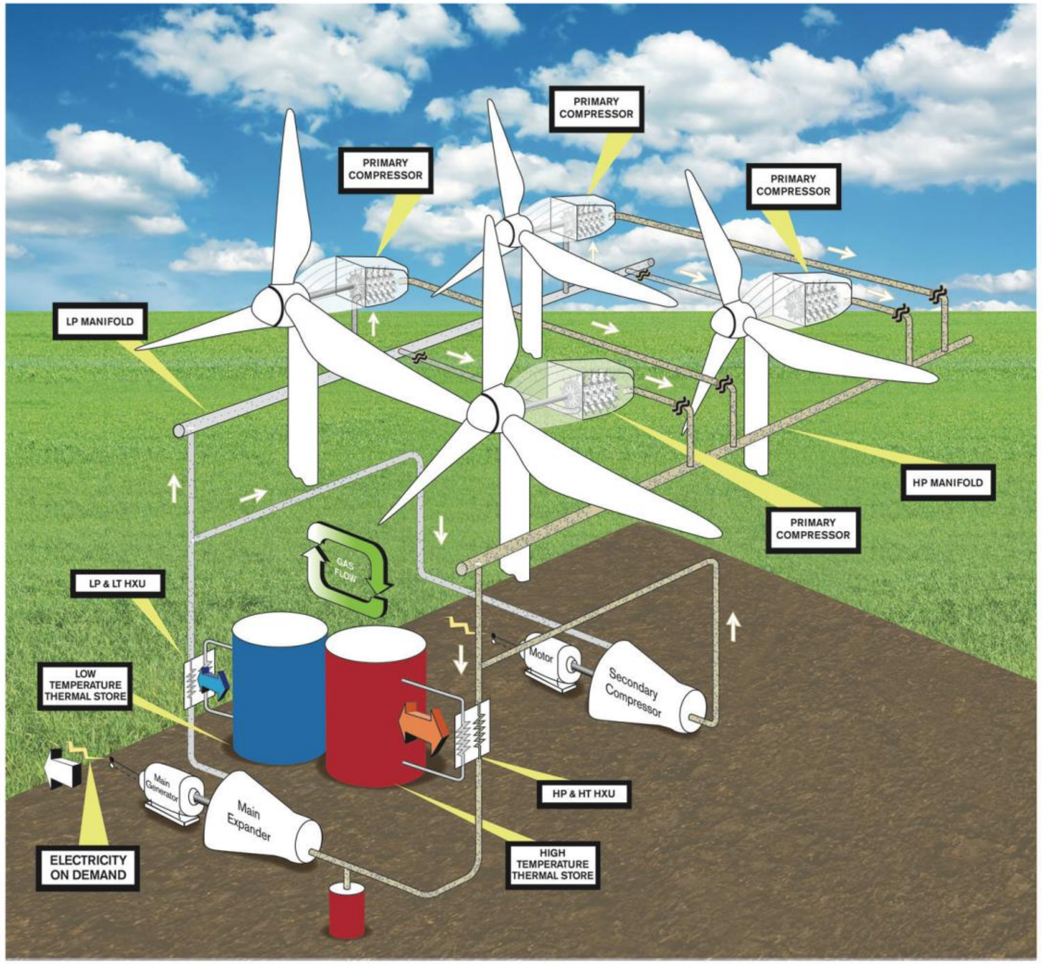
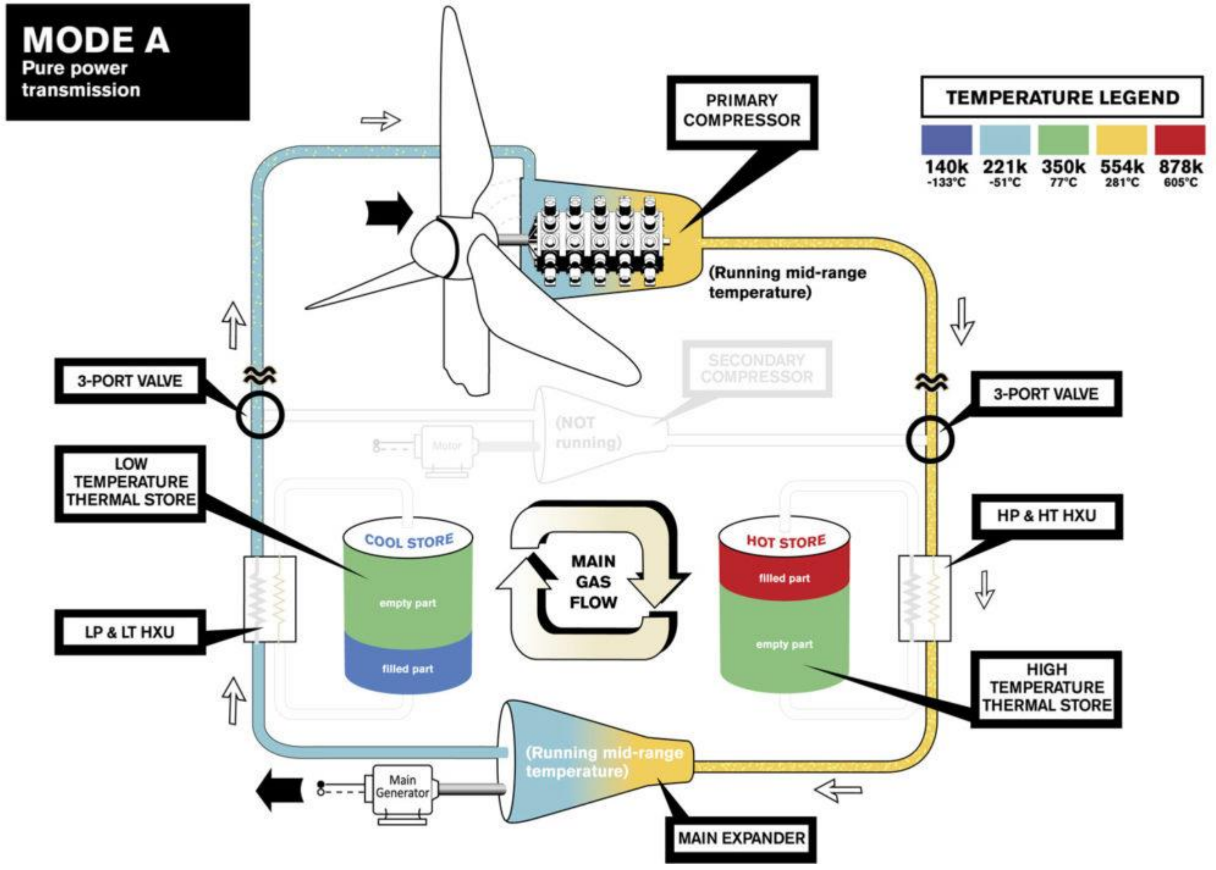
WindTP System Overview

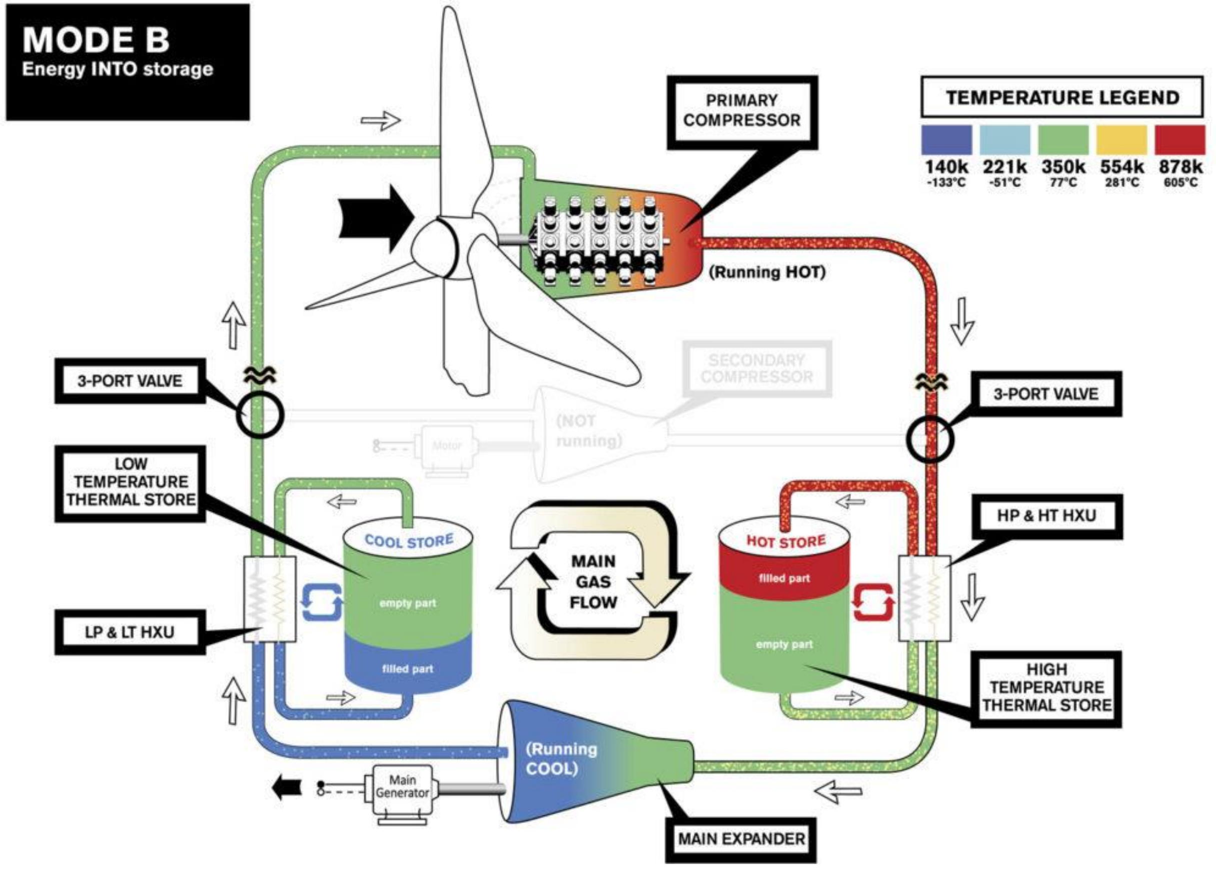
- *WindTP* stands for Wind-Driven Thermal Pumping
- Wind turbines directly drive efficient compressors. Gas is compressed adiabatically, increasing its temperature.
- Direct drive removes the need for a gearbox.
- *Thermal* storage, not *compressed air* storage.
- Made from readily available components – with one notable exception!



(Source: www.wind-tp.com)

WindTP System Overview





(Source: www.wind-tp.com)

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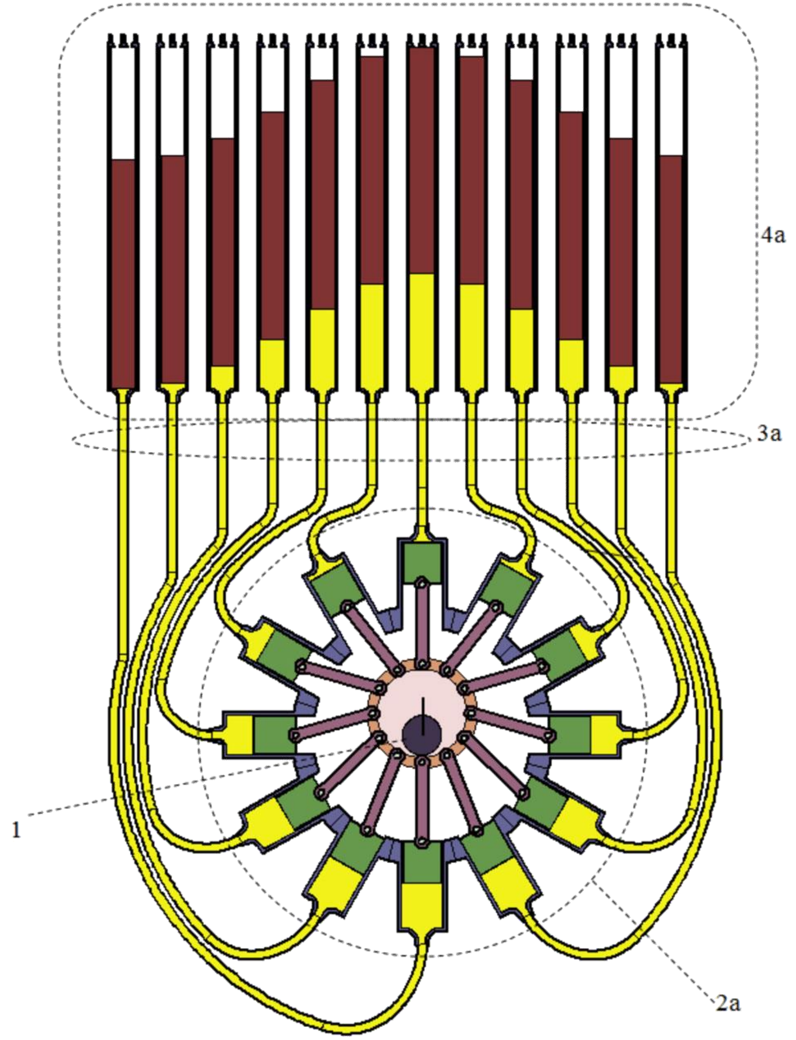
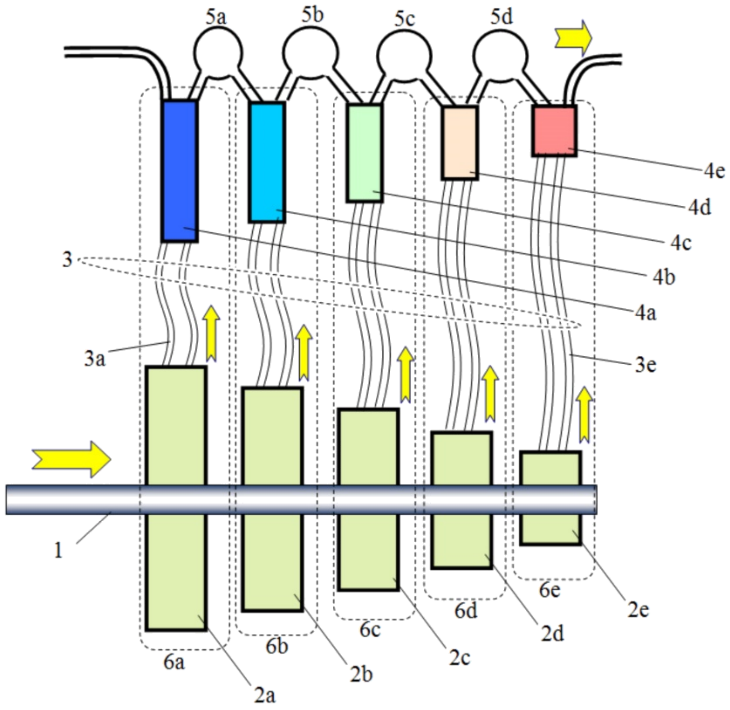
Compressor and Expander Technology

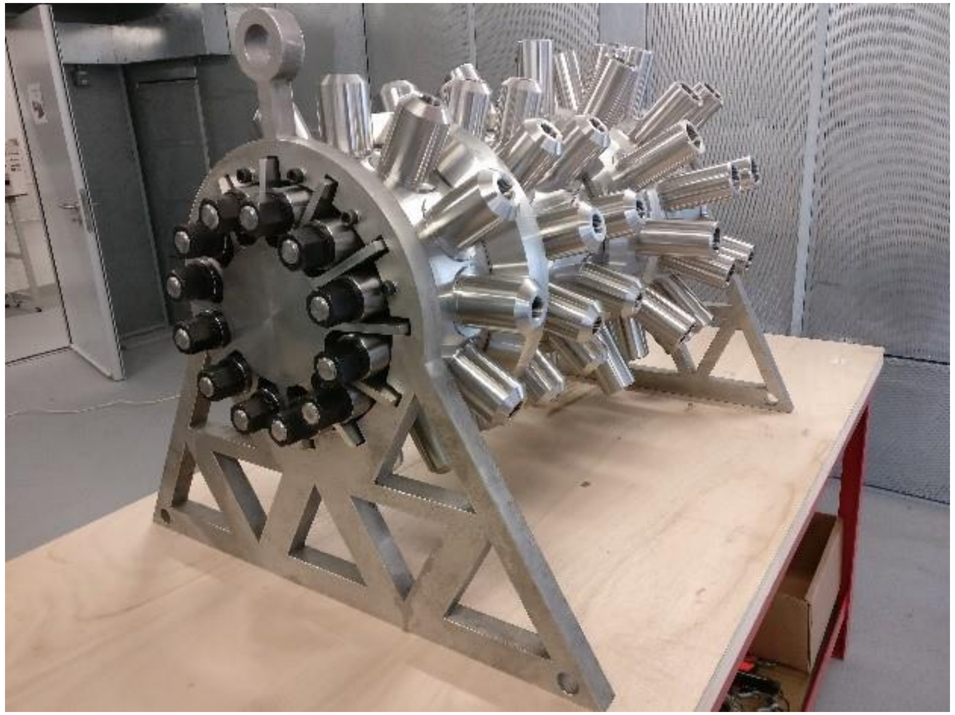


- Liquid piston adiabatic compressors/expanders.
- High efficiency a priority. Can “afford” to be efficient due to necessarily slow speed.
- Multi-stage to reduce ΔT in each stage. Balance of stages to reduce valve losses.
- Split into converter and displacer sections (pictured) to reduce heat transfer.



(Source: www.wind-tp.com)

Compressor and Expander Technology



Displacer section for 60kW compressor/expander prototype.

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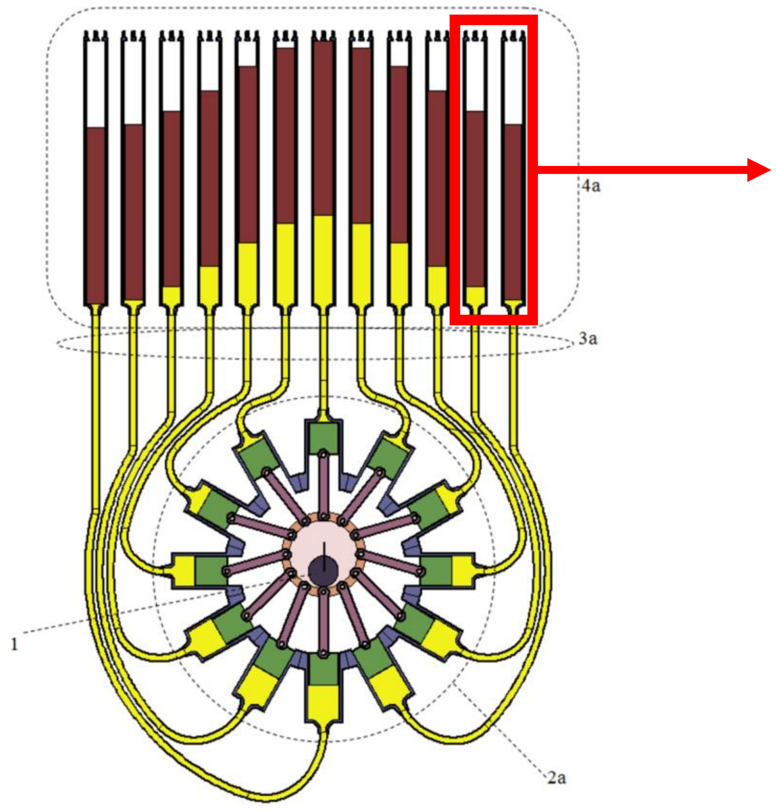
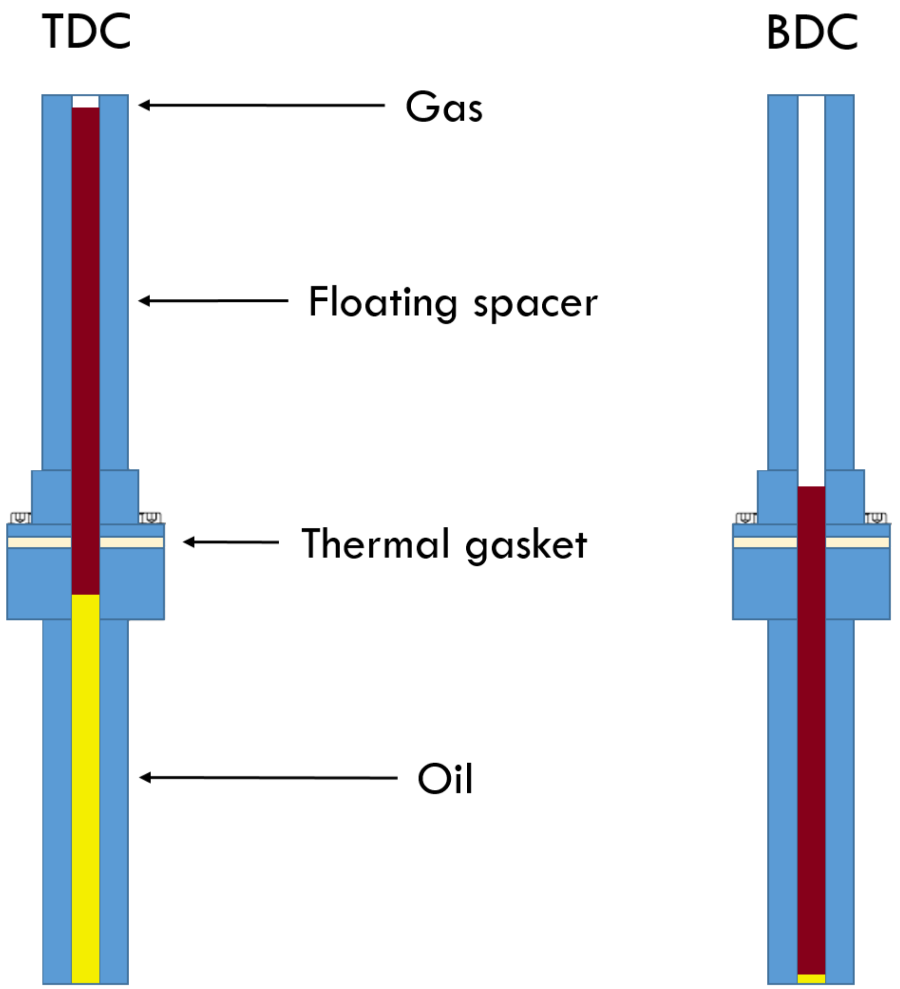
Floating Spacers and Thermal Gaskets





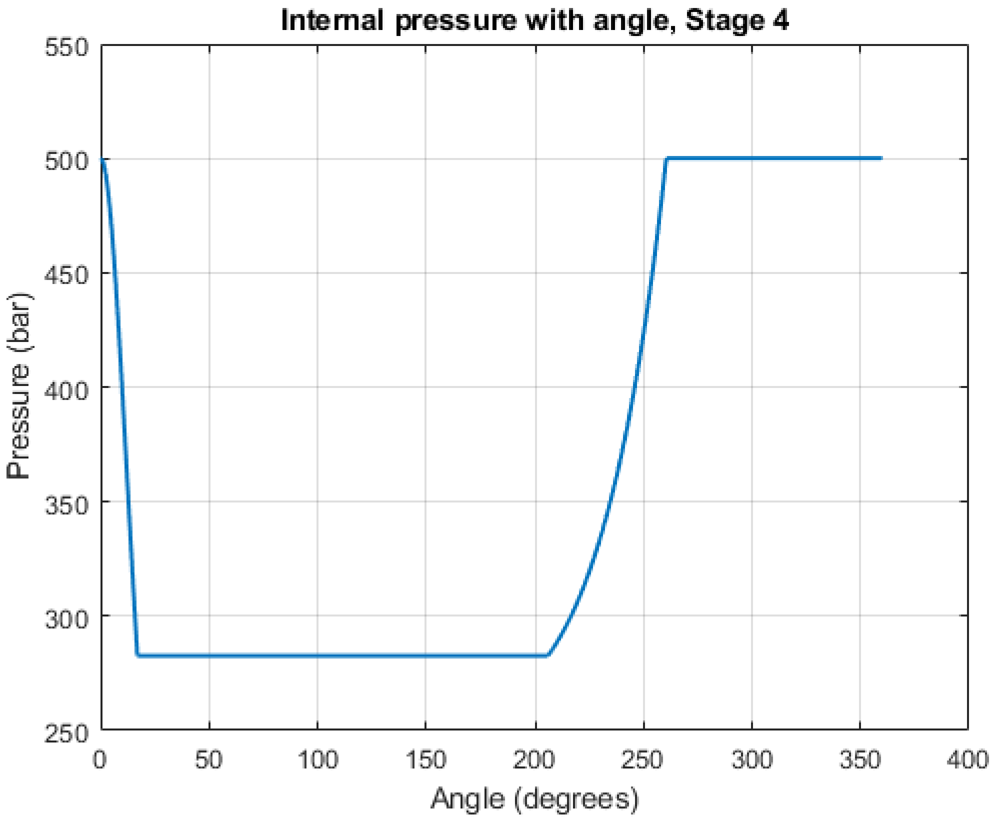
With the floating spacers and thermal gaskets working in tandem, there is no thermal path down the sides of the pipes.

Floating Spacer Requirements

Intended to thermally separate the extreme-temperature gas from the oil.

Material requirements:

- Extremes of temperature (-133^{o}C and +600^{o}C).
- High – and fluctuating – pressures (e.g. 282 bar to 500 bar in the HP end).
- Very low thermal conductivity.
- High stiffness. Nothing spongy!
- LIGHT – preferably lifted entirely by the oil.



A Suitable Material?

Fused silica glass:

- 1100°C upper working temperature.
- >1000 MPa compressive strength.
- 1.38 W/m·K thermal conductivity.
- High stiffness.
- 2200kg/m³. Still not light enough...?

Evacuated Tubes and Springs

By evacuating the tubes, we improve several properties:

- Lower overall thermal conductivity.
- All material in the spacer is constantly in compression – good for glass!
- Bulk density of the spacer is reduced significantly – much closer to the density of the oil (around 700 kg/m^3).

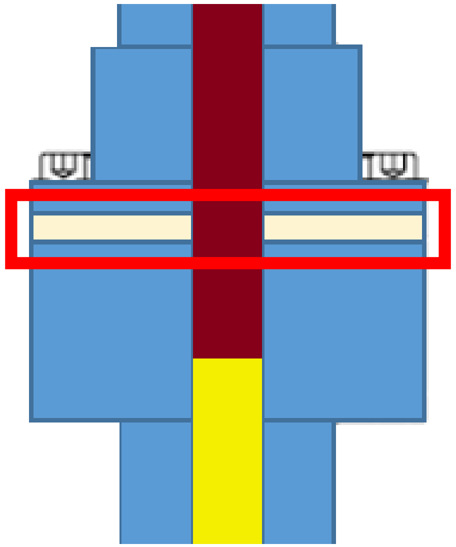
The mass not supported by the buoyancy force can then be held with (very) light springs. A second compressor design could increase the space available for oil to rise up the thermal spacer, increasing the potential buoyancy force.

Thermal Gasket Requirements

Used to remove the potential thermal path down the walls of the pipes.

Material requirements:

- Low thermal conductivity.
- Able to withstand high temperature gradient over a very short distance.
- Able to seal against pressures up to 500 bar.
- Similar coefficient of thermal expansion to stainless steel.



A Suitable Material?

Yttria-stabilised zirconia:

- 2.5 W/m·K thermal conductivity.
- >2000 MPa compressive strength.
- Can be ground optically flat for sealing – used in quarter-turn taps!
- 7 x 10^{-6} to 11 x 10^{-6}/K coefficient of thermal expansion (compared with 15 x 10^{-6}/K for stainless steel).

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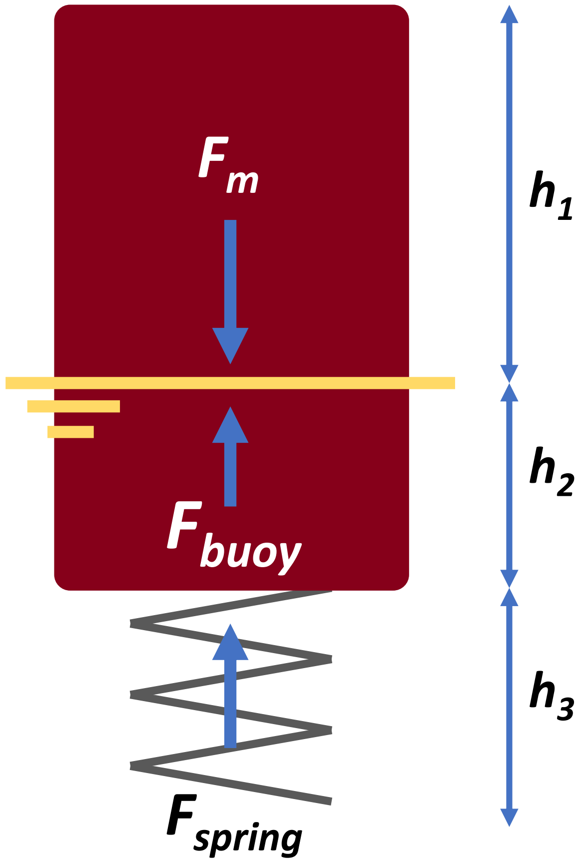
Forces in Floating Thermal Spacers

F_m – force due to floating spacer mass. Constant.

F_{buoy} – buoyancy force in oil. Dependent on h_2 **and on gas density** (increased gas density increases hydrostatic pressure at base of spacer). Force **increases** during gas compression from BDC to TDC.

F_{spring} – spring force. Dependent on h_3 and spring parameters. Force **decreases** during gas compression from BDC to TDC (due to reduced compression of spring).



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Wind TP
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Thank you for listening.

If you would like to contact me:
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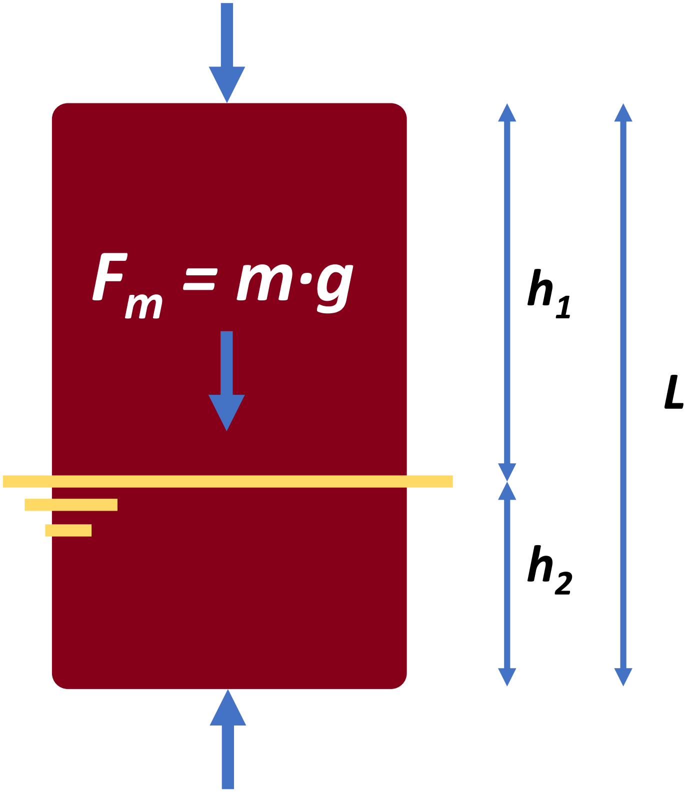
For more information on *WindTP:*
www.wind-tp.com

Extra Slide - Forces in Floating Thermal Spacers

$F_T = A \cdot p_{gas}$



$F_B = A(p_{gas} + \rho_{gas} \cdot g \cdot h_1 + \rho_{oil} \cdot g \cdot h_2)$

$mg + Ap_{gas} = A(p_{gas} + \rho_{gas} g h_1 + \rho_{oil} g h_2$

$m/A = \rho_{gas} h_1 + \rho_{oil} h_2$

$L = h_1 + h_2$

$m/A = \rho_{gas} L - \rho_{gas} h_2 + \rho_{oil} h_2$

$h_2 = [(m/A) - \rho_{gas} L] / [\rho_{oil} - \rho_{gas}]$