Preliminary CFD analysis of the Dual fluid reactor mini-demonstrator

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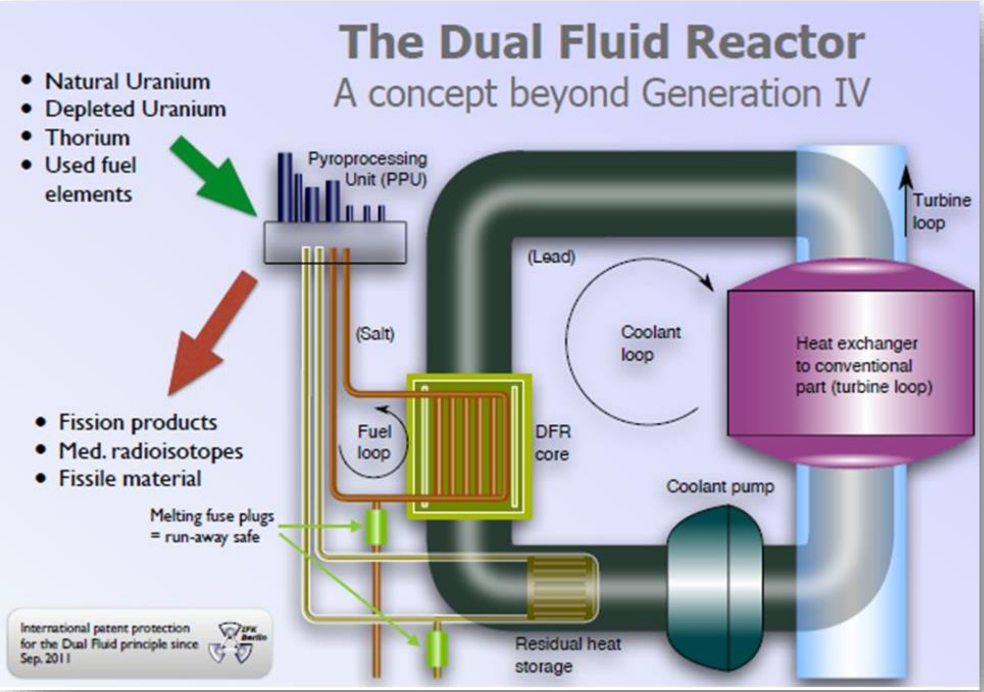
New reactor concepts and safety analyses for the Polish Nuclear Energy Program
POWR.03.02.00-00.I005/17

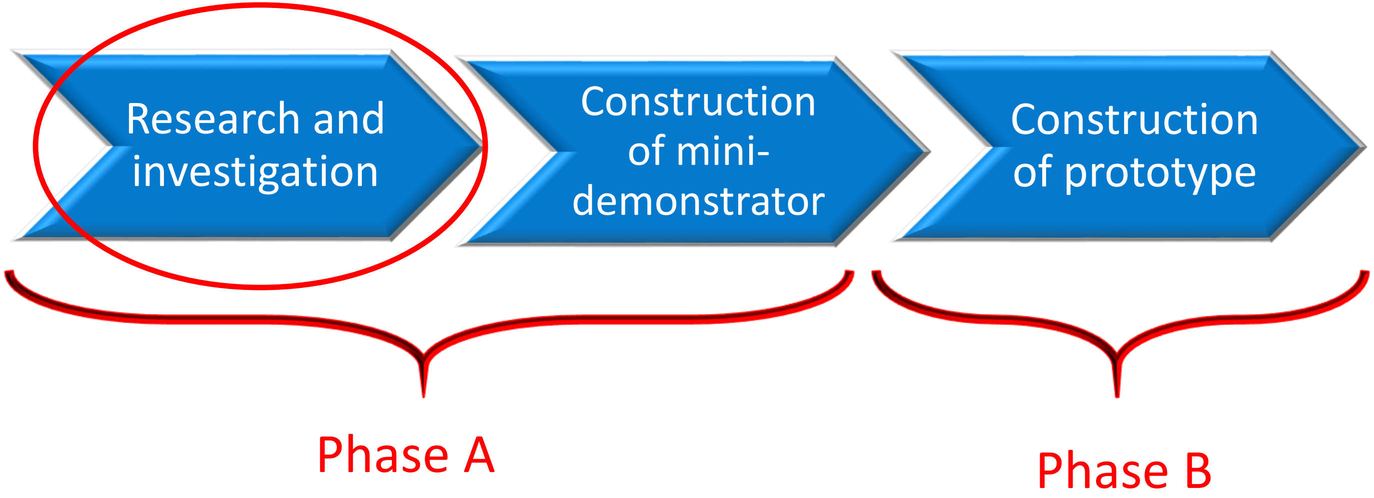
A- Description of reactor mechanism

Fuel: Uranium- Chromium Eutectic loop.

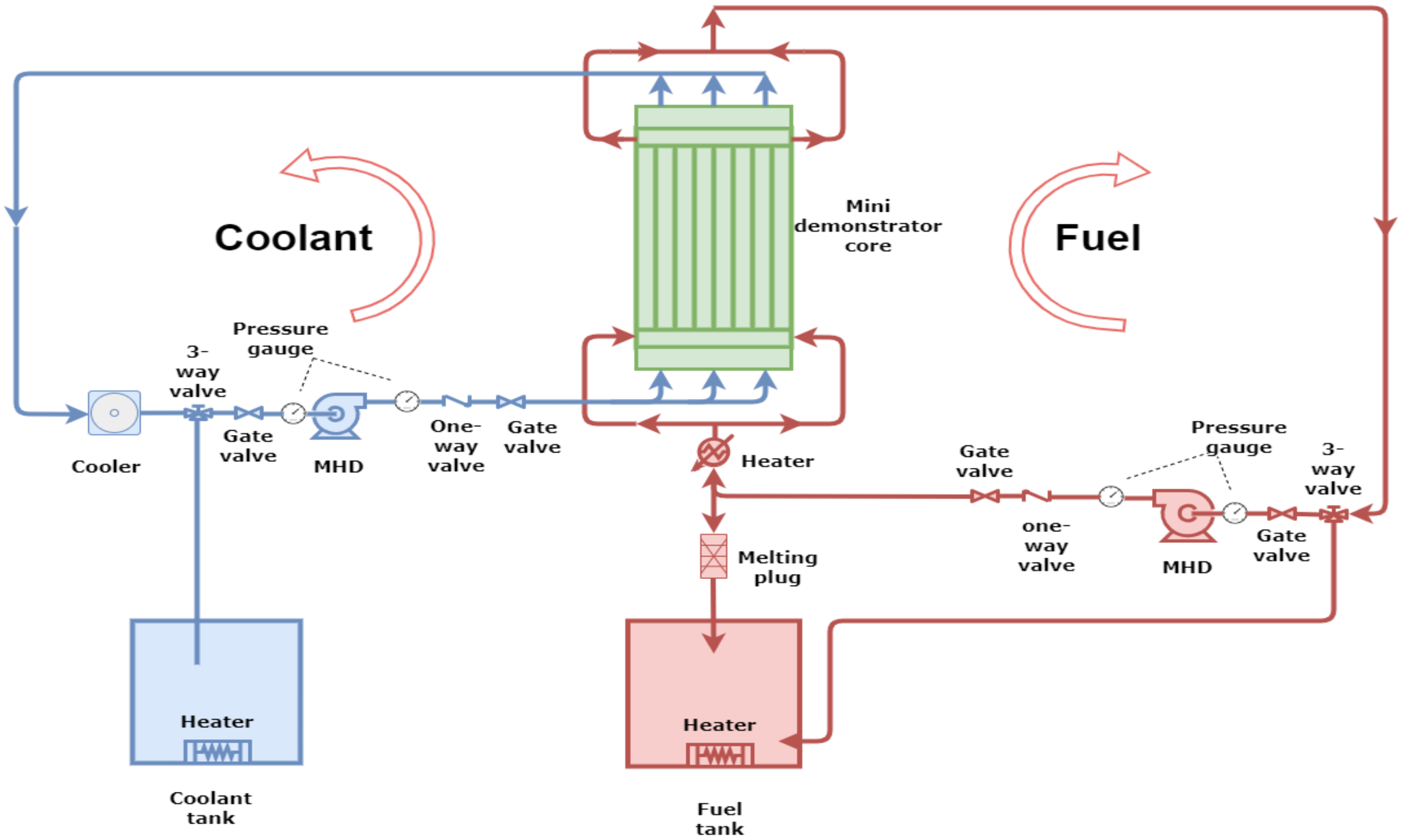
Coolant: Molten Lead loop.



B- Development sequence



A- liquid lead – lead loops description



B- Core Description.

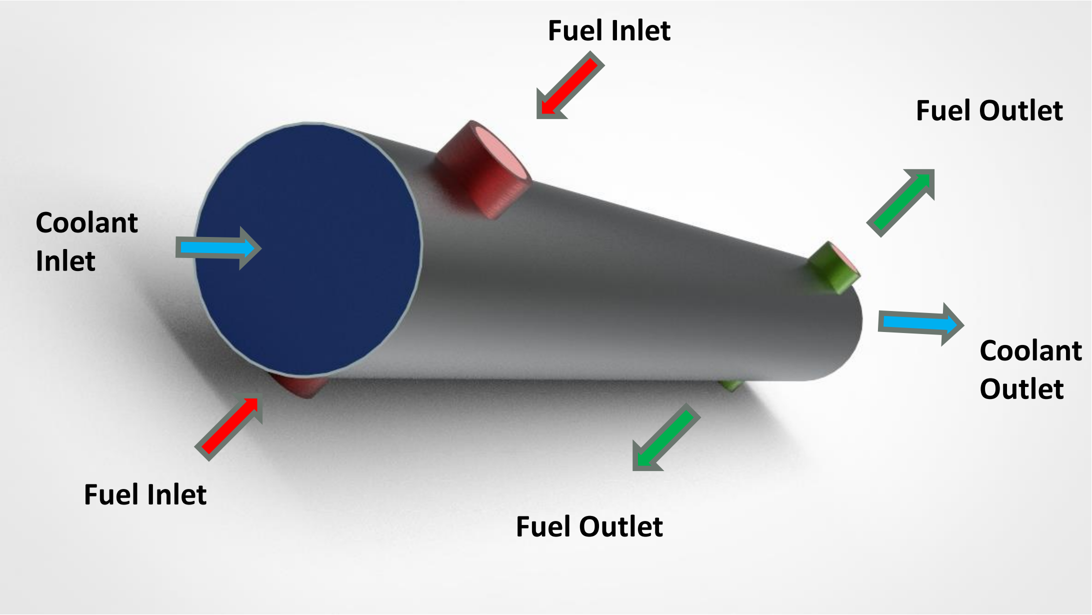
The mini-demonstrator core consists of:

- Two fuel Inlets and two fuel outlets, one coolant inlet and another outlet.

- 7 fuel pipes.

-12 coolant pipes on each side.

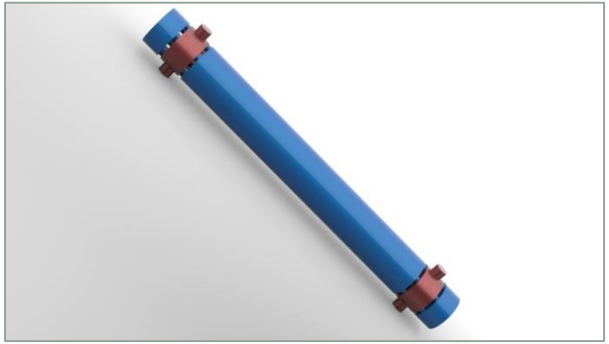
- Distribution zone and collection zone separated from the core by four separation discs.

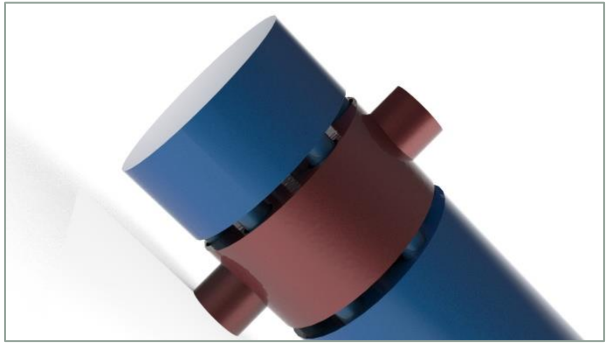


Mini-Demonstrator – cont.

B- Core Description (2)

Parameter	Values
Core zone inside Diameter D_{in} (mm)	130
Core zone Outside Diameter D_{out} (mm)	133
Core zone height H_{core} (mm)	880
Distribution zone D_{in} /H_{DZ} (mm)	130/70
Collection zone D_{in} /H_{CZ} (mm)	130/70
Number of fuel pipes	7
Fuel pin pitch (mm)	28
Outside/inside fuel tube diameter (mm)	23 / 19
Outside/inside large coolant tube diameter (mm)	23 / 19
Outside/inside Small coolant tube diameter (mm)	10 / 08

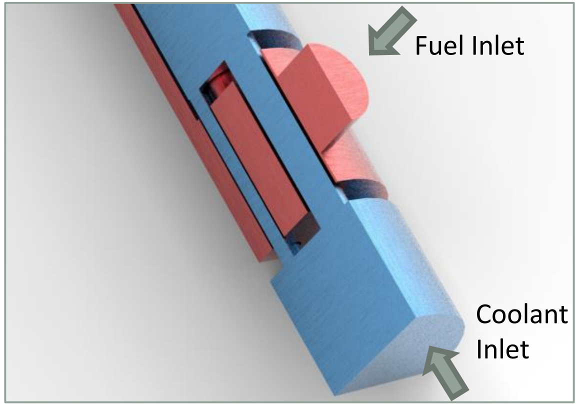


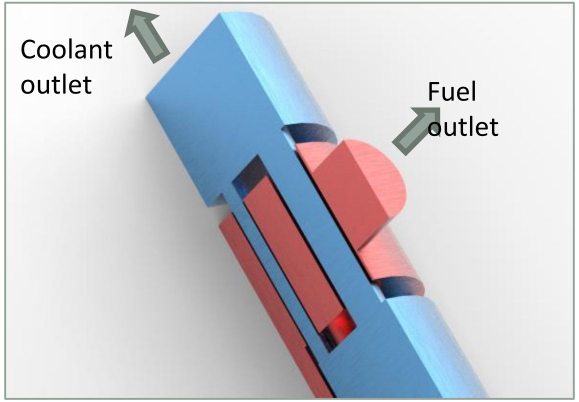


B- Core Description (3)

The first figure *(up-right)* shows the collection zone; where the coolant is being collected from the pipes coming from the core to the outside of the MD. As well, fuel exits after collection from the fuel pipes.

- The second figure *(down-right)* explains the distribution zone where coolant and fuel find their ways to the core, fuel in pipes, and coolant filling the core.



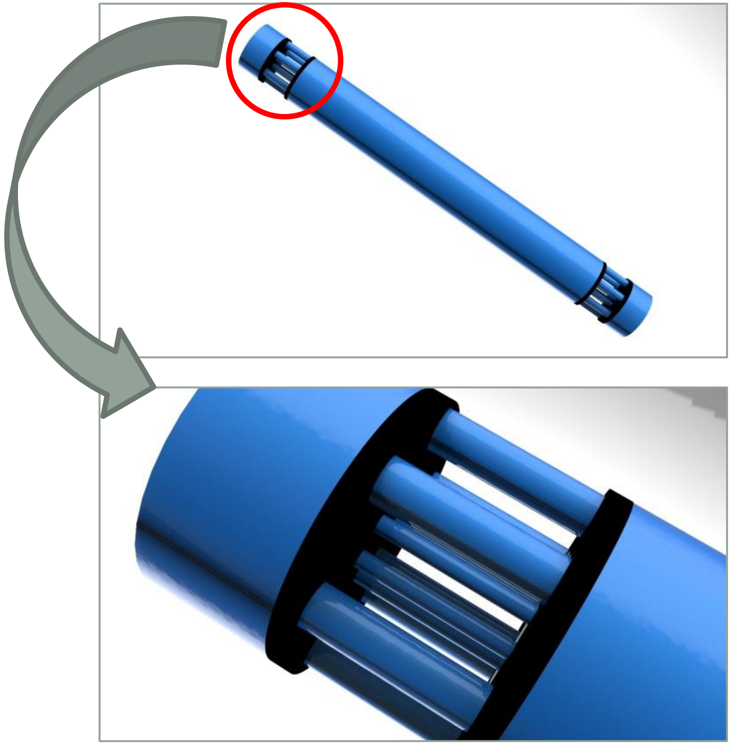


B- Core Description (4)

Coolant domain:

- Passes from the coolant inlet to the core.

- Coolant penetrates the distribution zone through 12 pipes (two different diameters)

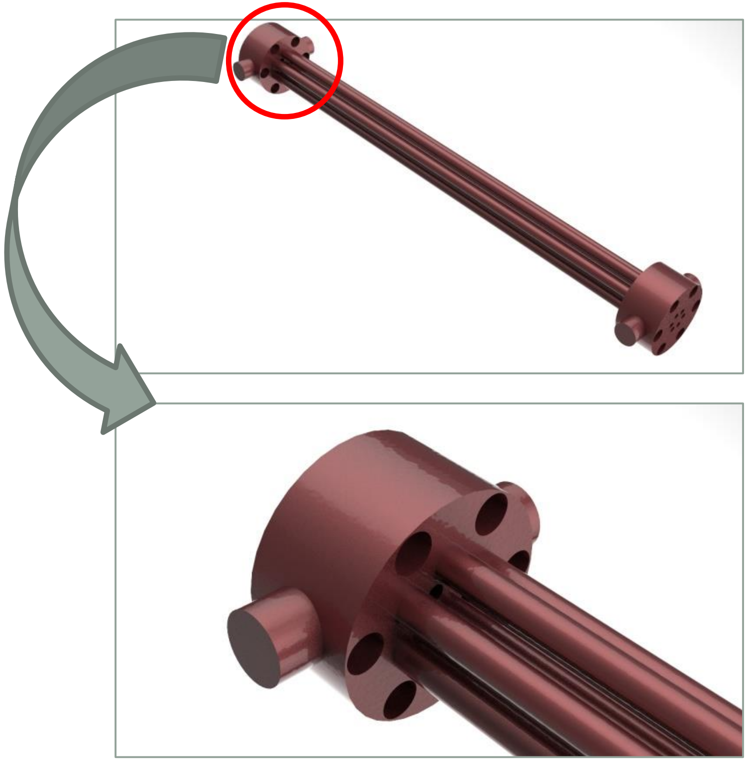


B- Core Description (4)

Fuel domain:

- Enters to the distribution zone directly.

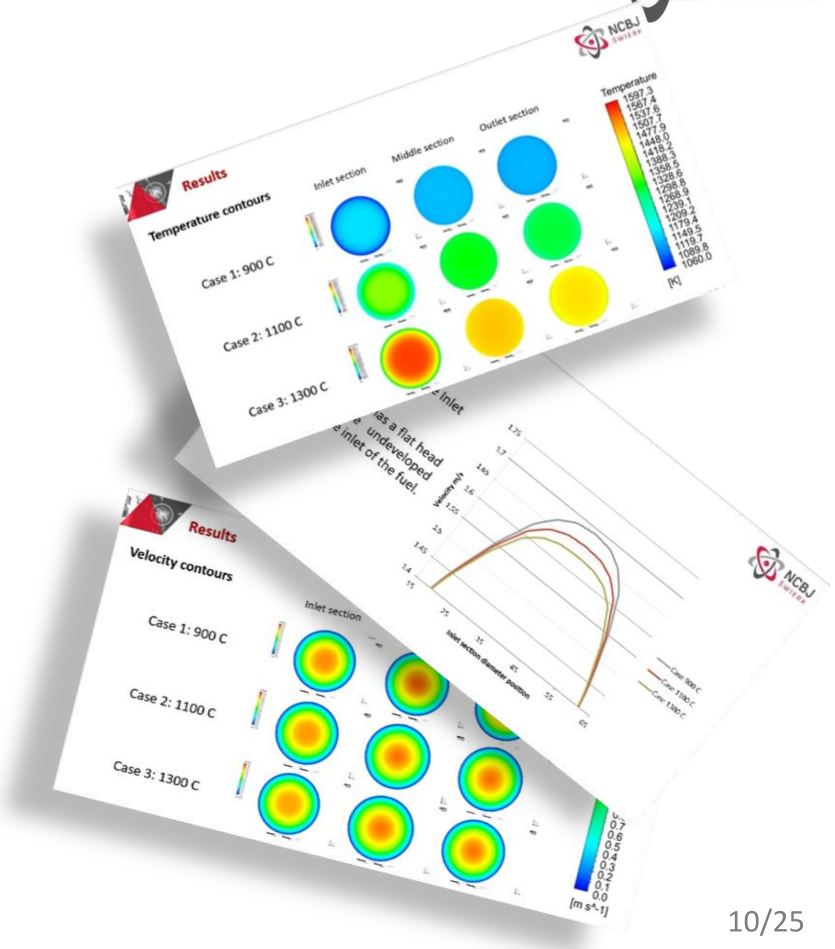
- Go through the core in 7 pipes to the exit in the collection zone.



Previous Investigation *(seminar 15th June 2021)*

The effect of the temperature variation on:

- *Viscosity*
- *Density*
- *Velocity profiles*
- *Pumping power*



What to investigate?

The effect of Fuel and coolant velocities on the following:

1- How will the variation of fuel/coolant velocities affect the rate of **heat transfer** between them in the MD case?

2- How the required **inlet pressures** of fuel and coolant will change as the change in their velocities will occur?

3- How this will affect the final outlet **fuel/coolant temperatures**?

Why to investigate?

Modelling the effect of Fuel and coolant velocities has important roles:

First: Operation

For the purpose of operation, the change in behavior of the MD is important, as it gives an idea to the **operator what to expect when an experiment is undergoing** similar conditions.

Why to investigate? – cont.

Second: Manufacturing

It is essential before manufacturing the MD to know if the **design** can **satisfy the targeted operations** meant to the device, in terms of materials, and equipment.

Third: Validation

Comparing the **model** results to **experimental** results later on, is essential to validate the models used in simulation.

Investigated scenarios

1- Variable fuel velocities:

Four Cases of different fuel velocities have been modelled with a constant coolant velocity.

2- Variable coolant velocities:

Four Cases of different Coolant velocities have been modelled with a constant Fuel velocity.

Variable **Fuel Velocity** *m/s* (constant coolant velocity of 0.5 m/s)	0.1	0.2	0.3	0.4
Variable **Coolant Velocity** *m/s* (at constant Fuel velocity of 0.1 m/s)	0.3	0.5	0.7	0.9

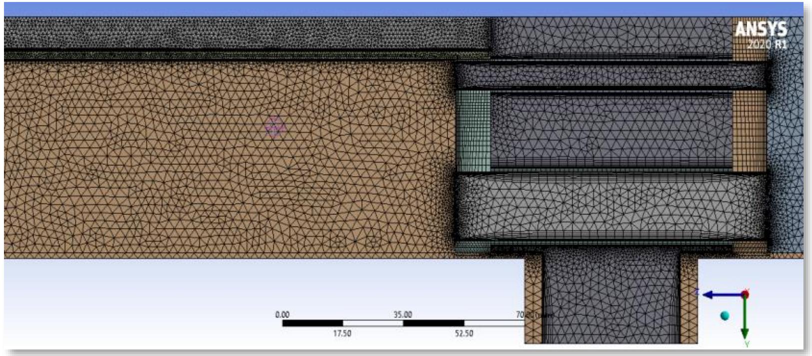
The velocities have been chosen for tuning around the default operational velocities.

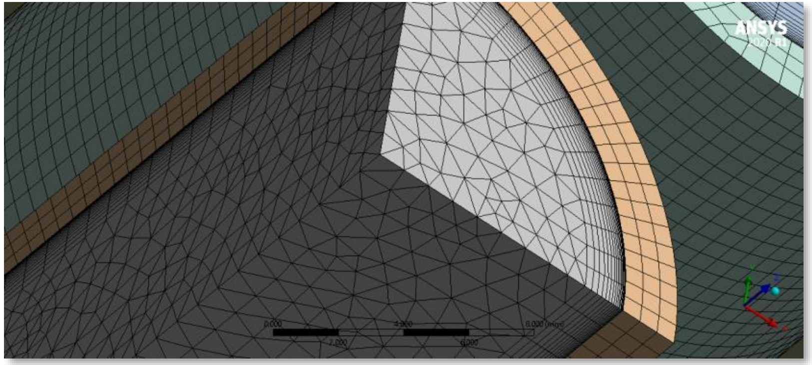
Meshing

- Mesh quality (skewness, orthogonality, mesh quality, … etc.) is ensured to be within the Ansys recommended ranges.

- Mesh was created With 15 inflation layers inside the fuel pipe boundary and 15 inflation layers outside the pipe boundary.

- Customized suitable sizing based on the location of the element has been constructed.





Solver and model

- Ansys-fluent solver has been used for this simulation.

- Turbulence model k-Omega.

-Liquid lead properties (density, heat capacity and viscosity) have been calculated using the temperature suitable range correlations.

Property	Interpolation function
Density (kg m-3)	$11463 – 1.32 \cdot T$
Heat capacity (J /kg.K)	$175.1 - 4.961\times10^{2}\cdot T + 1.985\times10^{-5}\cdot T^{2} - 2.099\times10^{-9}\cdot T^{3} - 1.524\times10^{6}\cdot T^{2}$
Viscosity (Pas)	$(1032.2 / T) - 7.6354$

Solution and results

A- Variable fuel velocity *(four cases)*

-B.Cs and resulted data are set as per the table.

Fuel Inlet velocity	F_Case_1	F_Case_2	F_Case_3	F_Case_4
Fuel inlet Velocity m/s	**0.1**	**0.2**	**0.3**	**0.4**
Fuel Mass flow rate kg/s	0.605	1.21	1.81	2 .42
Fuel Inlet Temp K	1473			
Fuel Outlet Temp K	872.9	899.79	914.4	945.8
Fuel Inlet pressure Pa	713	2513	5100	8343
Coolant Mass flow rate kg/s	17.087	17.08	17.08	17.08
Coolant Inlet Temp K	873			
Coolant Outlet Temp K	887.6	893.69	899.2	904.104
Coolant Inlet pressure Pa	154,828	154,726	154,920	155,028
Coolant Inlet vel. m/s	0.5			

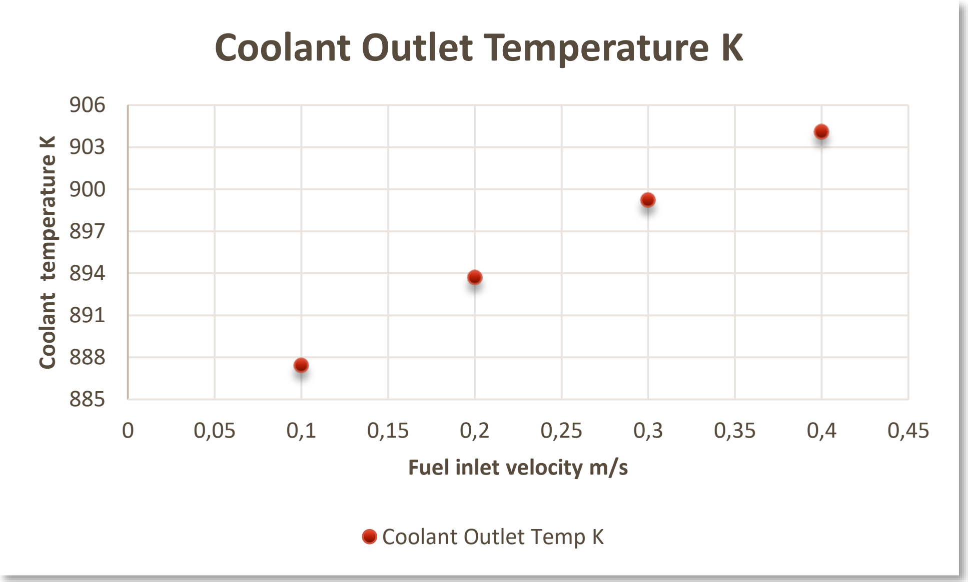
Solving and results – cont.

Results

A- Variable fuel velocity - cont.

As the fuel velocity increases *(constant fuel temperature),* the heat transfer from high temperature fuel to lower temperature coolant increases.

As a result; outlet coolant temperature increases.



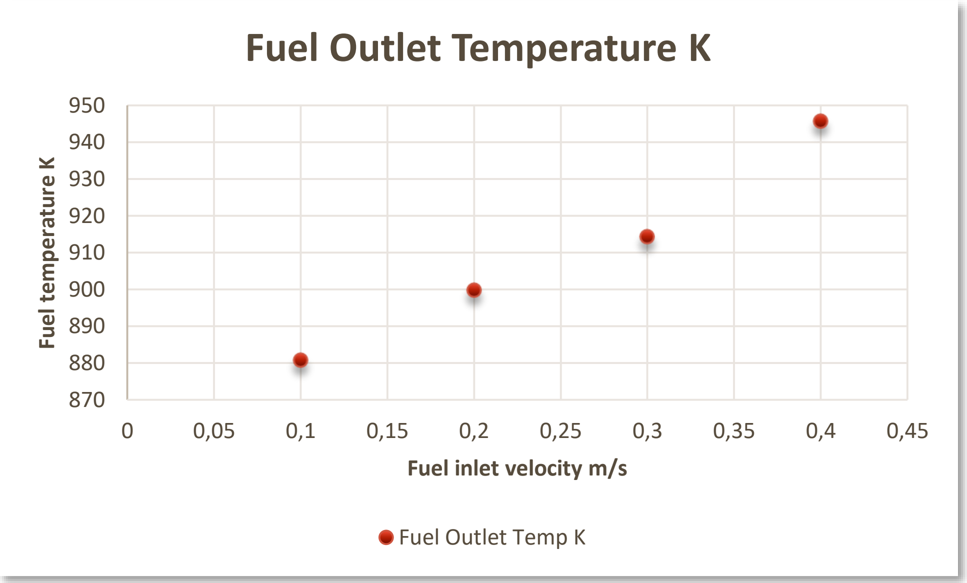
Results (2)

A- Variable fuel velocity - cont.

By the increase of the fuel inlet velocity, the mass flow rate increases, which should increase the heat transfer rate.

However, the outlet temperature of fuel increases!

Why??

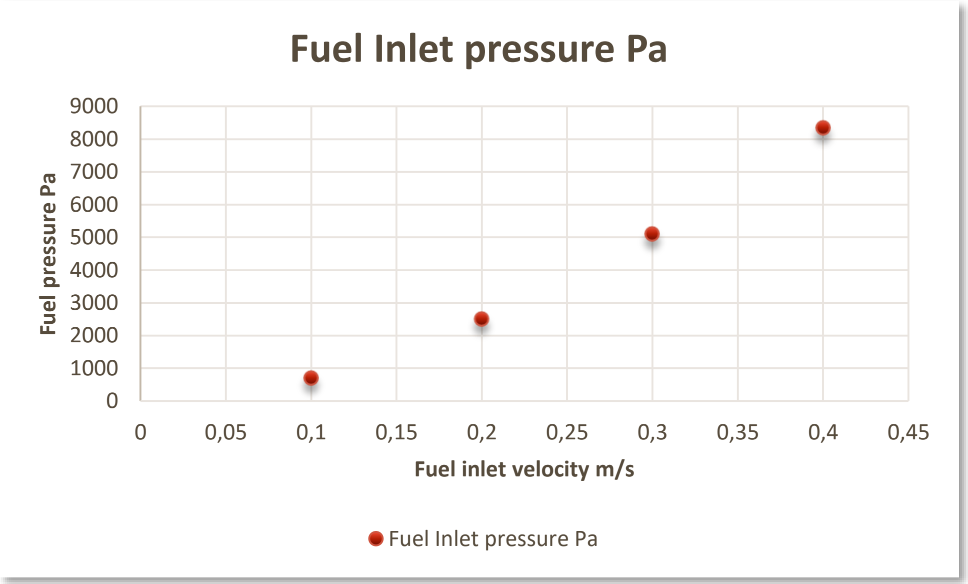


Results (3)

A- Variable fuel velocity - cont.

Increasing fuel velocity means adding more fuel in a shorter time

Which requires a higher pressure at the inlet (more pumping power).



Solution and results – cont.

B- Variable coolant velocity

Boundary conditions

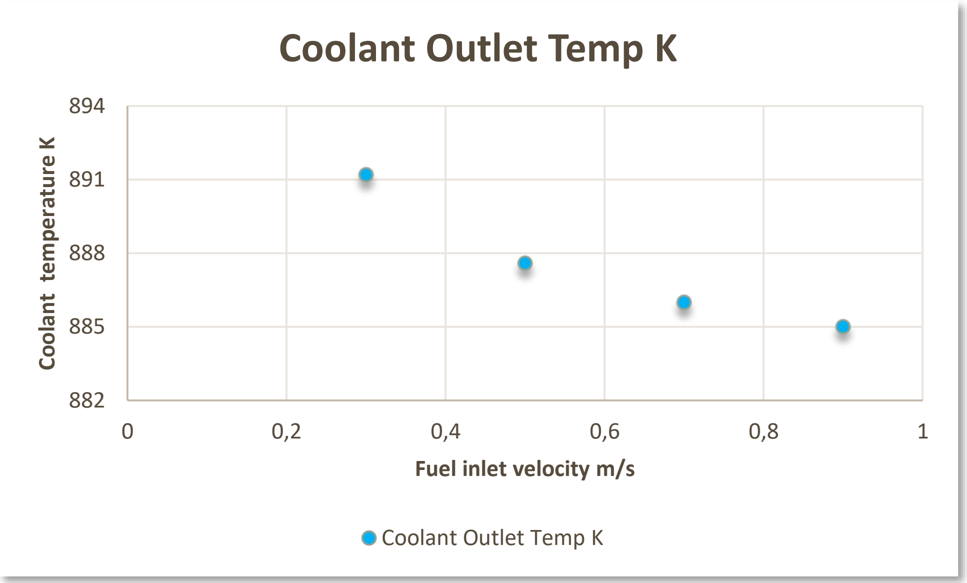
-B.Cs and resulted data are set as per the table.

Coolant Inlet velocity	C_Case_1	C_Case_2	C_Case_3	C_Case_4
Coolant Velocity m/s	**0.3**	**0.5**	**0.7**	**0.9**
Fuel Mass flow rate kg/s	0.605			
Fuel Inlet Temp K	1473			
Fuel Outlet Temp K	882.1	872.9	873.6	875.9
Fuel Inlet pressure	792.79	712.97	641.29	619.3
Fuel Inlet vel. m/s	0.1			
Coolant Mass flow rate kg/s	10.3	17.1	23.9	30.8
Coolant Inlet Temp K	873			
Coolant Outlet Temp K	891.2	887.6	885.99	885
Coolant Inlet pressure Pa	55,862	154,828	302,383	498,627

B- Variable coolant velocity

-Increasing the coolant velocity results in decreasing the outlet temperature of the coolant.

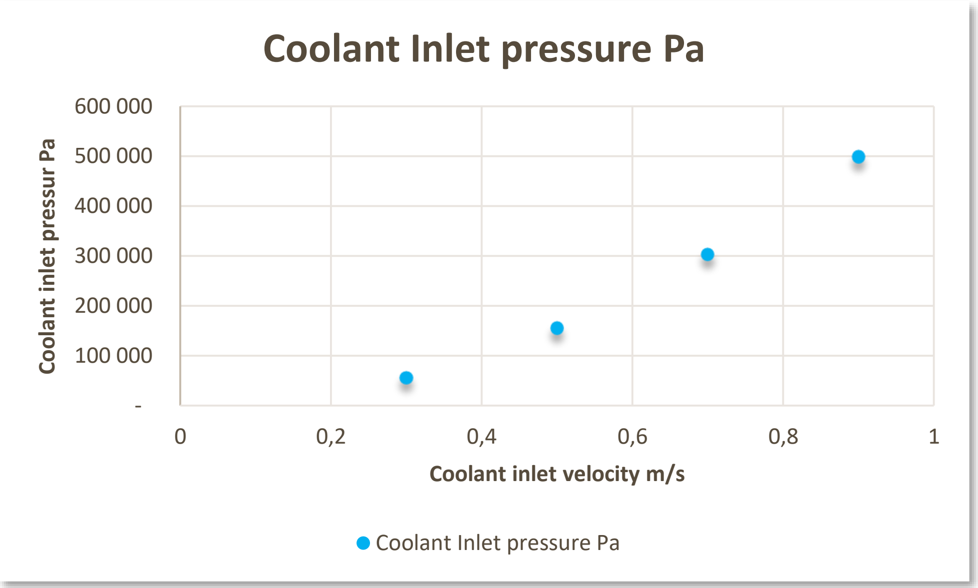
-Again, this is due to the less time taken for heat exchange in the core.



Solution and results – cont.

B- Variable coolant velocity

-Increasing the coolant velocity results in an increasingly changing pressure values, though, the pumping power required.



Summary

- By the **increase of the fuel velocity, both the fuel and coolant outlet temperatures are increasing**, as well as the total heat transfer.

- Contrarily, **Increasing the coolant velocity decreases fuel and coolant temperatures**, however, it still increases the total heat transfer.

- The cycle components (especially fuel cycle) must be able to **tolerate high fuel temperature** even after the fuel cooling stage in the core, specially in low coolant velocities or high fuel velocities.

- The fuel/coolant velocity variations, has a significant effect on the **pressure drop** (required pumping power), especially in the case of the coolant where higher turbulences occur.

Further work

- **Natural convection** heat transfer can be investigated in case of **losing pumping power**.
- **Counterflow heat exchange** can might cause an enhancement to the heat exchange process.
- **Turbulence model should be validated** and compared to similar experimental data.

Thank you for attention

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