DE LA RECHERCHE À L'INDUSTRIE

Preliminary Analysis on Possible Experiments in HELIOS Investigations for Helium Mass Expulsion and Heat Exchange Coefficients in CICCS

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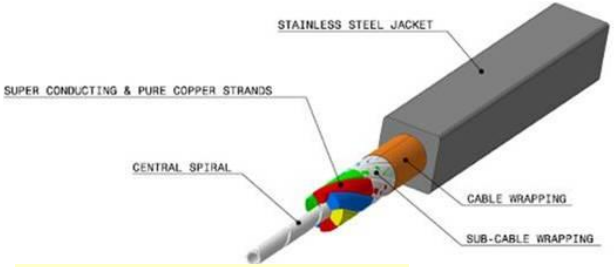
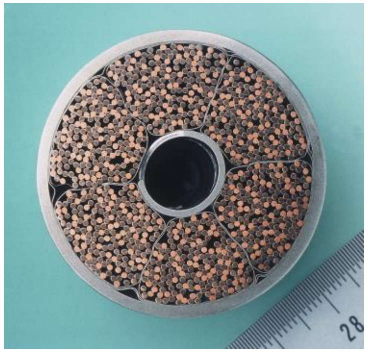
1) Introduction : CICC, Thermohydraulic Model and Code SuperMagnet

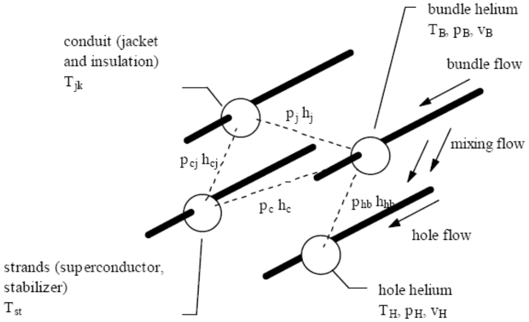
ITER Coils CICC model with SUPERMGANET (THEA + FLOWER + HEATER + POWER)

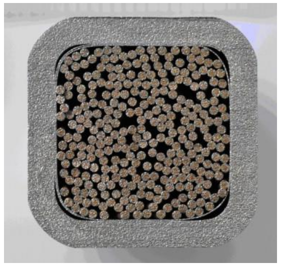
ITER TF CICC





JT-60SA TF CICC





CICC Characteristics	ITER TF	JT-60 SA TF
Geometrical characteristics		
Jacket type/ outer dimensions (mm)	Circular 316LN 43.7	Square/ 22 x 26
Cable type/ outer dimensions (mm)	Circular 39.7	Square /18 x 22
Stainless Steel Jacket cross section Ass (mm²)	262.01	176.0
Electrical characteristics		
RRR	100	
Number of strands	900	324 SC+162 Cu
Strands S/C diameter	0.82	0.81
SC Strands Cu :non-Cu ratio	1	1.6
Superconducting section (mm²)	235.33	56.8
Extra Cu cross section (mm²)	628.42	83.5
Total copper section (mm²)	508.32	180.0
Voltage threshold for discharge (V) Detection and action time Tda (s)	0.2 1.5	TBD TBD
Hydraulic characteristics		
Cooling channel length (m) (3 types of pancake)	380/ 311/106	113.8
Total Insulation section AIN (mm²)	194.0	100
Bundle		
Total conductor wetted perimeter (full) PHTC (m)	4.0383	1.236
Wetted perimeter Helium Jacket PHTJ=PHTCJ (mm)	62.36	37.85
Helium section in Bundle region AHEB (mm²)	344.4	123
Bundle region hydraulic diameter DHB (mm)	0.34112	0.45
Void fraction (%)	0.297	0.32
Spiral		no
diameter inner / outer = DHH (mm)	8 / 10	
Perimeter hole and bundle PHTHB (mm)	31.42	
Helium section in central hole AHEH (mm²)	78.54	
Surface perforatin ratio	0.15	

THEA Code [1] 1-D model for thermohydraulic simulation of Cable In Conduit Conductor.
→ 4 independent components: strands, conduit, bundle helium and central helium.
→ I, B (x,t) → Quench propagation and Joule heating computed with non-linear critical current density Jc (B,T)
FLOWER Code : Model of the cryogenic external loop

2) FRICTION FACTOR & HEAT EXCHANGE COEFFICIENT HCONV ON ITER & JT-60SA CICC

$\Delta P_f = (f_{EU} . m^2 . U . L)/(8 . \rho . A^3)$ $\quad$ $\mathrm{Re} = \rho \cdot v \cdot Dh/\mu = 4 \cdot m/\mu \cdot U$

SOFT 1998 $\quad$ $f_b = \frac{1}{V_f^{0.742}}(0.0231 + \frac{19.5}{\mathrm{Re}^{0.7953}})$

Production TF Spirals fh (New Fit) $\quad$ $f_{EU,TF-CN-RU} = 0.42 \cdot \mathrm{Re}_h^{-0.1}$

$f_{EU,ST} = 4\ f_{US,ST} = 4 * 0.046 \cdot \mathrm{Re}^{-0.2} = 0.184\,\mathrm{Re}^{-0.2}$

Smooth tube : turbulent & laminar $\quad$ $f_{EU,ST} = 64/\mathrm{Re}$

Evaluation of the ITER Cable In Conduit Conductor heat transfer**, **ICEC24

Reynolds-Colburn analogy between fluid friction and heat transfer, valid for fully developed turbulent flow in central hole region (Re_h near 10^5) as well as for laminar flow in bundle region (Re_b<2000).
The well known Colburn equation or the smooth tube is a particular case of these analogy.

→Expression of the convective heat exchange coefficient h_{conv} (W/m²K) from the experimental bundle region, and central hole region friction factor $f_{EU,b}$ & $f_{EU,h}$.

$St = Nu/\mathrm{Re} . \mathrm{Pr}$ $\quad$ $Nu = h_{conv} . Dh/\lambda$ $\quad$ $St . \mathrm{Pr}^{2/3} = f_{EU}/8$ $\quad$ **CR:** $h_{conv} = (f_{EU} . \lambda . \mathrm{Re} . \mathrm{Pr}^{1/3})/(8 . Dh)$

Other Correlations

Dittus-Boelter (DB): $Nu = 0.023 . \mathrm{Re}^{0.8} . \mathrm{Pr}^{1/3}$

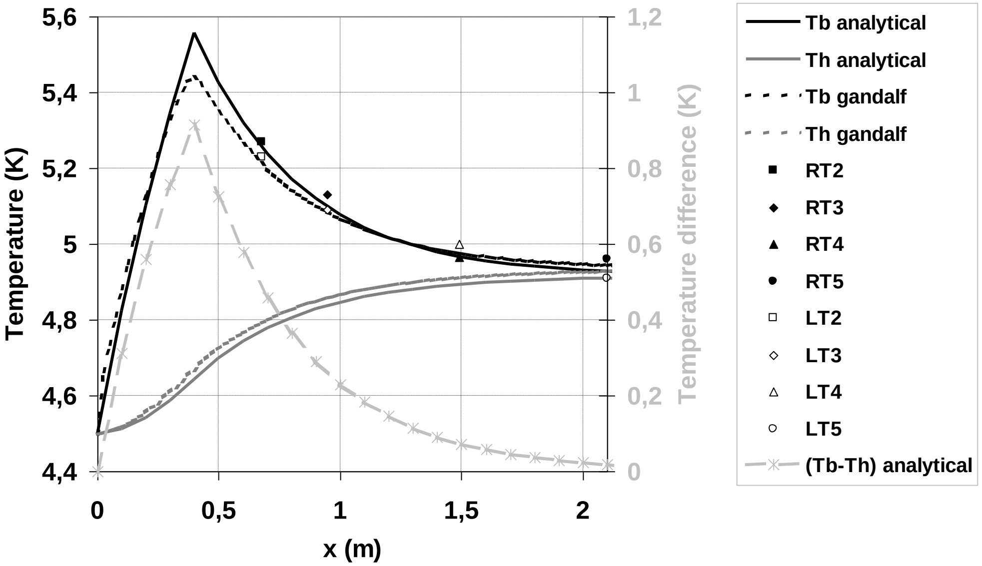
Laminar, Wachi $\quad$ $h_{conv} = 8.235 . \lambda_{He}/Dh$ $\quad$ Reb<2000

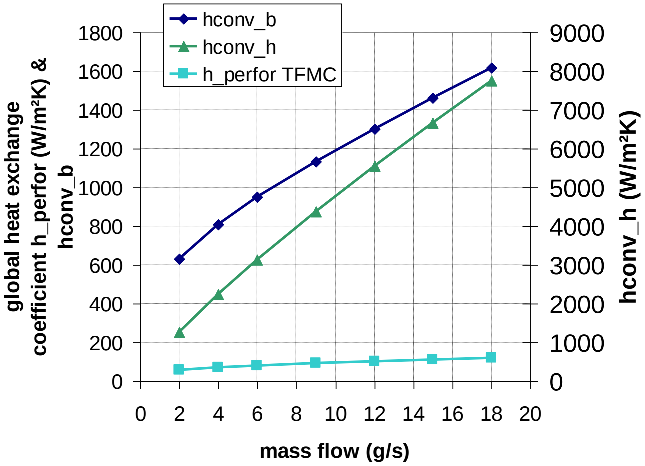
$h_{conv} = 4.3636 . \lambda_{He}/Dh$

Where : Re (-) : Reynolds Number, Pr (-): Prandtl number; St (-): Stanton Number, f_{EU}: Friction factor, ΔP (MPa): pressure drop; m (kg/s): mass flow, ρ (kg/m³): helium density; U (m): wetted perimeter; L (m): Length; A (m²): cross section; Dh (m): hydraulic diameter of the channel; λ (W/mK): helium thermal conductivity; μ (Pa.s): helium dynamic viscosity.

2) HEAT EXCHANGE COEFFICIENT HCONV, ON ITER & JT-60SA CICC

ICEC24, validation on PF-FSJS





Remark: global heat exchange coefficient between the two region h_{perfor} can be expressed in function of spiral perforation ratio (perfor), heat exchange coefficients h_{open} and h_{close} and the spiral stainless steel conductivity λ_{SS} (W/mK).

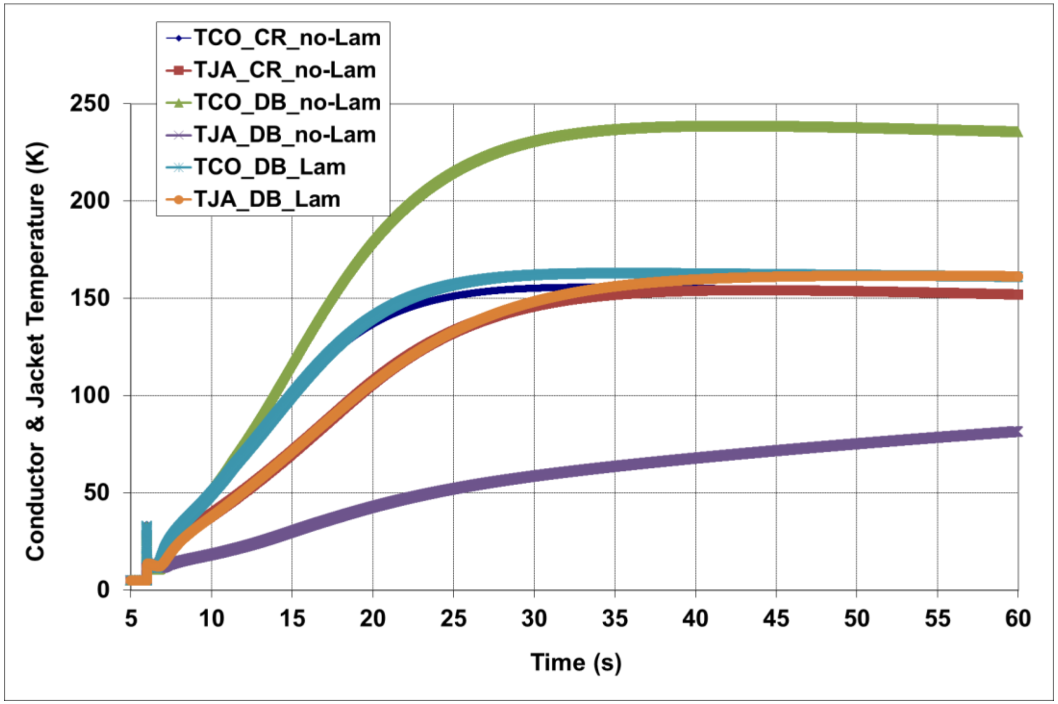
$$h_{perfor} = h_{open} \cdot perfor + h_{close} \cdot (1 - perfor)$$

$$1/h_{open} = 1/h_{conv,b} + 1/h_{conv,h}$$

$$1/h_{close} = 1/h_{open} + e/\lambda_{SS}$$

→ ***validation on JT-60SA CICC***
→ ***Validation on ITER TF CICC***

3) 1-IMPACT OF HEAT EXCHANGE ON HOT SPOT TEMPERATURE DURING QUENCH

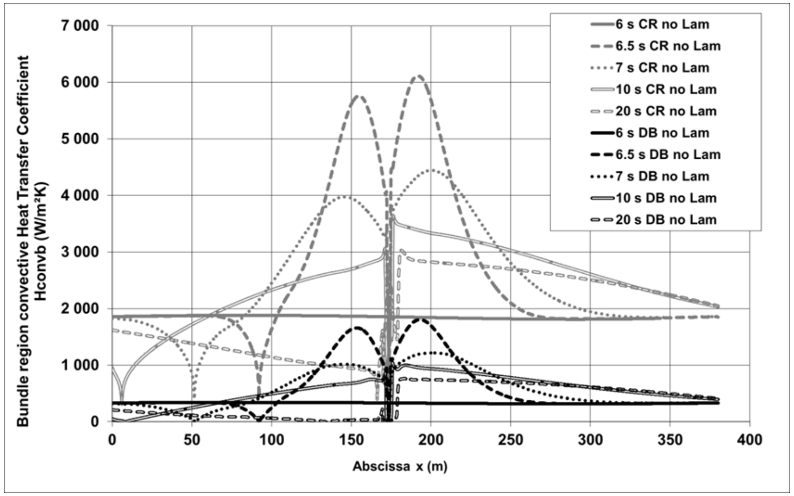


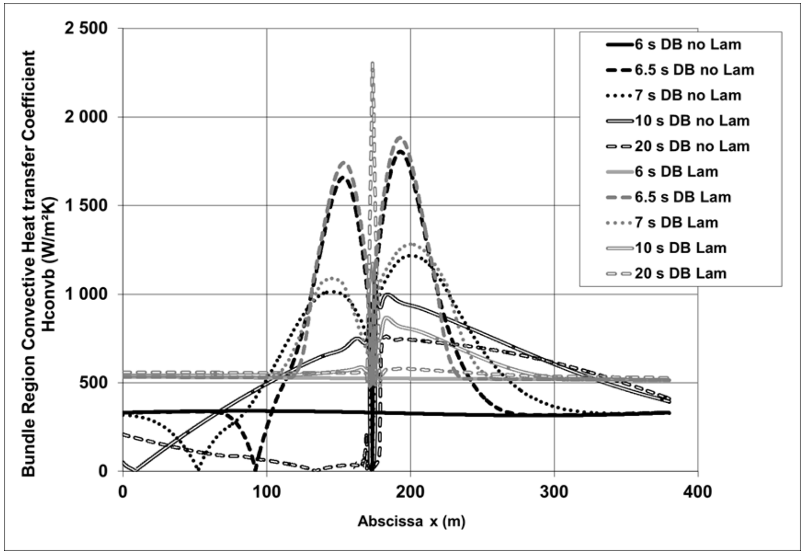
TCO &TJA, for quench initiated with MQE (1m, 1ms) at 173 m (B=2 T), current discharge triggered 1,5 s delay after Voltage threshold 0.2 V

$$\phi = h_{conv,CR}.L.U_{s}.(T_{s,CR} - T_{He}) = h_{conv,CR}.L.U_{JA}.(T_{He} - T_{JA,CR})$$

$$\phi = R.h_{conv,DB}.L.U_{s}.(T_{s,DB} - T_{He}) = R.h_{conv,DB}.L.U_{JA}.(T_{He} - T_{JA,DB})$$

$H_{conv,CR}$= 3 to 4 * $H_{conv,DB}$ → Same factor in (Tco-Tja) gradient in the first 6 to 10s, before Current discharge





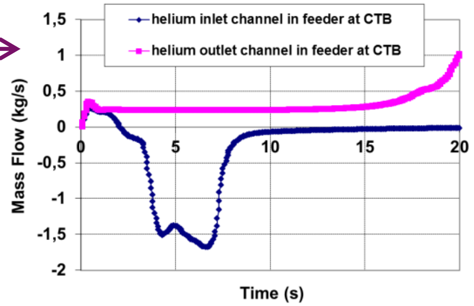
3) -UNDETECTED QUENCH, PRINCIPLE OF SECONDARY THERMOHYDRAULIC DETECTION

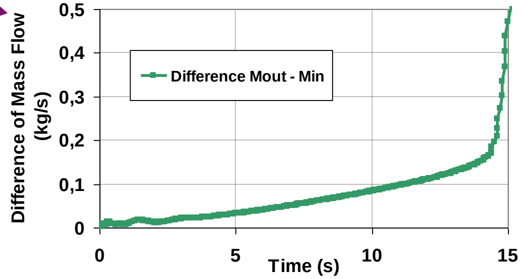
MT22

→ **At EOB, quench** triggered (**inner turn** P6, with I= 68 kA) with **MQE** (P= 200W/m, Δt= 1s , ε=-0.6767%) →**DT_{margin} minimum**.
→T signal changes slowly
m signal =**-0.2 kg/s at 3s change rapidly** & important back flow
→**used as secondary quench detection** in case of ΔV failure.

→initiated quench in CICC middle (190m<x<196m)
→mass flow difference (outlet - inlet) = only signal to be used = 0.08 kg/s (35% of nominal value of 0.23 kg/s) at t=10 s, due to propagation time duration

@ Cold Termination Box

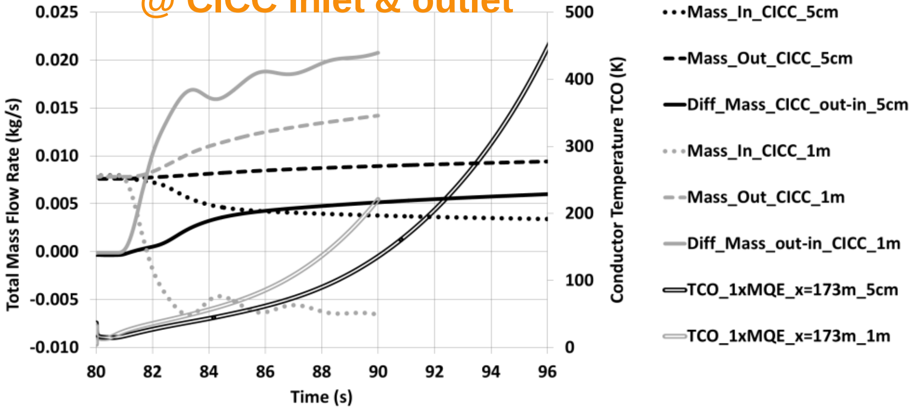




CEC-ICMC 2013 "SMOOTH QUENCH"

initiated quench at low B=2T @ x =173 m
MQE = 149 J (2720 kW/m, 5.5 cm, 1 ms)
MQE = 2277 J (1 m, 1 ms)
mass flow difference (outlet - inlet)
= 0.005 kg/s at t=8 s after quench initiation
=0.010 kg/s at t=2 s after quench initiation

@ CICC Inlet & outlet



4) HELIOS TEST FACILITY BUILT IN 2009

Travelling Crane: Maximal Weight m < 5 t

Cryostat: Height = H = 3 m
Inner Diameter = Din = 2 m

HELIOS TEST FACILITY
at INAC/SBT in CEA-Grenoble
→ Evaluate the pulsed heat load smoothing methods for supercritical helium

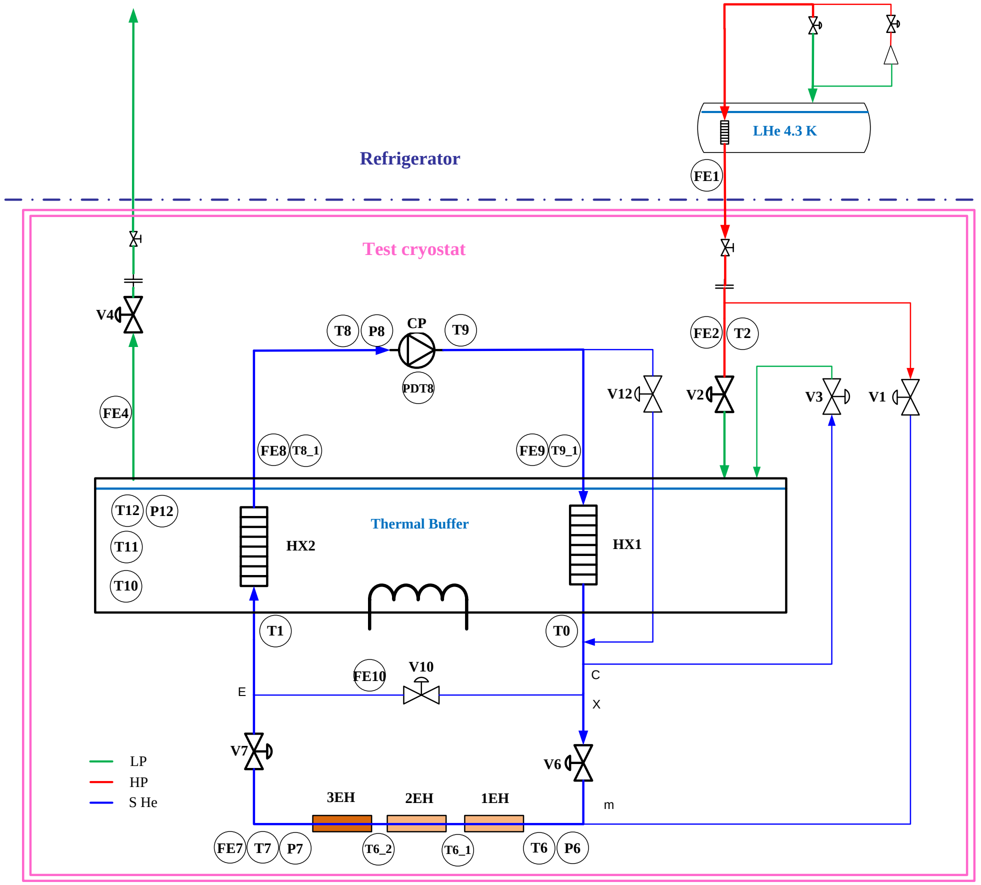
REFRIGERATOR CAPACITY = 800W @ 4.4 K

CONNECTED TO THE CRYOSTAT
- ***→ thermal Buffer : Bath Volume V = 340 l***
- ***→ Available refrigerator capacity = 350 W @ 4,5 K***
- ***→ Static heat loads = 100W***
- ***→ Available cryogenic Power Pcry = 250 W @ 4,5 K***
- ***→ Pump Mass Flow Rate m = 50 g/s***
  Pump Pressure Head DP = 0,1 MPa
- ***→ Maximal Pressure in circuit P < 0,9 Mpa***

- ***→ Total Volume of the closed loop = near 140 l***

Experience Feedback:
Dead Volumes to be taken into account

4) HELIOS CLOWER LOOP: FLOWER MODEL



Volumes

Vn = 1,0 E-3 m3 with n = 1 to 17
Pini,n = 0,55 MPa and Tini,n = 5 K

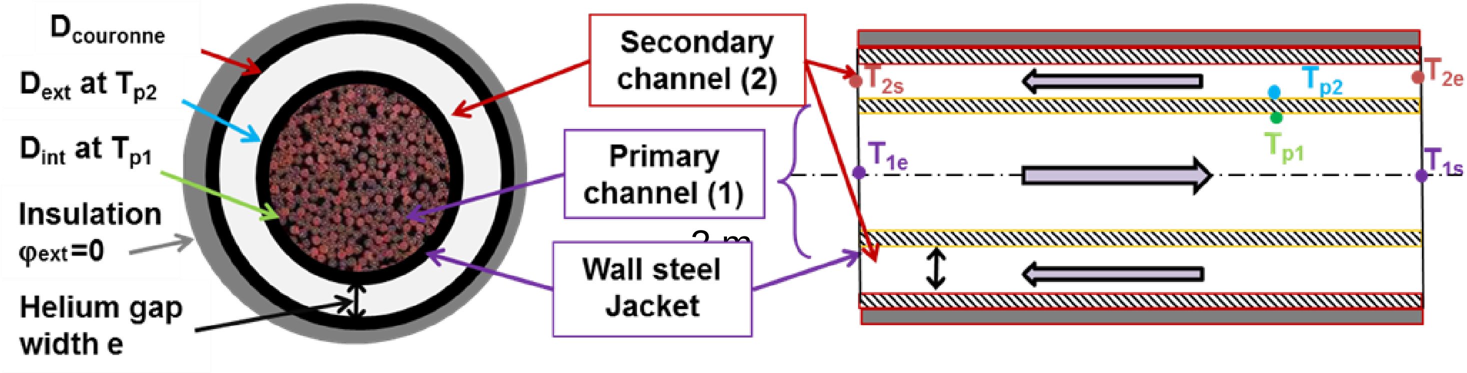
V18 = 340 E-3 m3
Pini,v18 = 0,101 MPa and Tini,v18 = 5 K

Junctions

	N	type	DI (mm)	A (m^2)	Wp (m)	L (m)	V(m^3)	Parameters
Pump	1	Pump		707 E-6		2		
CP-HX1	2	Cpipe	30.1	711.6 E-6	94.6 E-3	11.38	0.0081	N=12
HX1	3	Cpipe	10	100 E-6	2	31.00		N=31, HTC=500
HX1-X	4	Cpipe	30.1	711.6 E-6	94.6 E-3	1.86	0.0013	N=2
X-V6	5	Cpipe	30.1	711.6 E-6	94.6 E-3	7.84	0.0056	N=8
V6	6	CV		711.6 E-6		1.00		csi=1.7
V6-m	7	Cpipe	30.1	711.6 E-6	94.6 E-3	12.40	0.0088	N=12
m-1EH	8	Cpipe	30.1	711.6 E-6	94.6 E-3	10.35	0.0074	N=10
heated tube	9	external	30.1	711.6 E-6	94.6 E-3	100.62	0.01	
1EH			10	711.6 E-6	94.6 E-3	25.67	0.0020	
1EH-2EH			10	711.6 E-6	94.6 E-3	8.21	0.0006	
2EH			10	711.6 E-6	94.6 E-3	25.67	0.0020	
2EH-3EH			10	711.6 E-6	94.6 E-3	8.73	0.0007	
3EH			10	711.6 E-6	94.6 E-3	32.34	0.0025	
3EH-V7	10	Cpipe	30.1	711.6 E-6	94.6 E-3	27.72	0.0197	N=28
V7	11	CV		711.6 E-6		1.00		csi=1.7
V7-E	12	Cpipe	30.1	711.6 E-6	94.6 E-3	2.39	0.0017	N=3
E-HX2	13	CPipe	30.1	711.6 E-6	94.6 E-3	1.34	0.0010	N=2
HX2	14	Cpipe	10	100 E-6	2	31.00		N=31, HTC=500
HX2-CP	15	CPipe	30.1	711.6 E-6	94.6 E-3	12.46	0.0089	N=14
X-V10	16	Cpipe	23.7	441.2 E-6	74.5 E-3	1.143	0.00050	N=2
V10	17	CV		711.6 E-6		1.00		csi=1.7
V10-E	18	Cpipe	23.7	441.2 E-6	74.5 E-3	1.997	0.00088	N=2

5) COEFFICIENT DETERMINATION IN HEAT EXCHANGER, 5.1) CALCULATION, MODEL

Objective : estimate the global heat exchange coefficient as a function of the flow regime (Re), and to help crosschecking the validity of the usefull correlation (e.g. Wachi for laminar, or Dittus-Boelter of Colburn-Reynolds analogy, etc…)



Global Heat exchange → Heat transfer through wrapping not taken into account

Steady State equations : heat flux conservation

$$\phi = m_2.(h_{2,in} - h_{2,out}) \qquad \phi = h_{conv,2}.S_2(T_{2,av} - T_{p,2})$$

$$\phi = S_2.\frac{2.\lambda}{\ln(\frac{D_{ext}}{D_{\text{int}}}).D_{ext}}(T_{p,2} - T_{p,1})$$

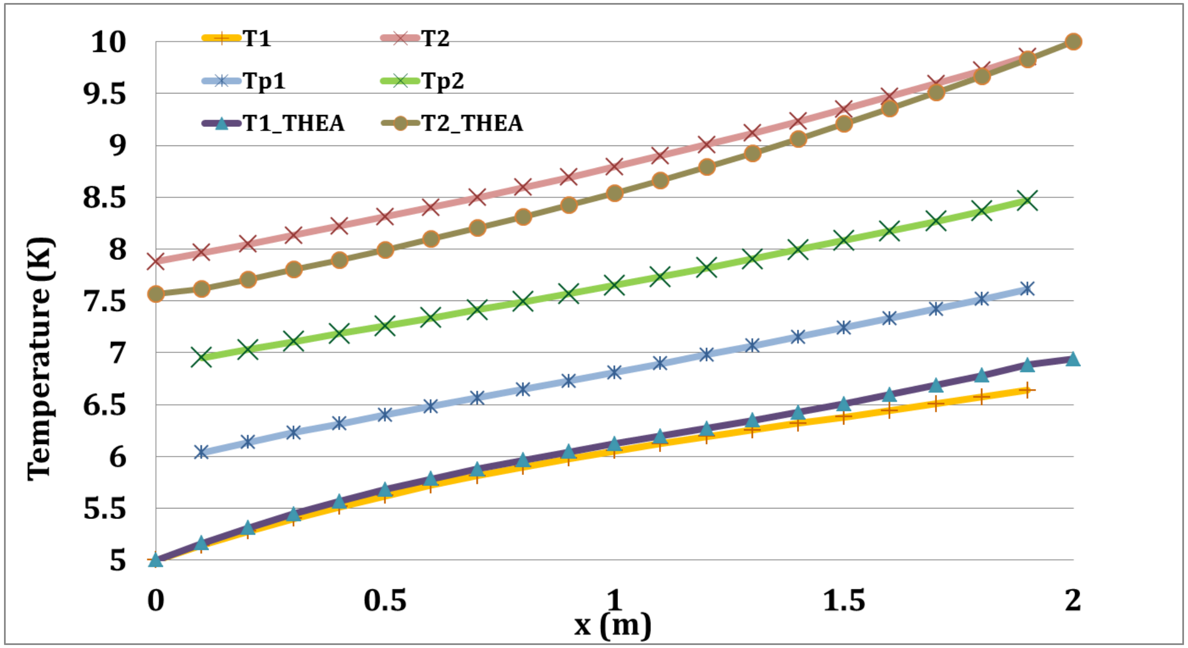
$$\phi = h_{conv,2}.S_1(T_{p1} - T_{1,av}) \qquad \phi = -m_1.(h_{1,in} - h_{1,out})$$

Different heat exchanger are studied as a function of :

- **flow regime (Re)**
- **The specific geometries of the CICC**
- **Flow test conditions (P, T, m)**
- **Kind of heat exchanger : co-flow or counter-flow**

5) COEFFICIENT DETERMINATION IN HEAT EXCHANGER, 5.2) VALIDATION ON A SMOOTH TUBE

FIRST VALIDATION ON A SMOOTH TUBE With 2 MODELS : EXCEL-VBA and THEA



	Primary circuit (1)	Secondary circuit (2)
	Smooth Tube (ST)	Smooth Tube (ST)
Hydraulic diameter Dh (m)	Dh1 = 0.01 m = Dint Dext = 0.014 m	Dh2 = 2 x e = 0.006 m Dext = 0.02
Wetted Perimeter U (mm)	U1 = 31.4159	U2=94.25
Section SS (mm²)	S1 = 75.39	S2 =125.6
Helium section (mm²)	She1 = 78.539	She2 = 160.221
Pressure (MPa)	P1in = 0.5	P2in = 0.5
Inlet Temperature (K)	T1in = 5	T2in = 10
mass flow (g/s)	M1= 1	M2 = 1

Fluid and Wall temperature for counter flow heat exchanger with λss=0.3 W/mK at 10 K

$$R^{'} = (T_{1,Out,Thea} - T_{1,Out,Excel})/(T_{1,Out,Excel} - T_{1,In,Excel})$$

The thermal conductivity of Stainless Steel (λss=0.3 W/mK at 10 K) is taken into account in vba Model

In THEA, this is not the case
→ Difference R’= 15 %

If λss= infinite value (1000 W/mK)
→ Difference R’= 4 %
→ May be due to helium properties difference

5) COEFFICIENT DETERMINATION IN HEAT EXCHANGER, 5.3) SENSITIVITY STUDY

Objective : Obtain best sensitivity by varying the parameters: T1in, T2in, m1, m2, L and e.

Parameters: T1in = 28 K
T2in = 5 K
m1=2 g/s
m2=20 g/s
e=5 mm
L= 2 m

Gives: T1out= 7,**27 K**
T2out = **6,45 K**

Precision on Temperature Measurements
± 0,05 K

	hCR	T1out	T2out
+20%	2701,2	7,20	6,46
+15%	2493,5	7,22	6,46
+10%	2285,7	7,24	6,45
+5%	2181,8	7,26	6,45
	2077,9	**7,27**	**6,45**
-5%	1974,0	7,29	6,45
-10%	1870,1	7,31	6,45
-15%	1662,3	7,35	6,45
-20%	1454,5	7,41	6,44

e (mm)	m1 (kg/s)	m2 (kg/s)	T1in (K)	T2in (K)	Variation CR %
1	1	1	5	10	18
5	1	1	5	10	35
1	7	1	5	10	22
5	7	1	5	10	15
1	1	7	5	10	27
5	1	7	5	10	19
1	**7**	**7**	**5**	**10**	**12**
5	7	7	5	10	15
1	1	1	10	5	13
5	1	1	10	5	34
1	**7**	**1**	**10**	**5**	**12**
5	**7**	**1**	**10**	**5**	**12**
1	**1**	**7**	**10**	**5**	**12**
5	**1**	**7**	**10**	**5**	**12**
1	7	7	10	5	13
5	7	7	10	5	20

**By varying $h_{conv,1,CR}$
from ± 5, 10, 15, 20%
Configuration Variation h >25%
(de -10% à + 15%)**

First Results of sensitivity Studies

5) COEFFICIENT DETERMINATION IN HEAT EXCHANGER, 5.3) SENSITIVITY STUDY

COMPLEMENTARY STUDY by varying the different input parameters:

e = 1 or 5 mm, m_1= 1, 2 , 4 g/s, m_2= 15, 20 g/s, T1in= 10, 20, 28 K, T2in= 5, 8 K and L = 0.5 or 2 m.

→ **configuration with counter flow heat exchanger is slightly better**

→ **Shorter length of heat exchanger gives a better sensitivity: we will choose 0.5 m**

hydraulic establishment length L_e = 20 x Dh , thermal establishment length L_{te} = L_e x Pr

→L_e = 9 mm (CICC) and L_e = 12 cm (channel 2) →L_{te} = 0.9 L_e at 5 K and L_{te} = 0.7 L_e at T=20 K).

→ **Smaller mass flow in channel 1 increases the sensitivity.**

JT-60SA TF Coil operation : nominal mass flows in CICC = 4 g/s (during plasma burn) or 2 g/s (for dwell).

→ **Important temperature variation (inlet–outlet) of channel 1 increases the sensitivity.**

T_{1in}, should be high (near 20 K), but compatible Pcryo HELIOS : $m_{1.}(h_{s,in} – T_{cryo})<P_{cryo}$= 300 W.

→ **Mass flow in channel 2 to conserve a minimum temperature difference of 0.5 K (inlet –outlet)**

e (mm)	m1 (g/s)	m2 (g/s)	T1,in	T2,in	L (m)	Variation CR %	Variation DB %
5	2	20	28	5	2	> 20	< 20
5	2	5	28	5	0,5	20	< 10
5	2	5	28	5	2	> 20	< 15
5	**2**	**20**	**20**	**5**	**0,5**	**< 10**	**< 10**
5	**4**	**20**	**10**	**8**	**0,5**	**< 20**	**< 10**
5	6	20	20	5	0,5	< 20	< 15
5	8	20	20	5	0,5	> 20	< 15

Counter-Flow

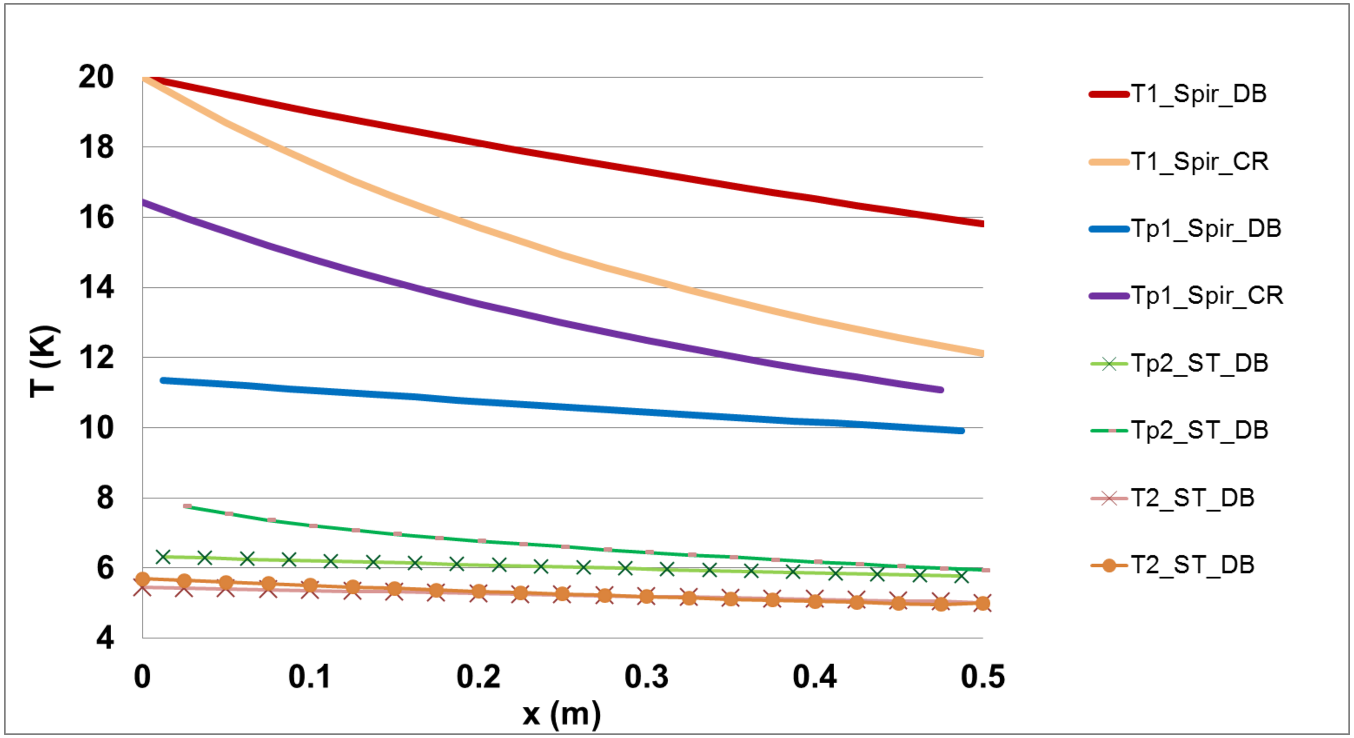
Co-Flow

Optimized configuration allows assessing the overall heat exchange coefficient (precision nearly 10 %).

Optimal Configuration

e (mm)	m1 (g/s)	m2 (g/s)	T1in	T2in	L (m)
5	**2**	**20**	**28**	**5**	**0,5**

5) COEFFICIENT DETERMINATION IN HEAT EXCHANGER, 5.4) SPIRAL / ST CONFIGURATION



Spiral inside a tube counter flow heat exchanger

Tests Conditions : m_1=2 g/s, $T_{1,in}$=20 K, m_2=20 g/s, $T_{2,in}$=5 K

Channel 1 and 2 fluid and wall temperature (inner-Tp1 and outer-Tp2)

→ 78000 < Reh < 86000 turbulent

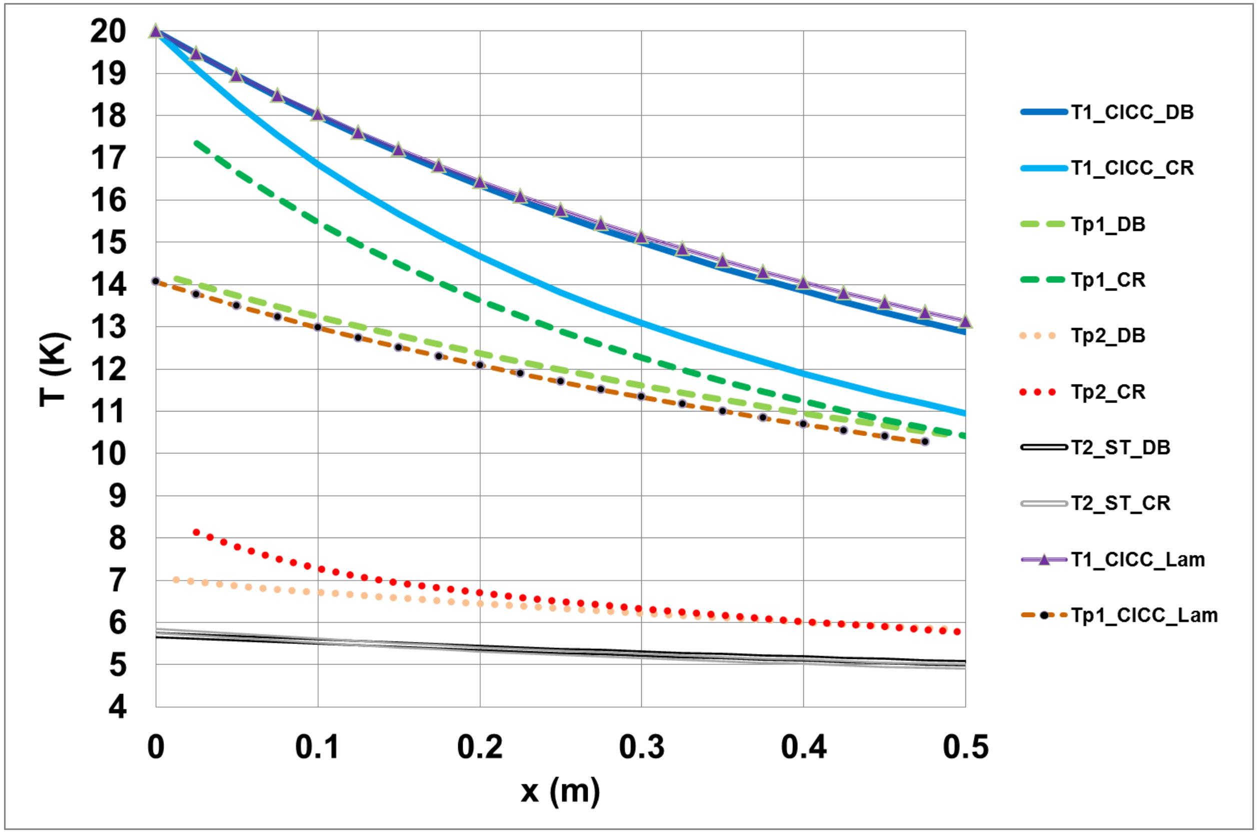
Colburn Reynolds (CR) analogy → hconv,h = 420 W/m²K

$$h_{conv} = (f_{EU} . \lambda . \mathrm{Re} . \mathrm{Pr}^{1/3}) / (8 . Dh)$$

and Dittus-Boelter (DB) correlation → hconv,h = 2900 W/m²K

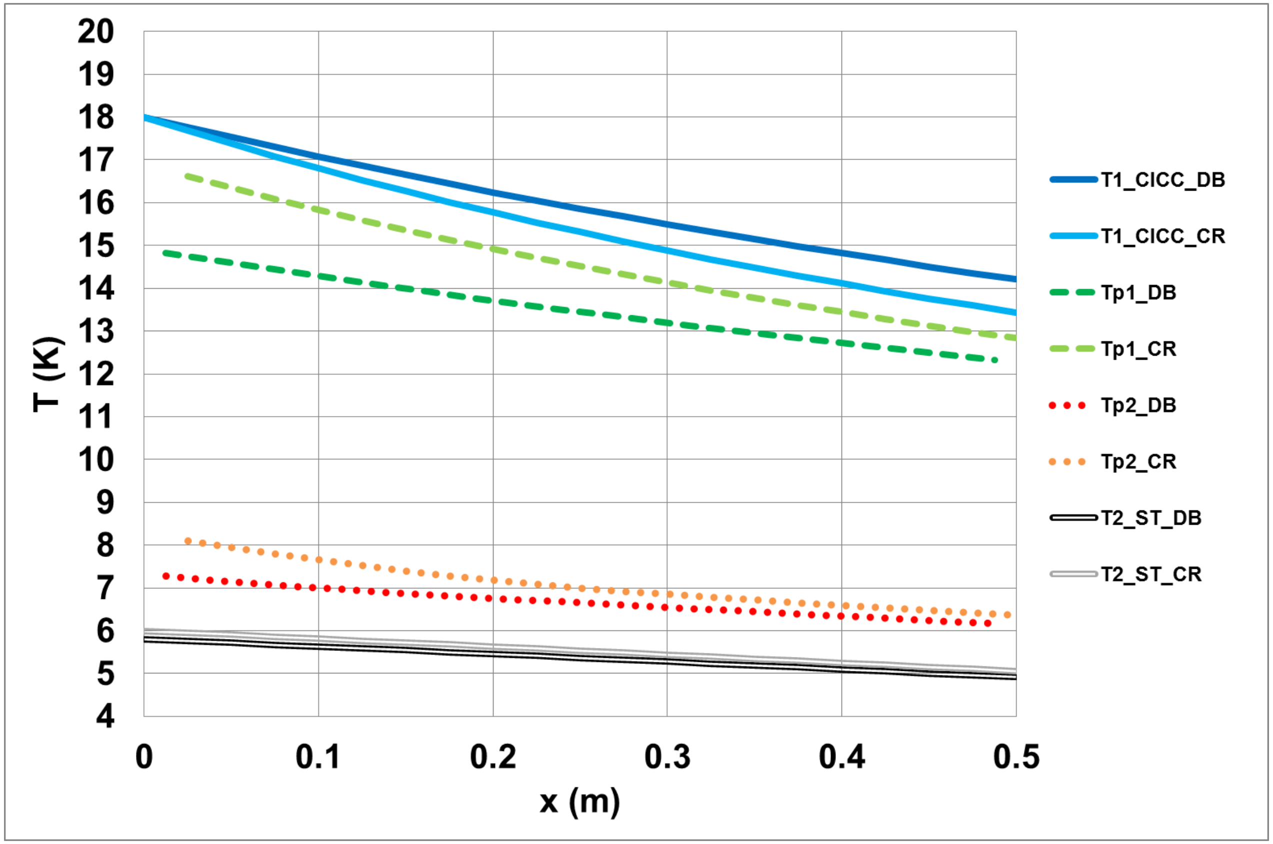
$$Nu = 0.023 . \mathrm{Re}^{0.8} . \mathrm{Pr}^{1/3}$$

5) COEFFICIENT DETERMINATION IN HEAT EXCHANGER, 5.4) JT-60SA TF CICC LAMINAR / ST



JT-60SA TF CICC inside a tube counter flow heat exchanger,
Flow Conditions : **m_1=2 g/s**, $T_{1,in}$=20 K, m_2=20 g/s →**1800 < Re1,CICC < 2200 (Laminar)**
Channel 1 and 2 fluid wall temperature (inner-Tp1 and outer-Tp2)
→Colburn Reynolds (CR) analogy **T1out=11 K** →Dittus-Boelter (DB) correlation
→Laminar Wachi (W) correlation Hconv,DB=Hconv,W = 550 W/m²K →T1out=13 K

5) COEFFICIENT DETERMINATION IN HEAT EXCHANGER, 5.4) JT-60SA TF CICC / ST



JT-60SA TF CICC inside a tube counter flow heat exchanger,

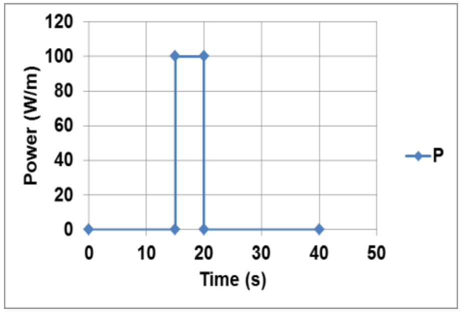
Flow Conditions : **m_1=5 g/s**, $T_{1,in}$=20 K, m_2=20 g/s →**4500 < $Re_{1,CICC}$ < 5100 (turbulent)**

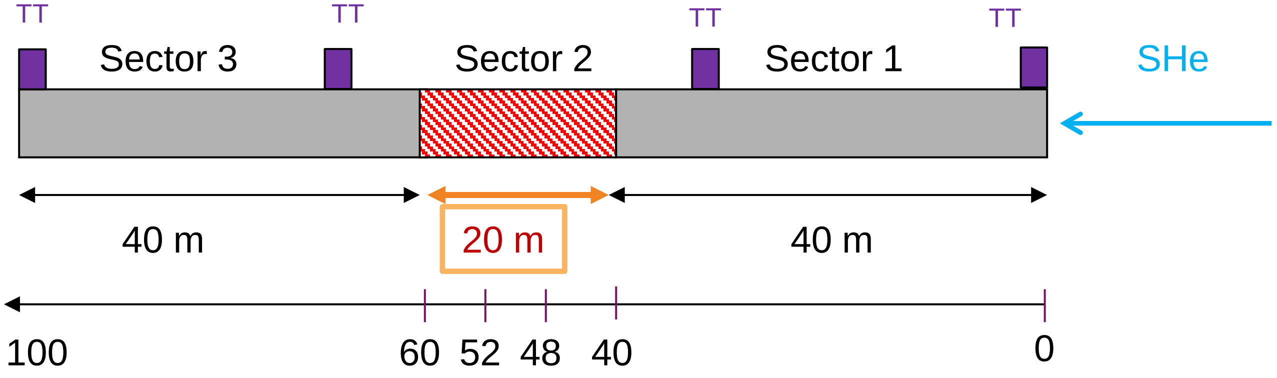
Channel 1 and 2 fluid wall temperature (inner-Tp1 and outer-Tp2)

→Colburn Reynolds (CR) analogy **3600 < $H_{conv,CR}$< 3800 W/m²K, T_{1out}=13.5 K**

→Dittus-Boelter (DB) correlation **$H_{conv,DB}$= 1100 W/m²K**, **T_{1out}=14.1 K**

6) EXPERIMENTS OF MASS FLOW EXPULSION
6.1) ON 100 M SMOOTH TUBE





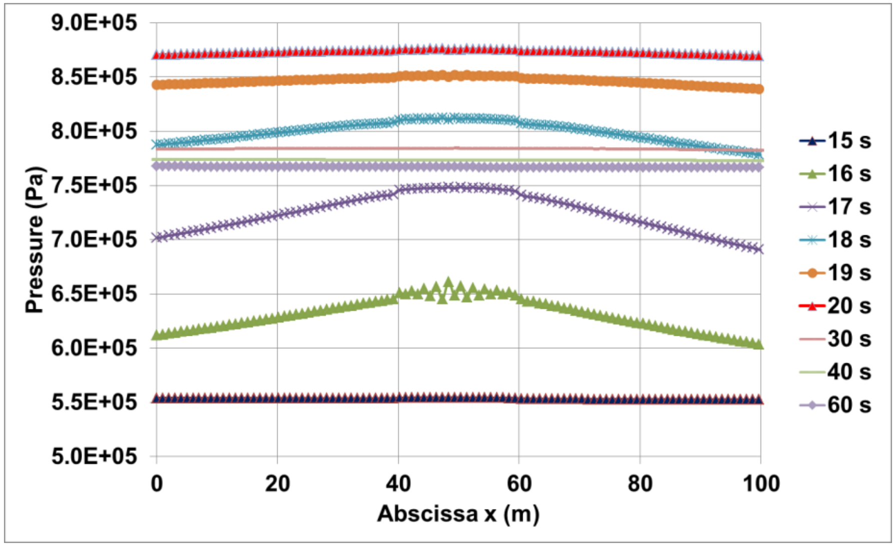
Inner Diameter ID = 10 mm,
Ahe = 78,54 mm², Uh = 31,4 mm
Stainless Steel ASS = 100 mm² (e= 3 mm)

Pini = 0,55 MPa, Tini = 5K, m ini = 4 g/s

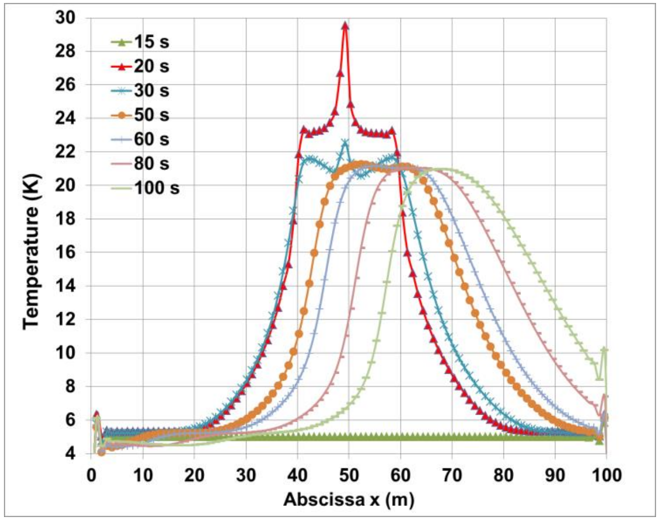
Power : 100 W/m (Pmax = 3W cm²)
over 5 s from time = 15 to 20 s
over 20 m (40 m < x < 60 m)
over 10 m (45 m < x < 55 m)
over 4 m (48 m < x < 52 m)

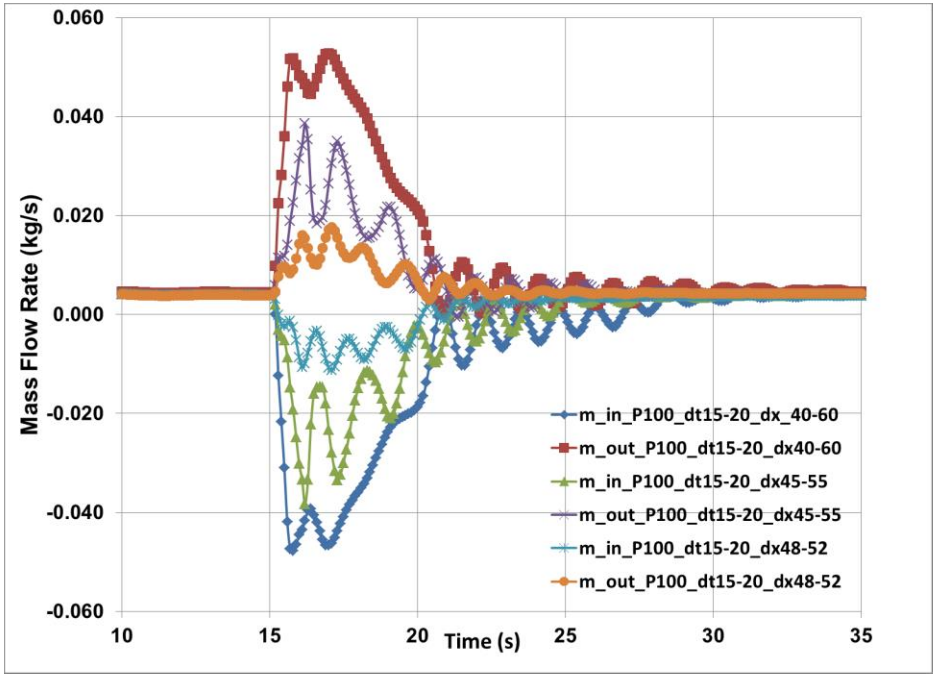
→ 10 000 J, 100 s → 100 W @ 4,5 K < Pcryo

→ Pmax=0.87 MPa



6) EXPERIMENTS OF MASS FLOW EXPULSION
6.1) ON 100 M SMOOTH TUBE



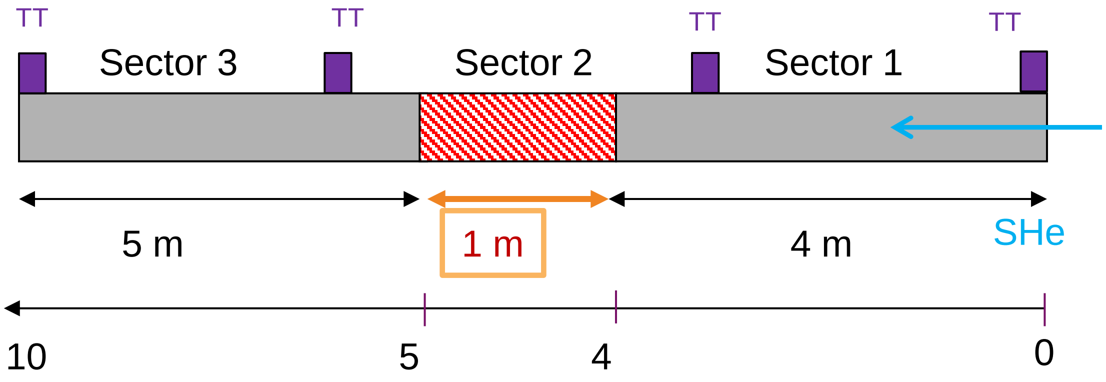


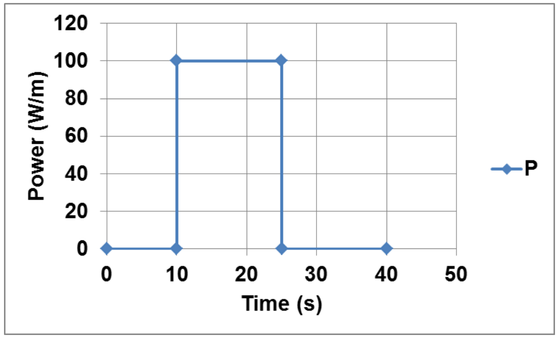
Temperature follows the heated power → Tmax = 30 K

No cooling power in the circuit

Inlet & outlet Massflow Evolution for P=100 W/m from 10 to 15 s:
DX= 40-60 m : Increase at the outlet + 0,05 kg/s, Reverse flow at inlet -0,04 kg/s
DX=45-55 m : same phenomenon but some oscillations (may be due to pressure in HELIOS circuit)
DX=48-52 m : oscilllations, Increase at the outlet + 0,01 kg/s, Reverse flow at inlet -0,01 kg/s

6) EXPERIMENTS OF MASS FLOW EXPULSION
6.1) ON 100 M SMOOTH TUBE

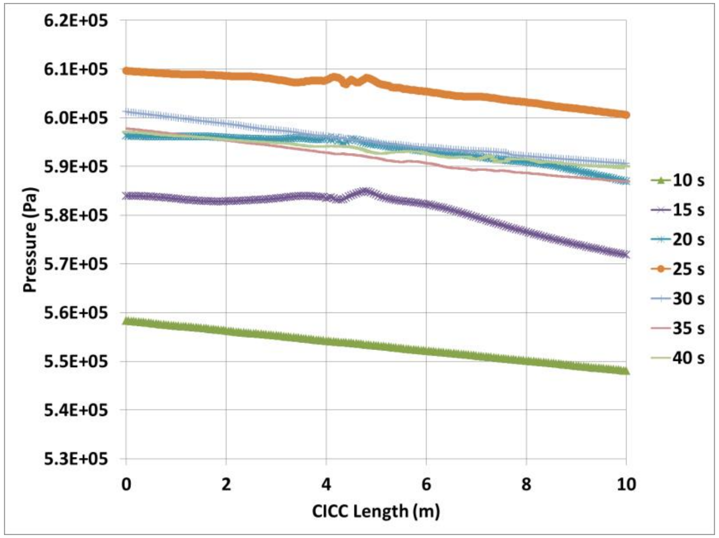




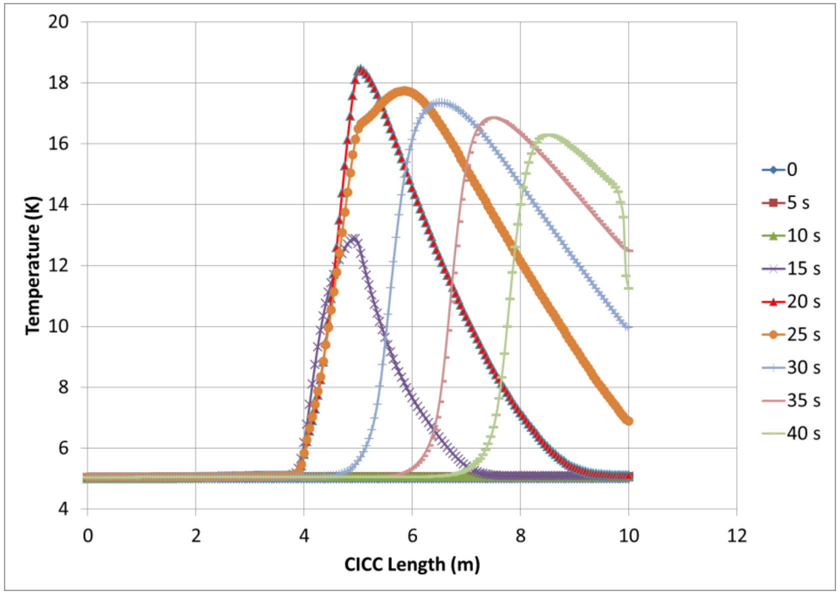
JT-60SA TF CICC

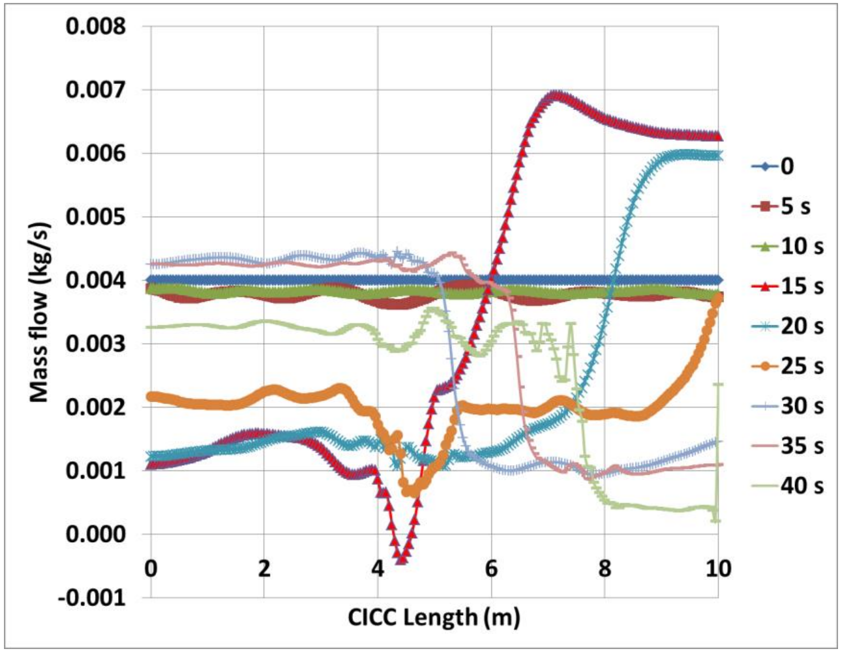
Pini = 0,55 MPa, Tini = 5K, m ini = 4 g/s

Power : 100 W/m (Pmax = 3 W/cm²)
50, 150 and 200 W/m
15 s from time = 10 to 25 s
1 m (4 m < x < 5 m)
→ 1 500 J (divided by 6) → DP/6
→ Pmax = 0.61 MPa



6) EXPERIMENTS OF MASS FLOW EXPULSION 6.2) ON 10 M JT-60SA TF CICC





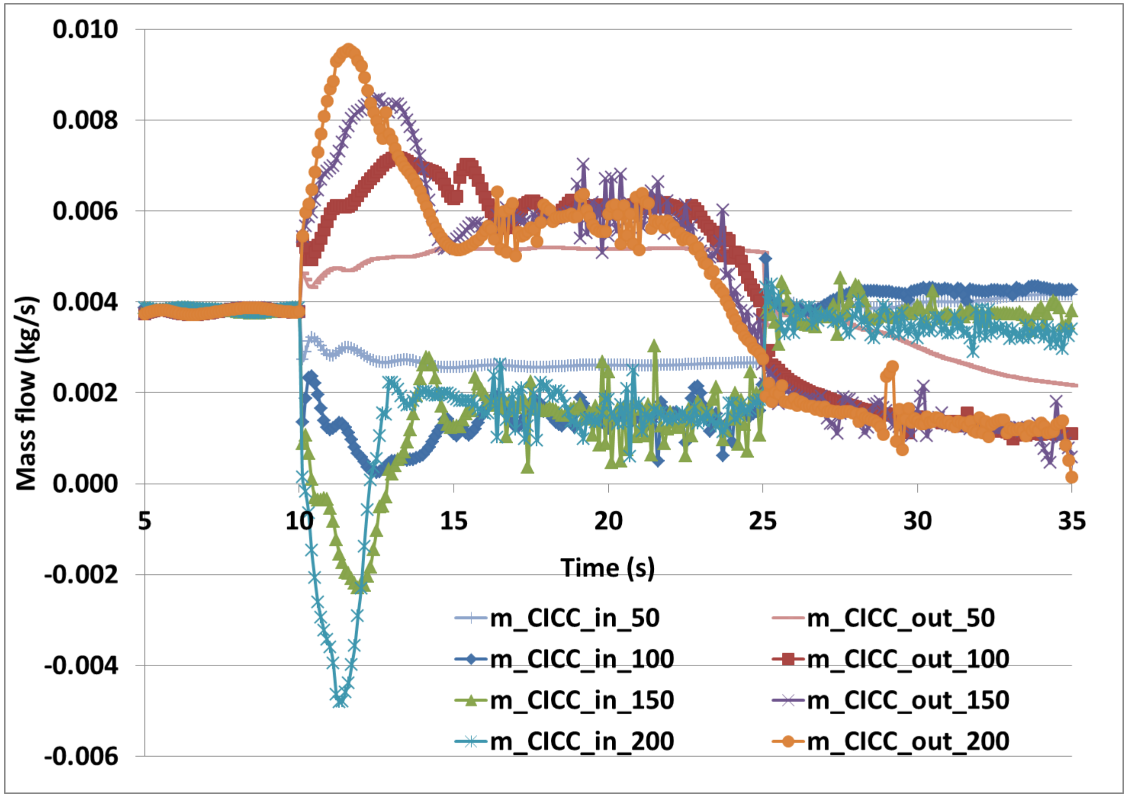
& Temperature Evolution < 20 K
T max near the middle of the heated zone

Bath of the heat exchanger
HX1 & HX2= Volume 18
→ Pressure < 1,04 bar
→ Temperature < 5,12 K
→ NO COOLING POWER IN THE CIRCUIT

At time 30, 35 and 40 s, the hot helium (smaller density, smaller mass flow) is still expulsed from the sample (at the outlet)

Whereas, HELIOS loop is gradually imposing He circulation at nominal conditions

6) EXPERIMENTS OF MASS FLOW EXPULSION
6.2) ON 10 M JT-60SA TF CICC



JT-60SA TF CICC

Pin = 0,55 MPa
Tin = 5K
min = 4 g/s
Power : 50, 100, 150 & 200 W/m
15 s (10 to 25 s) &
1 m (4 m < x < 5 m)

→ Reverse flow observed at inlet (min =-2 g/s for 150, & -4g/s for 200W/m)
Reduction for other cases

→ Acceleration of outlet mass flow (mout = +9.5 g/s for 200 and +5g/s for 50W)

→ The Idea is here also to compare measured (test conditions) with calculated values (codes)

→ It should bring confidence to the principle of the quench secondary detection (by helium mass expulsion) and provide elements of qualification for the measurement system.

7) CONCLUSION

→Importance of convective heat transfer coefficient for hot spot temperature (coupling TCO & TJA)
→different tests are envisaged on several samples in the HELIOS Test Facility at CEA Grenoble.

For Hconv, a counter Flow heat exchanger configuration experiment is foreseen.

- → Experiment principle validation should be performed on a smooth tube/ST sample.
- → Further experiments on central spiral (at high Re) could validate the usual correlations (Colburn Reynolds CR or Dittus Boelter DB correlation) for turbulent flows.
- → For intermediate and low Re, the laminar correlation for CICC bundle region could be determined with a rather good precision (Tout important difference)
- → Application to the efficiency of other cooling systems (cooling pipes of ITER TF Casing).

Concerning the secondary thermohydraulic quench detection principle (He expulsion)

- → Some validation should be also performed on a smooth tube sample (external heating).
- → Calculated helium expulsion mass flows (& P& T) determined by SuperMagnet codes (tests conditions like in HELIOS test Facility).
- → A good agreement with measurements should bring confidence in repeatability of such phenomenon and information importance of these signals, as they may reach the range of interest for secondary detection (several g/s difference).
- → For ITER Coils CICC →permits to confirm feasibility and criteria of such a quench detection (especially for smooth quench, with small deposited energy & reduced mass flow variations).
- → This detection being “safety class” for the ITER TF system, elements of validation should be profitable before commissioning of such systems.

Thank you for your attention

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