PREDICTIVE FUNCTIONAL CONTROL

J.Richalet   Oulu 2013

WHO INVENTED

PREDICTIVE CONTROL ?

ERGONOMY OF FLIGHT CONTROL

- In the fifties :
- How the pilot manages his aircraft ?
- What operating image ?
- Comparison between:
- Human control and Automatic control :

SURPRISE ! ….

Jean Piaget (1896 / 1980)

- Swiss Grand Father of Cognitive Psychology
- How the child learns and controls his environment

.   Four phases ….!

4 PIAGET BASIC PRINCIPLES

– OPERATING IMAGE

–INTERNAL MODEL

– TARGET – Sub TARGET

-REFERENCE TRAJECTORY

– ACTION

-STRUCTURATION OF THE MV

– COMPARISON BETWEEN

PREDICTED AND ACHIEVED RESULT

-ERROR COMPENSATION

• *NATURAL CONTROL : “ YOU DO NOT DRIVE YOUR CAR WITH A PID SCHEME”*

PREDICTIVE CONTROL

IS NOT

AN INVENTION

BUT A DISCOVERY ….!

ELEMENTARY TUTORIAL EXAMPLE

$$P = \frac{G\,e^{-\theta s}}{1+Ts} = M = \frac{y}{u}$$

θ = Tsamp . r

Trajectory expo. : λ

1 coincidence point: H

1 Base function: step

y(n) = α y(n-1) + (1- α) . u(n-1-r) . G $\quad \alpha = e^{\frac{-Tsamp}{T}}$

Processus with delay $y_{Pr}(n) = y_P(n) + y_M(n) - y_M(n-r)$

Target : $\Delta_P(n+H) = (C - y_{Pr})(1 - \lambda^H)$

Model :

Free mode $y_M(n)\,\alpha^H$

Forced mode $u(n)\,.\,GM\left(1 - \alpha^H\right)$

(Liebniz 1674)

Model increment :

Increment = Free(n+h) + Forced(n+h)- ymodel(n)

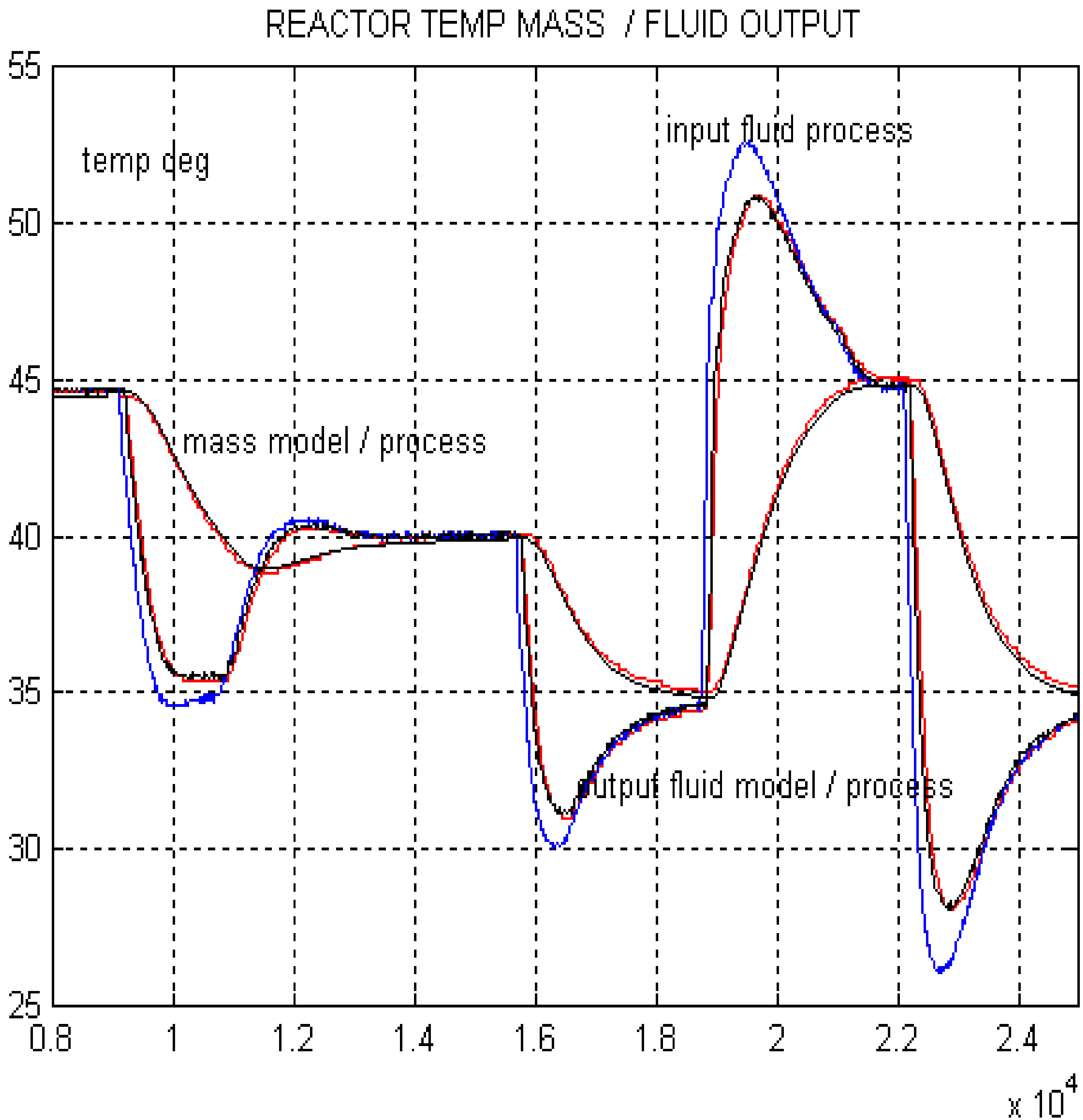
Control equation :

The only mathematical problem for trainees …!

$$\Delta P(n+H) = \Delta M(n+H)$$

$$(C - y_{Pr}(n))\;(1 - \lambda^H) = y_M(n)\;\alpha^H + u(n)\,GM(1 - \alpha^H) - y_M(n)$$

$$u(n) = \frac{(C - y_{Pr}(n))\;(1 - \lambda^H)}{GM(1 - \alpha^H)} + \frac{y_M(n)}{GM}$$



BAYER reactor

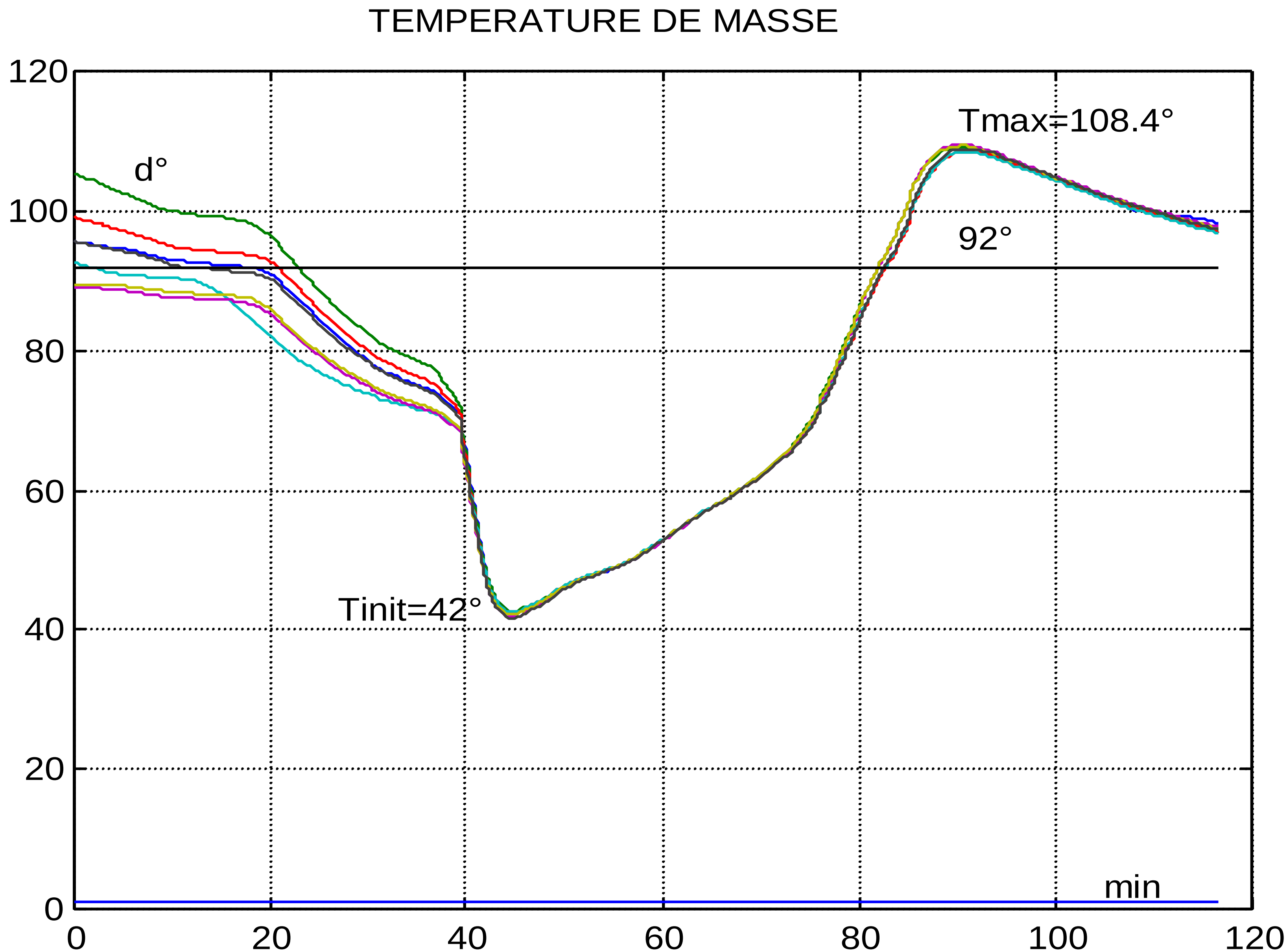
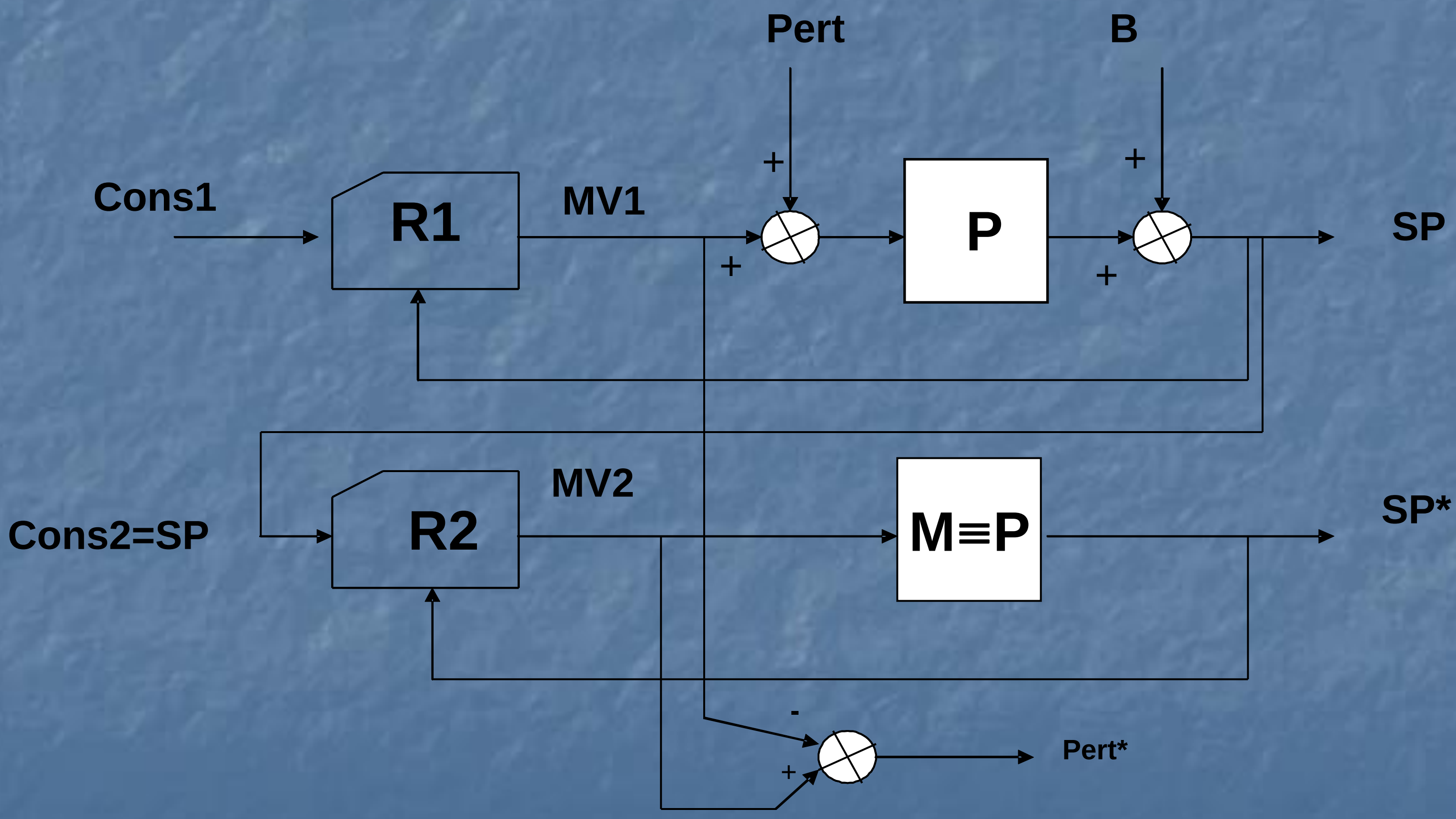

TEMPERATURE DE MASSE
120
100
80
60
40
20
0
0
20
40
60
80
100
120
Tmax=108.4°
d°
92°
Tinit=42°
min

Figure 4

ON LINE ESTIMATOR of DISTURBANCES



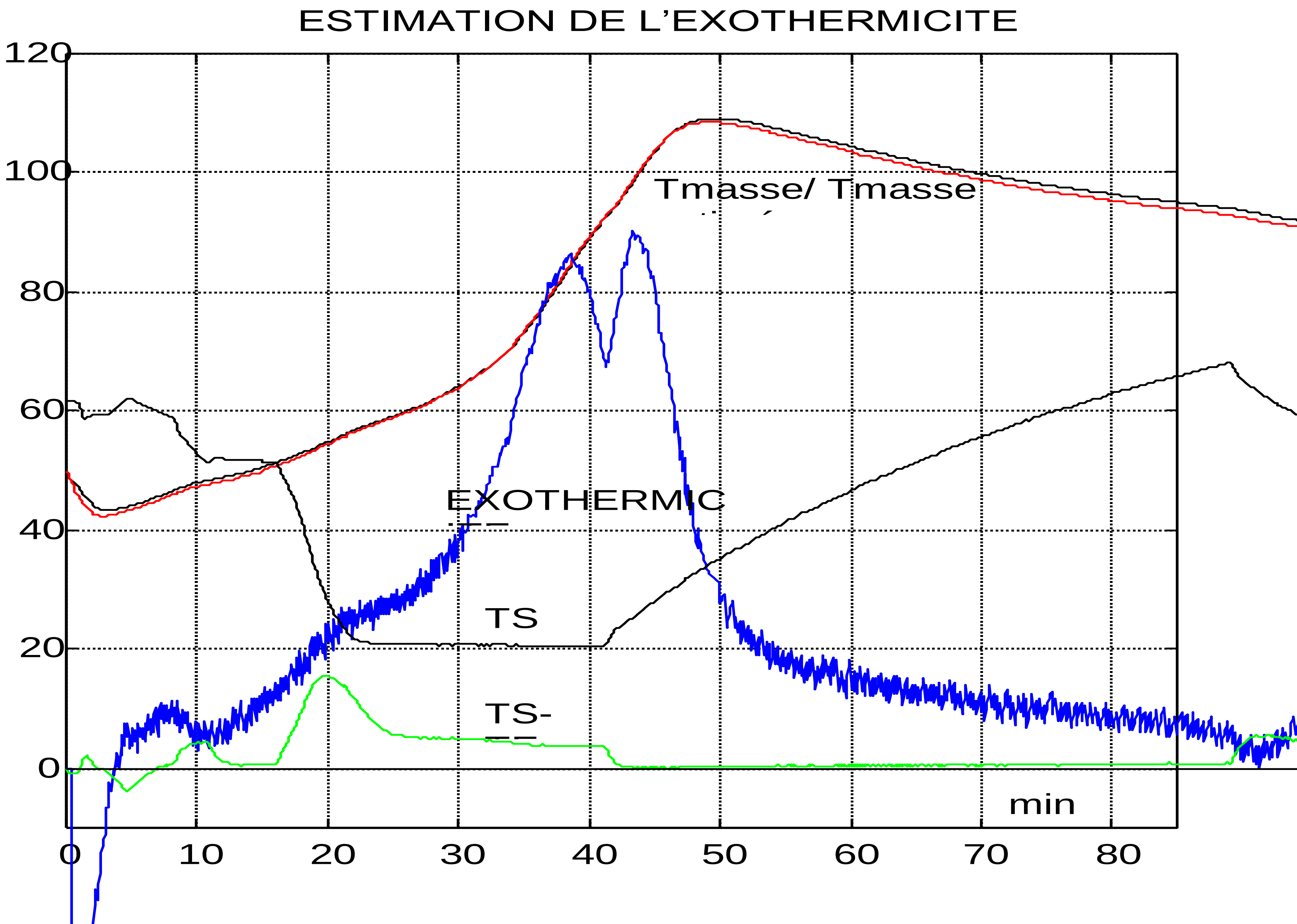
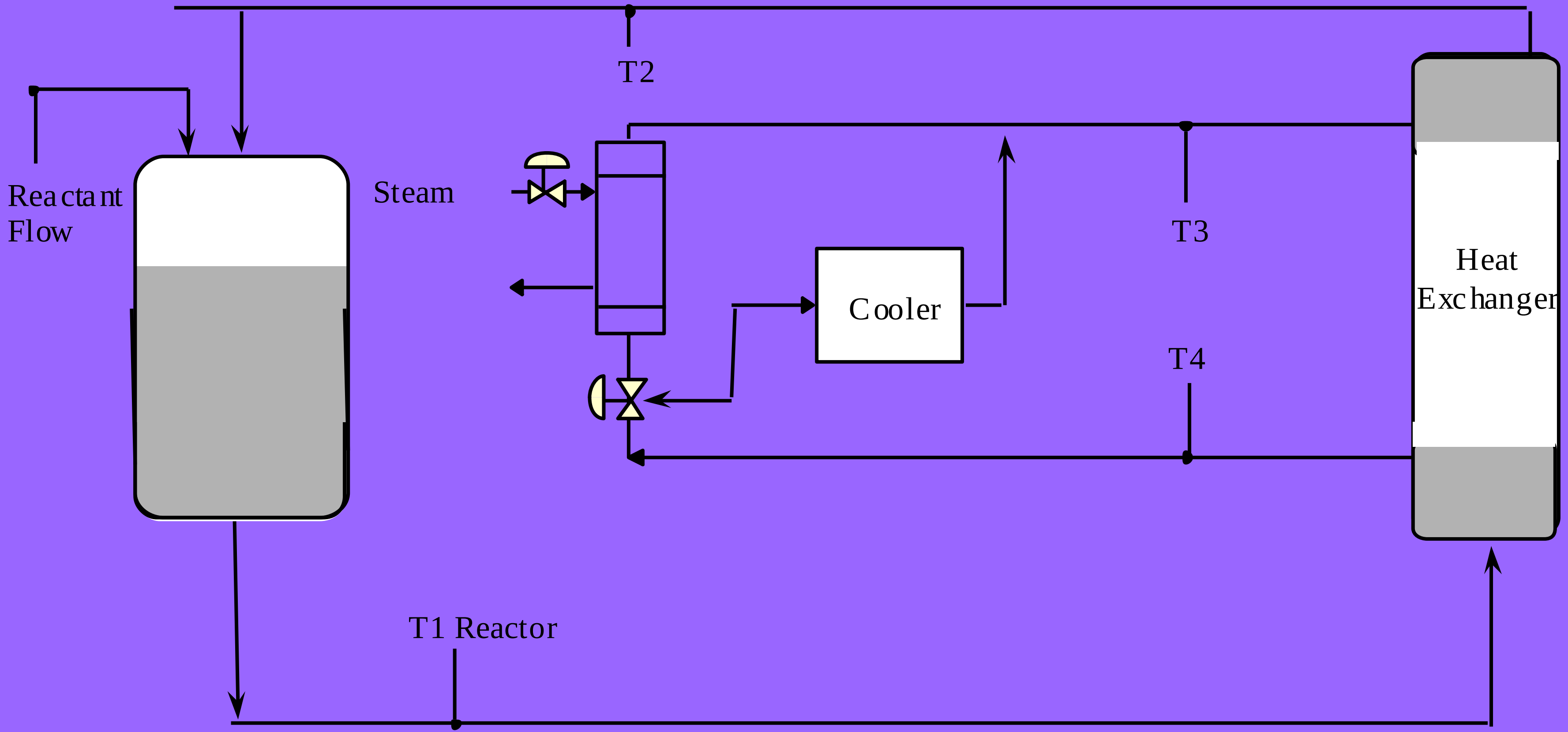
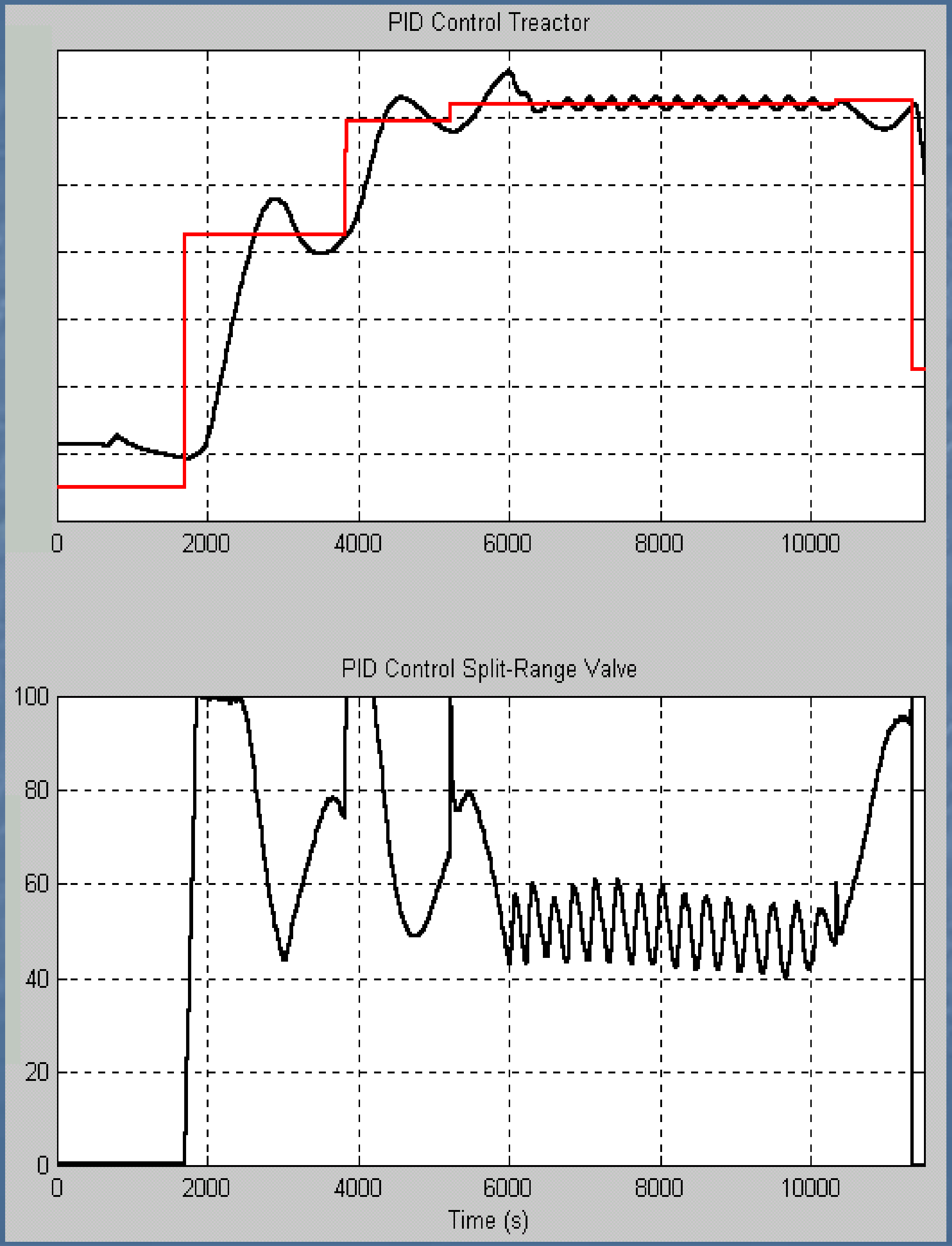

ESTIMATION DE L'EXOTHERMICITE
120
100
80
60
40
20
0
Tmasse/ Tmasse
EXOTHERMIC
TS
TS-
min
0
10
20
30
40
50
60
70
80

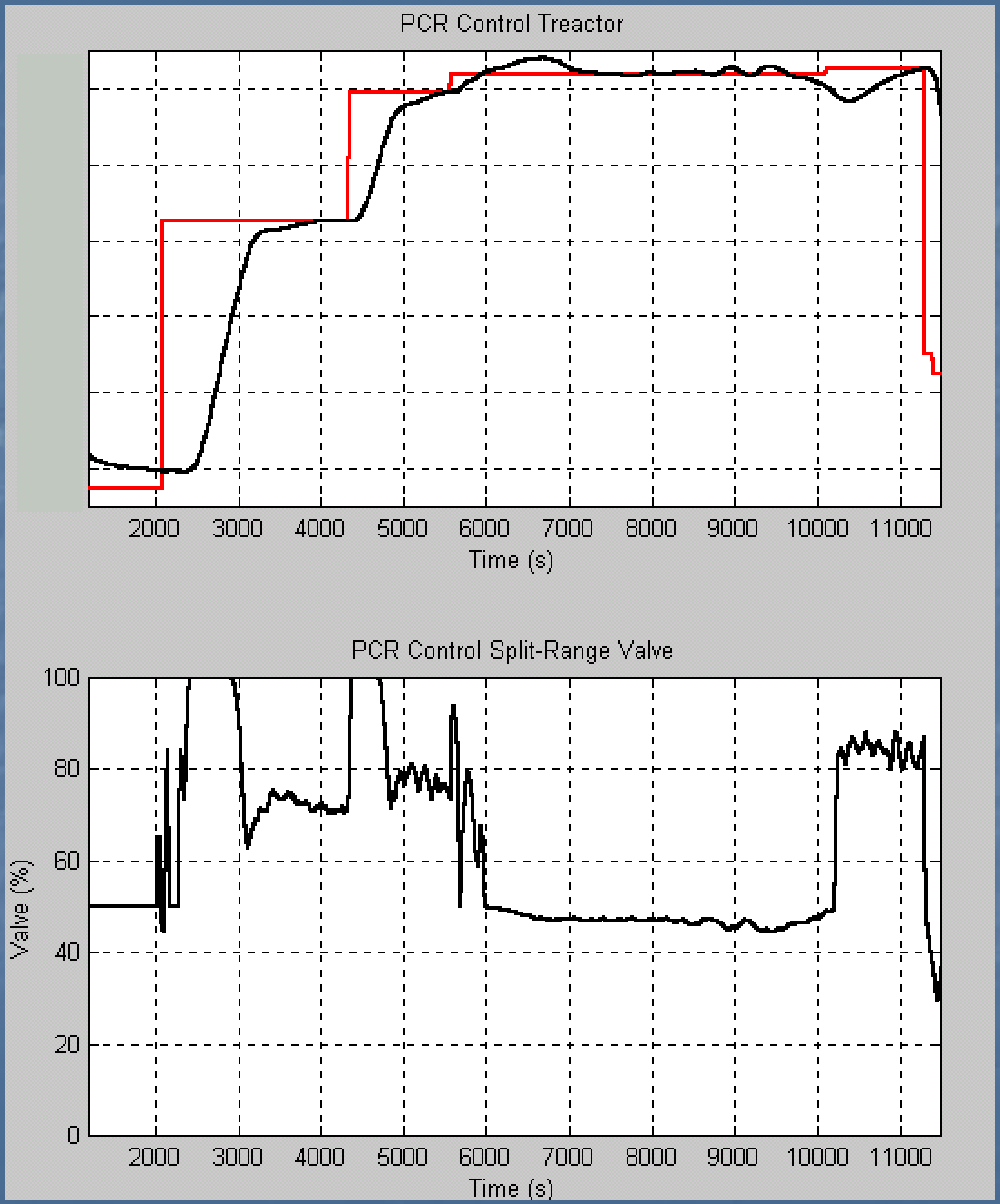
Figure 3



T2
Reactant Flow
Steam
T3
Heat Exchanger
Cooler
T4
T1 Reactor

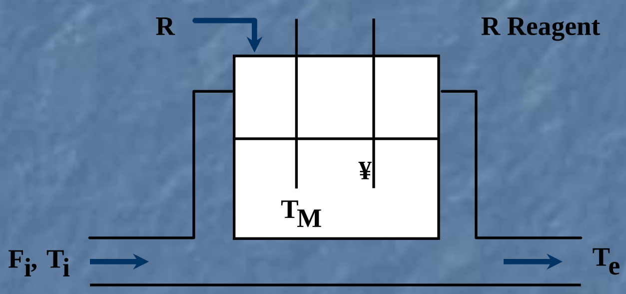
BASF


PID Control Treactor
0
2000
4000
6000
8000
10000
PID Control Split-Range Valve
100
80
60
40
20
0
0
2000
4000
6000
8000
10000
Time (s)



PCR Control Treactor
2000 3000 4000 5000 6000 7000 8000 9000 10000 11000
Time (s)
PCR Control Split-Range Valve
100 80 60 40 20 0
Valve (%)
2000 3000 4000 5000 6000 7000 8000 9000 10000 11000
Time (s)

4 CONTROL STRATEGIES OF BATCH REACTORS



$$\rho_M.Cp_M.V_M.\frac{dT_M}{dt} = U.A.(T_e - T_M) + \Delta Hx$$

$$\rho_e.Cp_e.V_e.\frac{dT_e}{dt} = \rho_e.F_i(T_i - T_e) + U.A.(T_M - T_e)$$

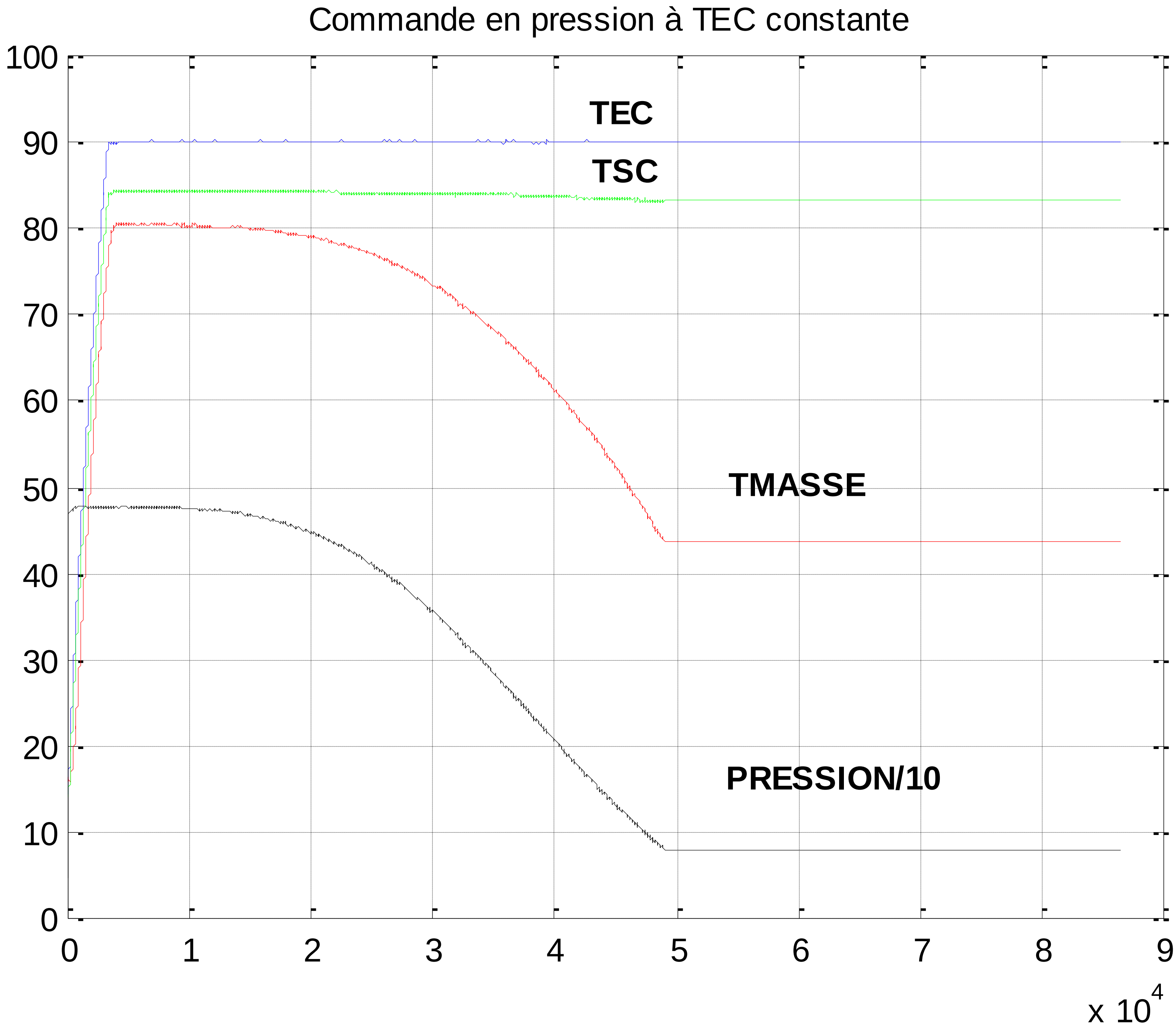
$$\rightarrow \quad q(F_i)\,\dot{T}_M + T_M = T_i$$

1) Fi =ct / MV= Ti CV=TM / level 0 =Ti ? :PFC

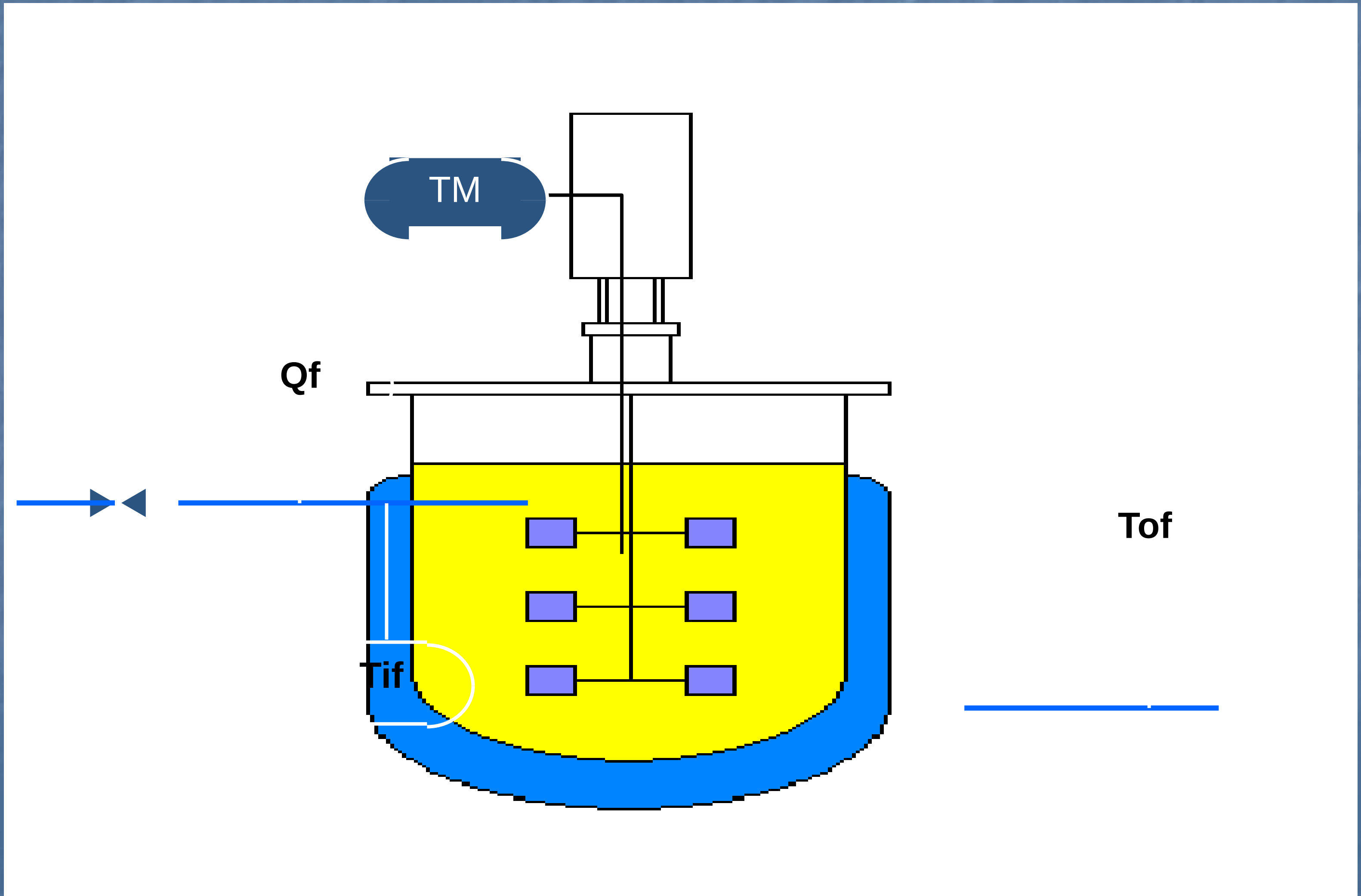
2) Ti =ct (!) MV=Fi Parametric Control non linear :PPC

3) MV : Ti and Fi : Enthaplic control (power) :PPC+

4) MV : Pressure of reactor :PFC

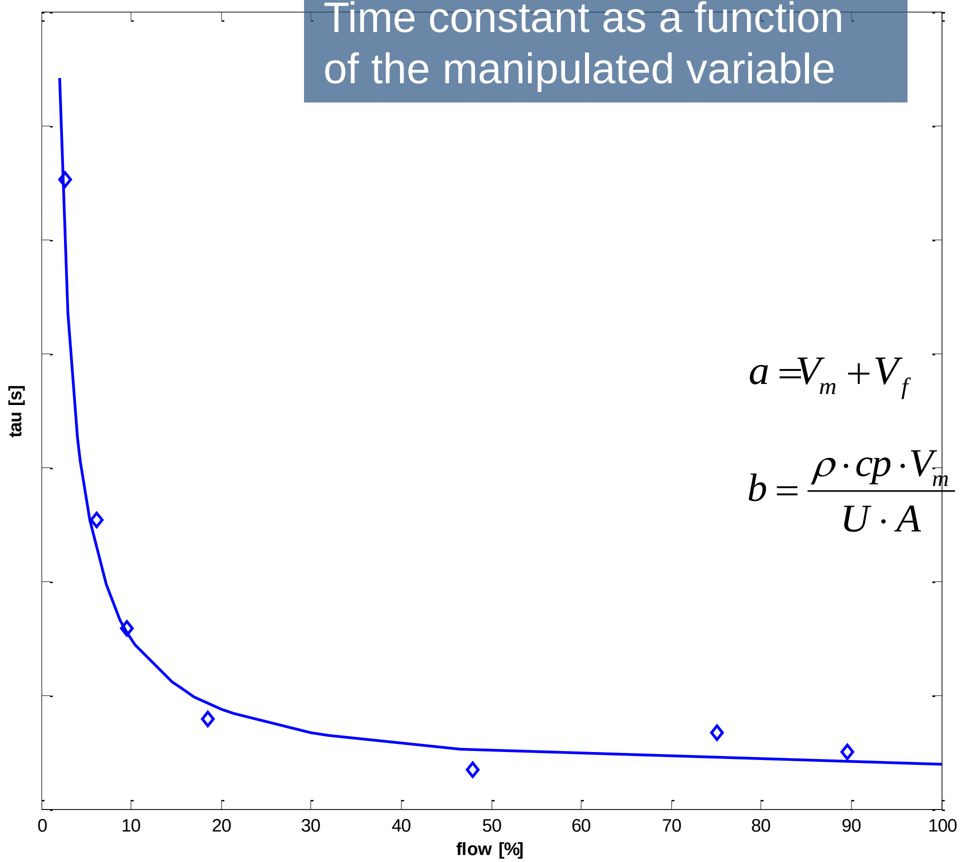

Commande en pression à TEC constante
TEC
TSC
TMASSE
PRESSION/10
100
90
80
70
60
50
40
30
20
10
0
0
1
2
3
4
5
6
7
8
9
x 10^4

Batch Reactor : MV=Qf / CV= TM DEGUSSA EVONIK



Identification of characteristics

Time constant as a function of the manipulated variable



$$a = V_m + V_f$$

$$b = \frac{\rho \cdot cp \cdot V_m}{U \cdot A}$$

Q_f: flow

V_m: mass volume

V_f: jacket volume

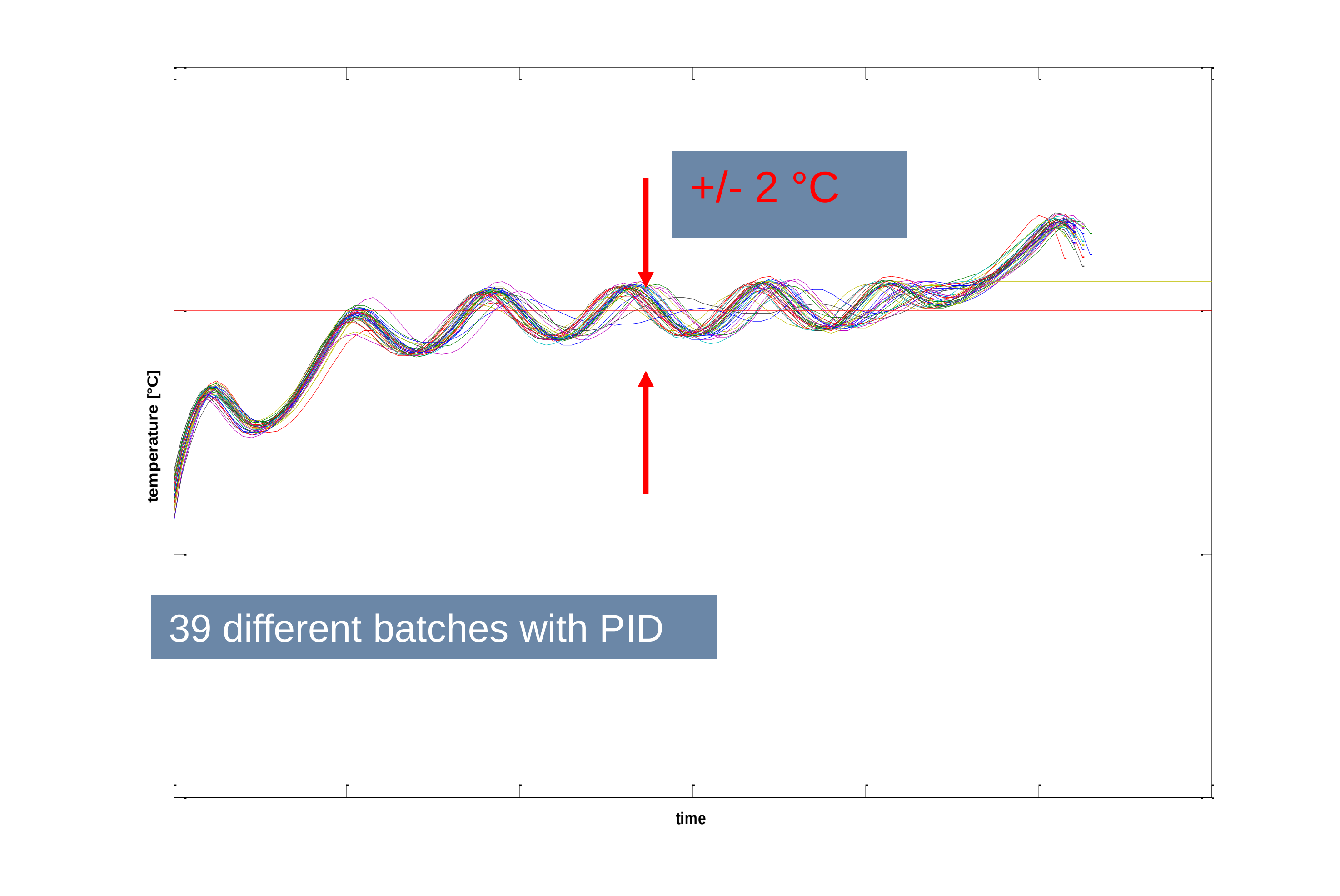
r: density

cp: heat capacity

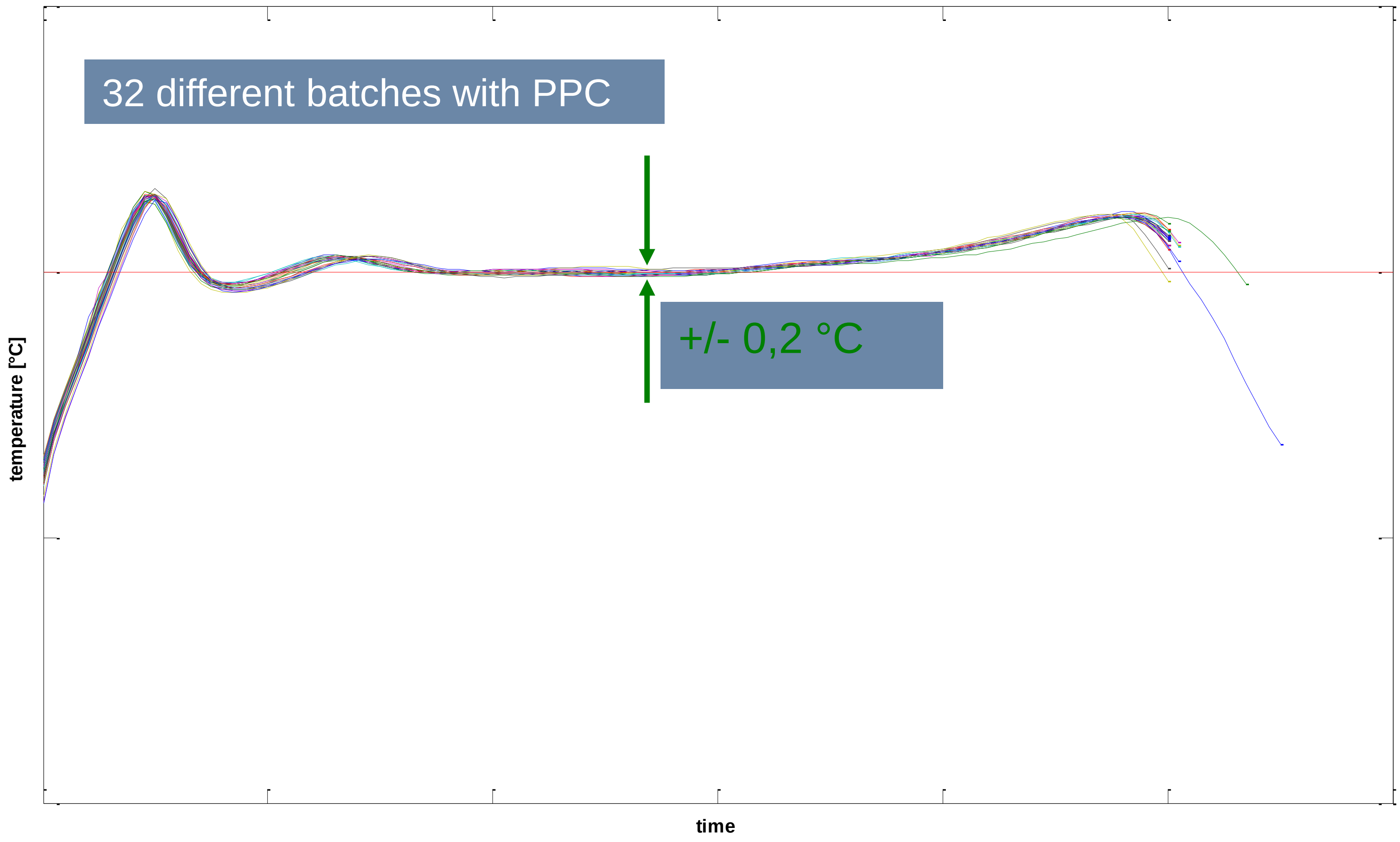
U: constant

A: heat transfer surface

Control PID   Degussa / EVONIK



Control PFC Degussa / EVONIK



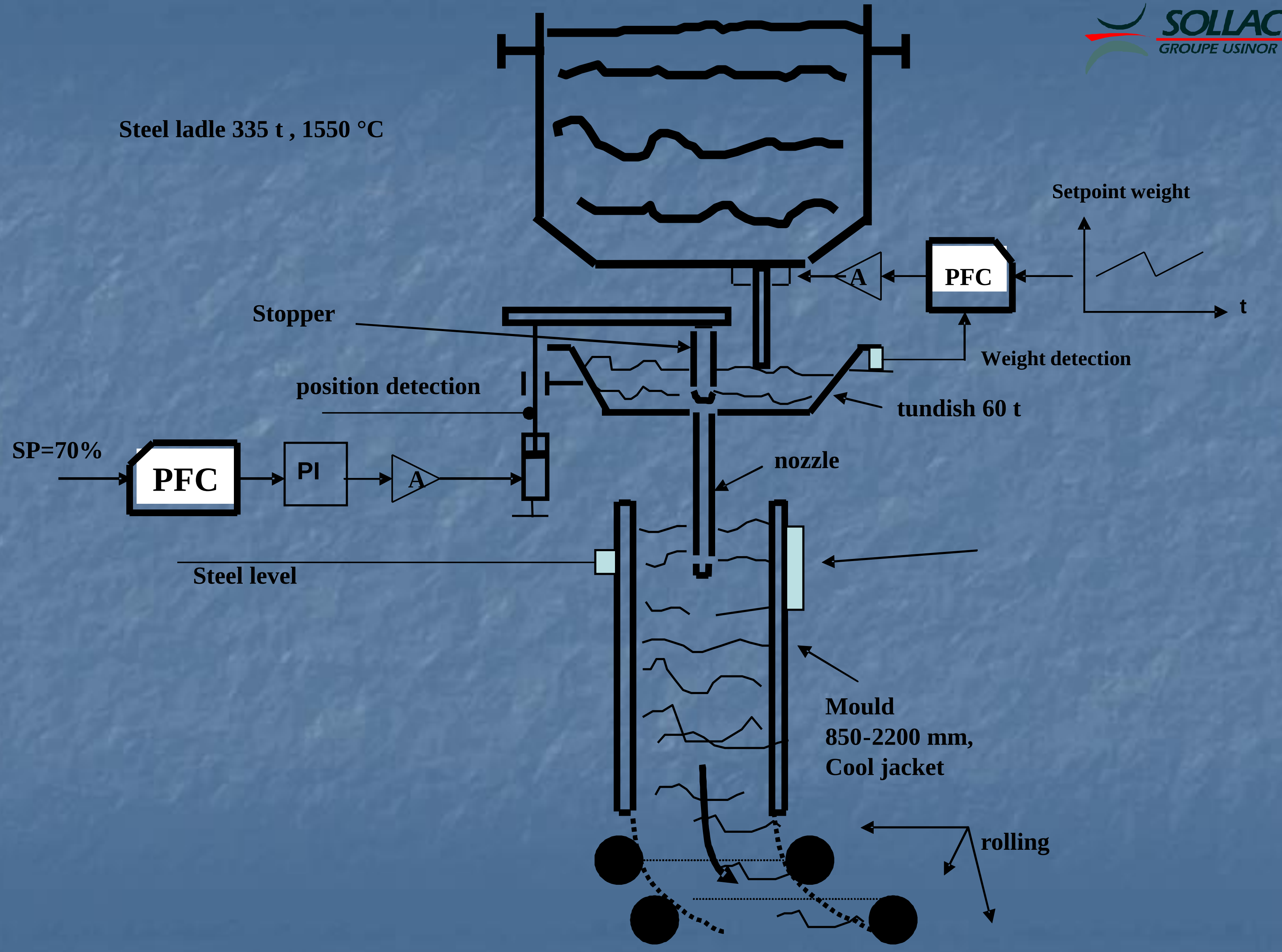
ArcelorMittal

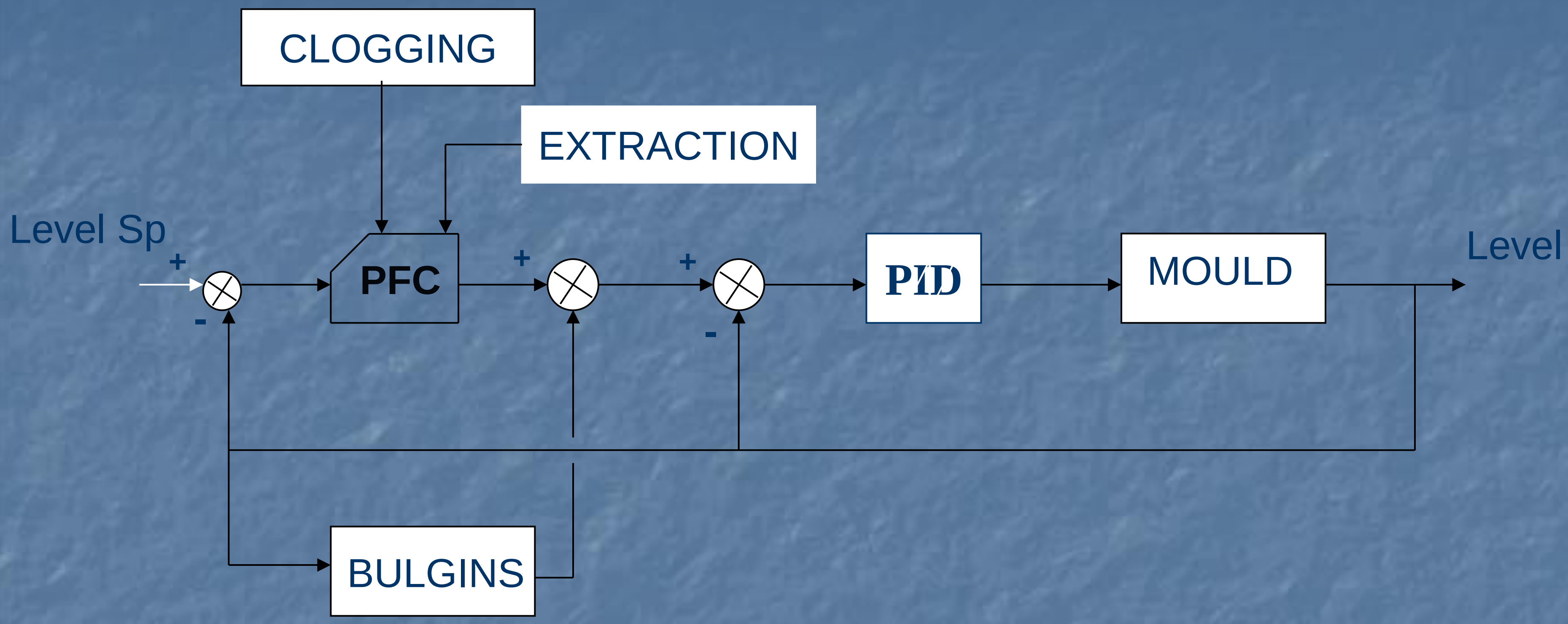
Régulation de Niveau d'Acier en Lingotière sur Machine de Coulée Continue :

Aciérie de Dunkerque

22/06/2012

CONTINUOUS CASTING


SOLLAC
GROUPE USINOR
Steel ladle 335 t , 1550 °C
Setpoint weight
A
PFC
t
Stopper
Weight detection
position detection
tundish 60 t
SP=70%
PFC
PI
A
nozzle
Steel level
Mould
850-2200 mm,
Cool jacket
rolling



TRANSPARENT CONTROL
3 MODULES

IDENTIFICATION

- **Ultra-low level test signals ! ! ….**

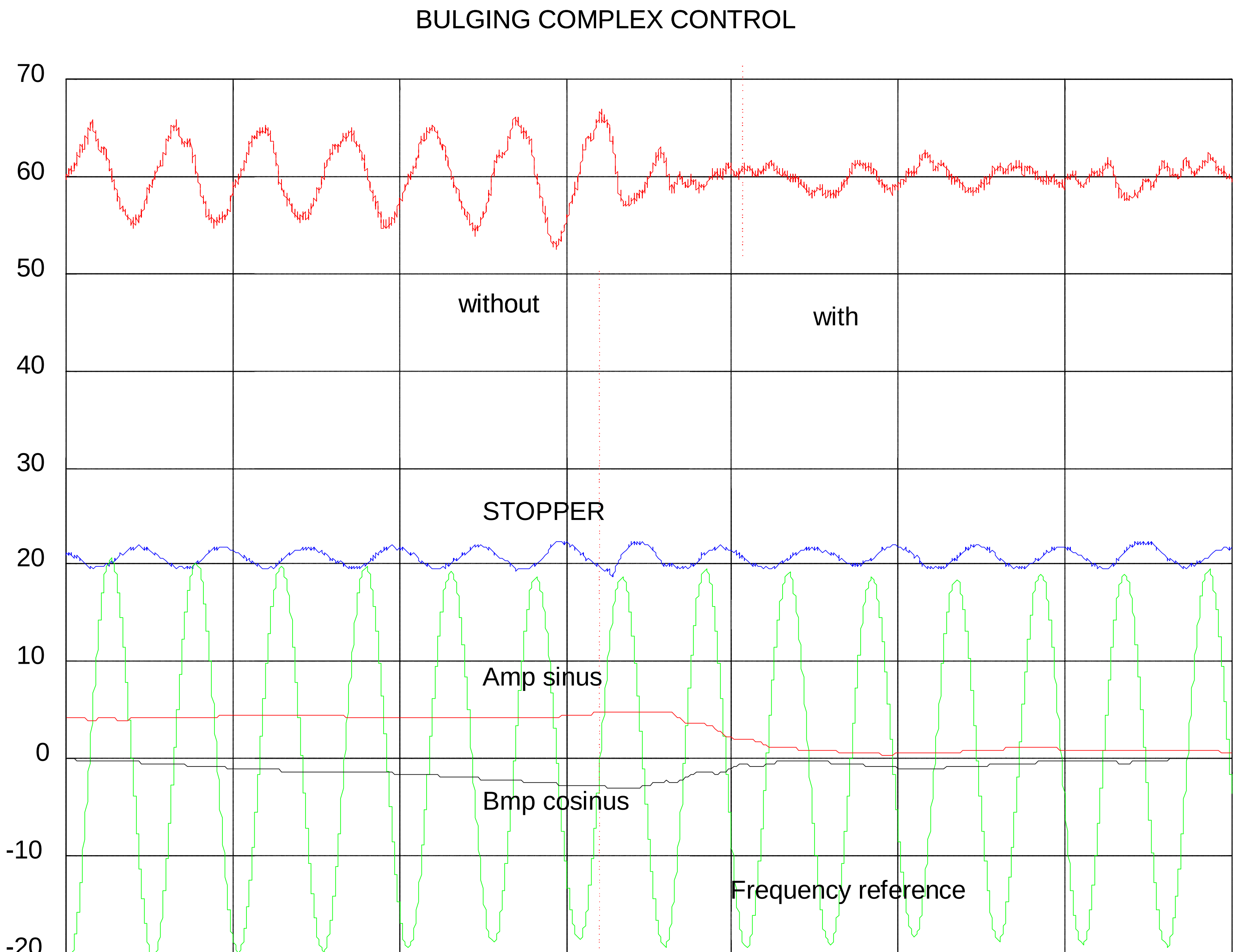
« I do want to see your test signal on the level ..!«

- **Set of harmonics signals**
  Eigen function

- **High level Parallel filtering**

.- **Different metal alloys**

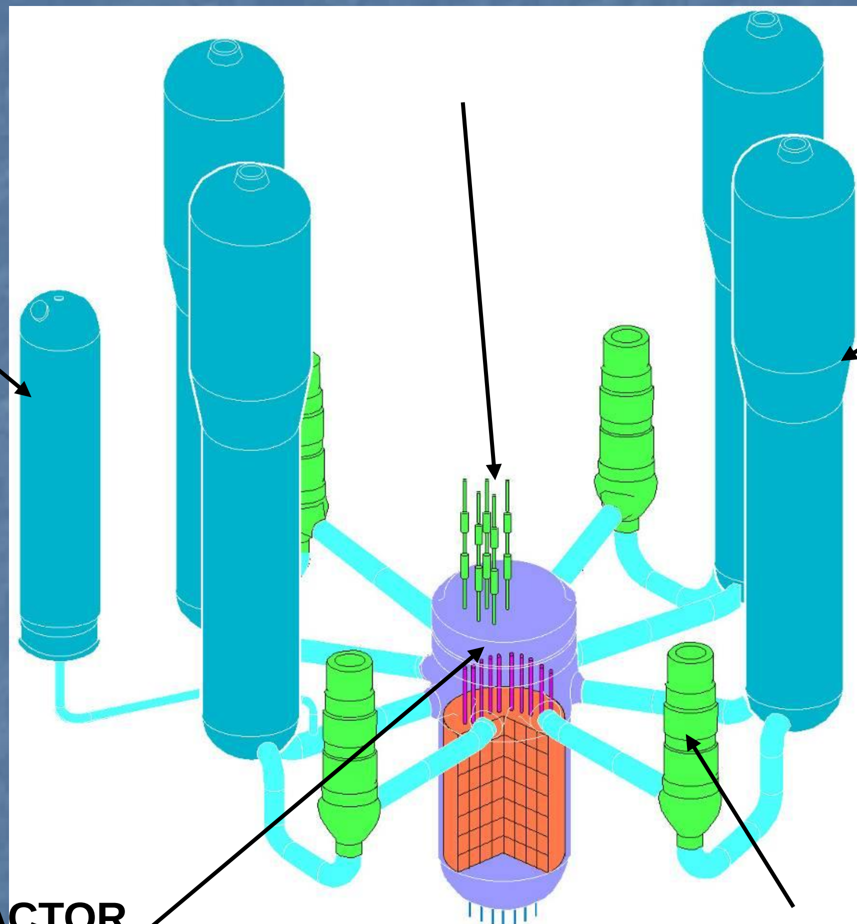
COMPLEX ALGEBRA PREDICTIVE CONTROL ?!



Bench test of pump gaskets

- Flow : **35000 m3/h** ….! ?
- Pressure : 17.50 MPa
- Temperature : 330 d°

CONTROL ENVIRONMENT



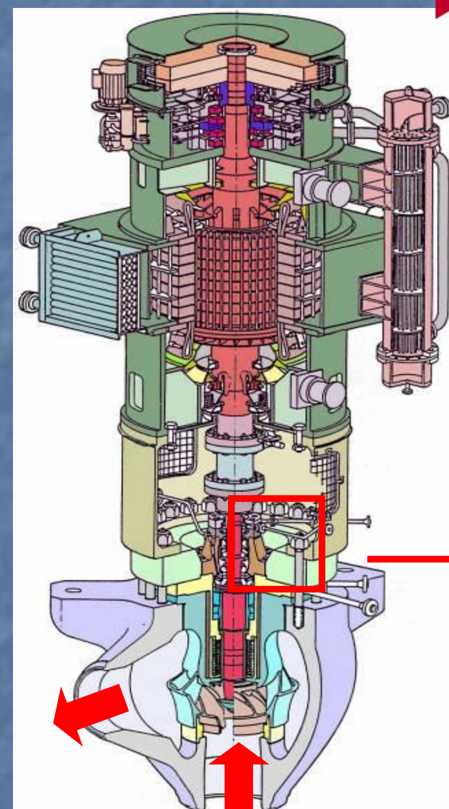
PFC controller

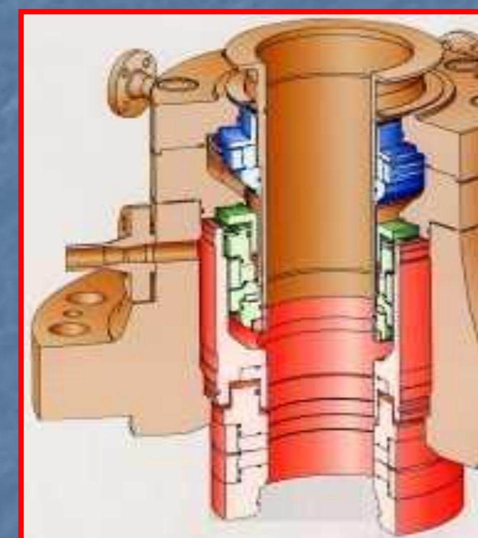
:

- **Size : 10 m**
- **Mass : 100 tons**
- **Flow: ~35000 m3/h**

Engine

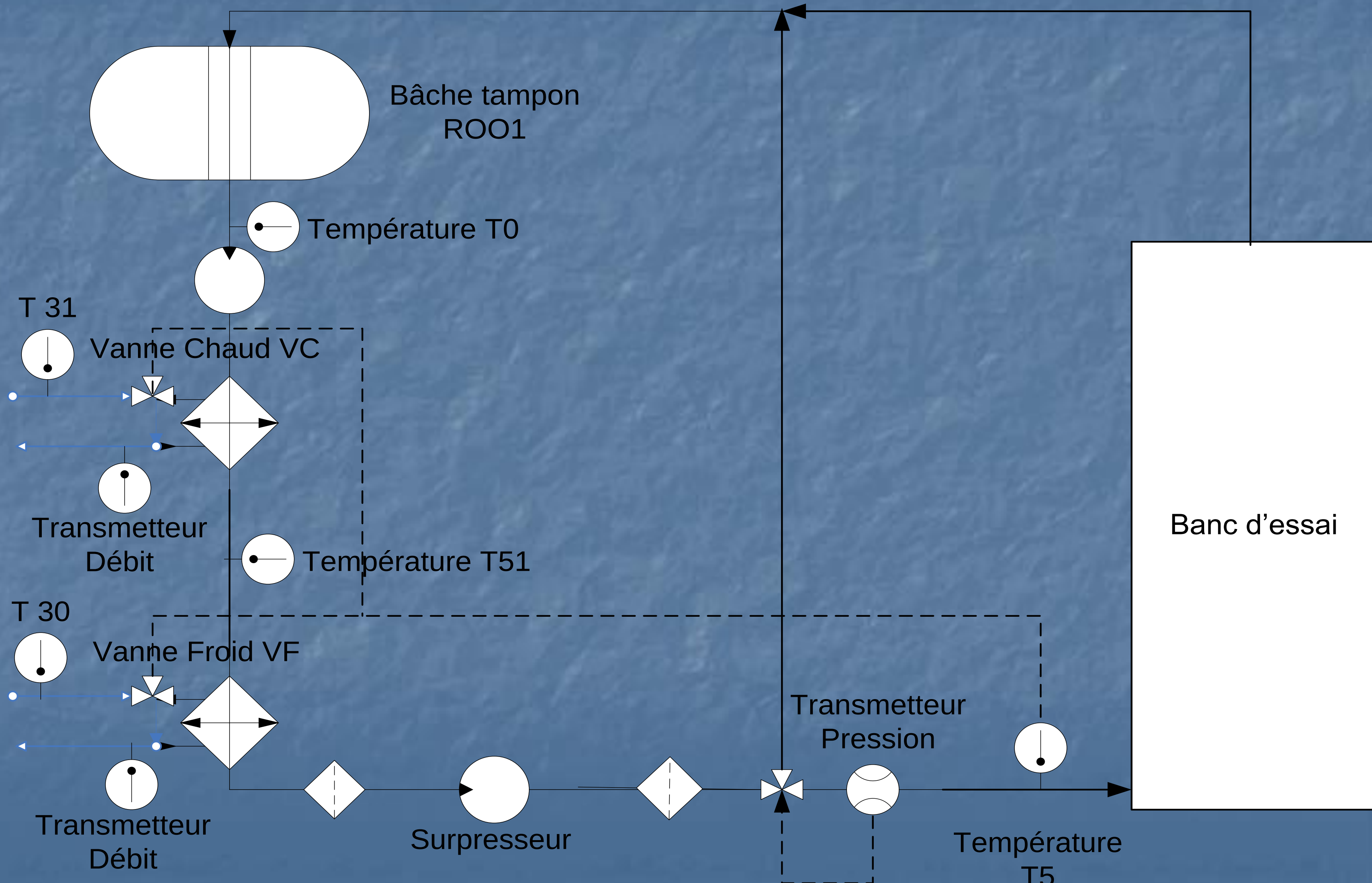
Pump

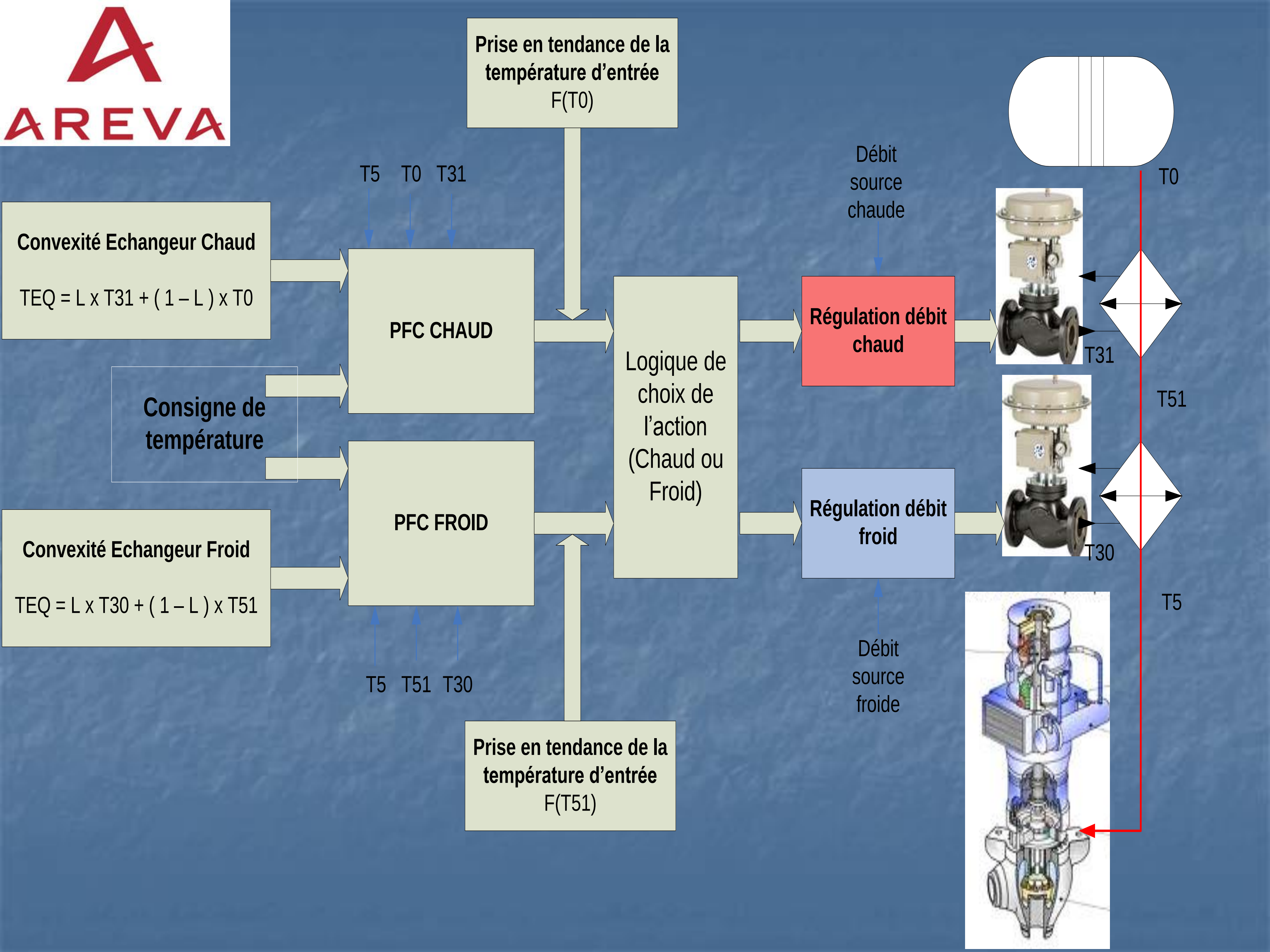




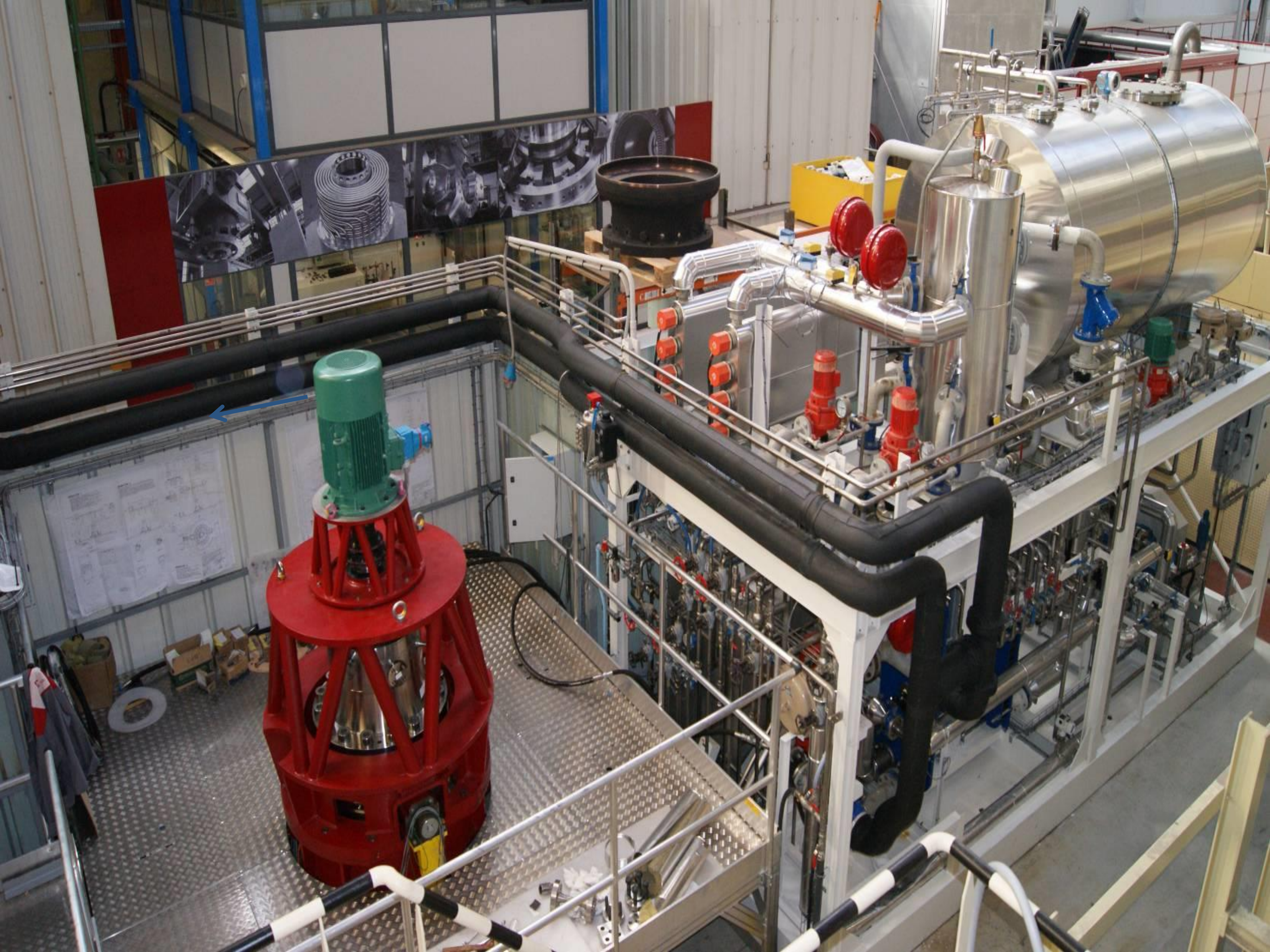
Support

PFC control joints

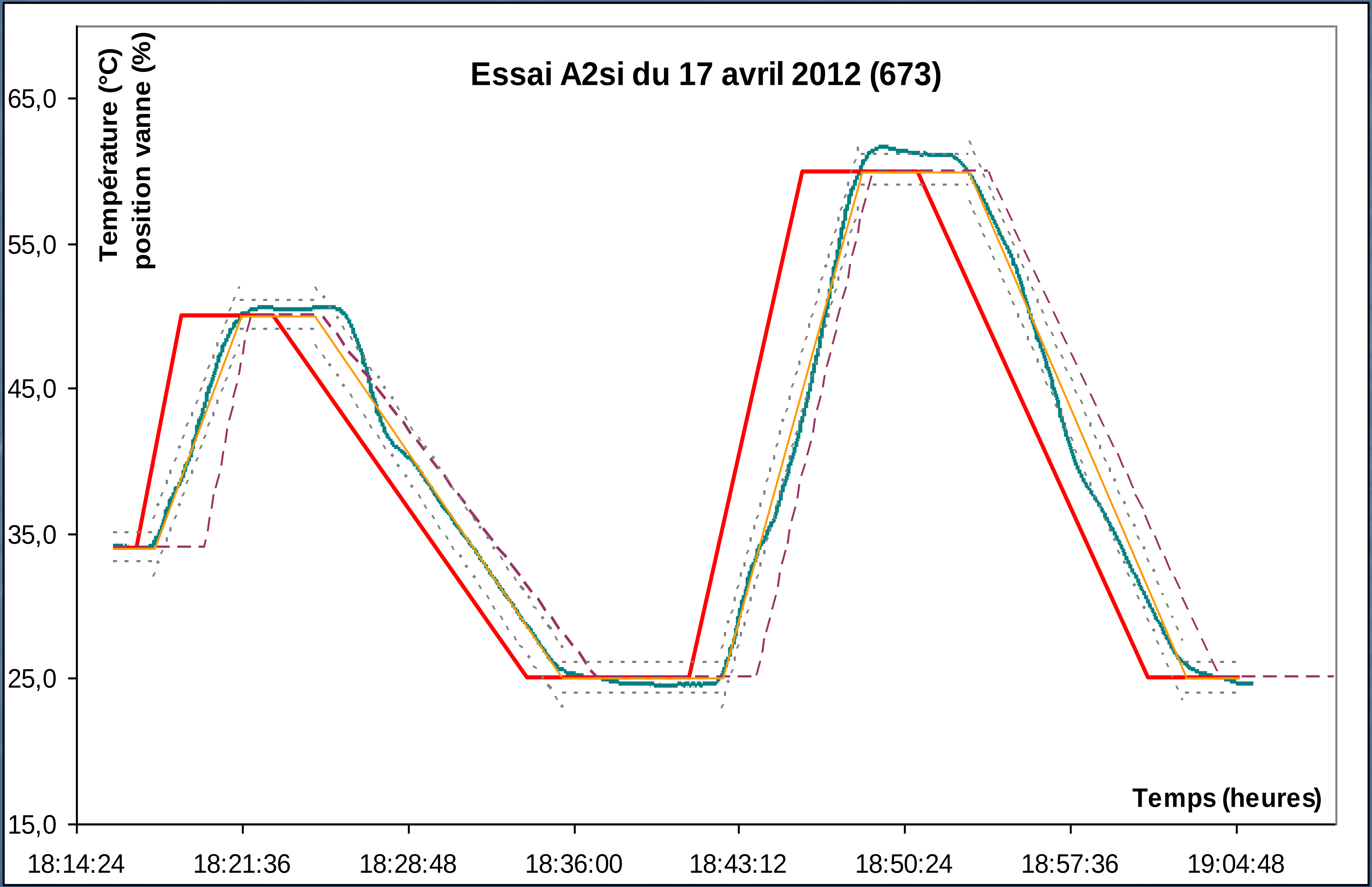

Bâche tampon
ROO1
Température T0
T 31
Vanne Chaud VC
Transmetteur
Débit
Température T51
T 30
Vanne Froid VF
Transmetteur
Débit
Surpresseur
Transmetteur
Pression
Température
T5
Banc d'essai



AREVA
Prise en tendance de la température d'entrée F(T0)
Convexité Echangeur Chaud
TEQ = L x T31 + (1 – L) x T0
T5 T0 T31
PFC CHAUD
Consigne de température
PFC FROID
Convexité Echangeur Froid
TEQ = L x T30 + (1 – L) x T51
T5 T51 T30
Prise en tendance de la température d'entrée F(T51)
Logique de choix de l'action (Chaud ou Froid)
Débit source chaude
Régulation débit chaud
Régulation débit froid
Débit source froide
T0
T31
T51
T30
T5

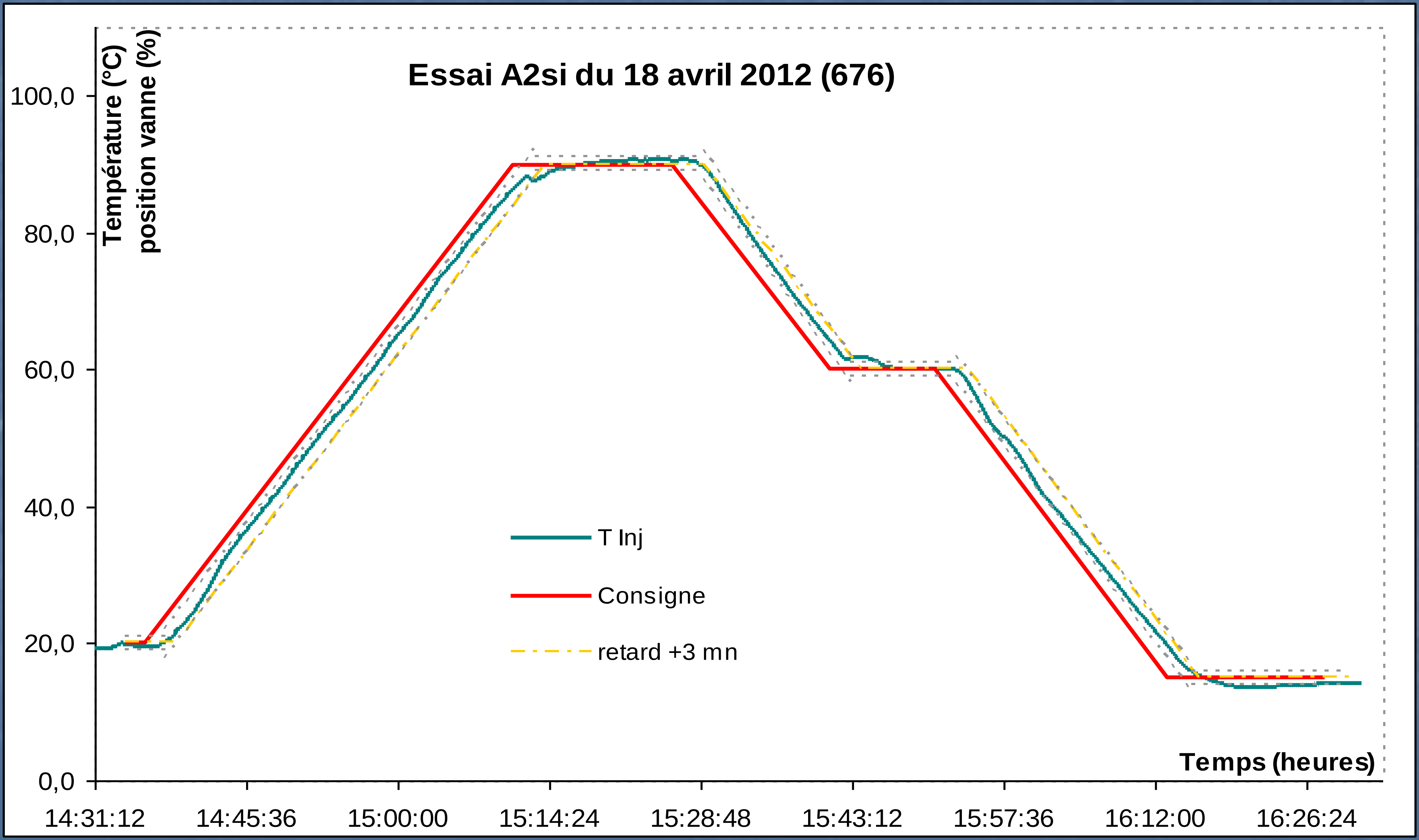


PID



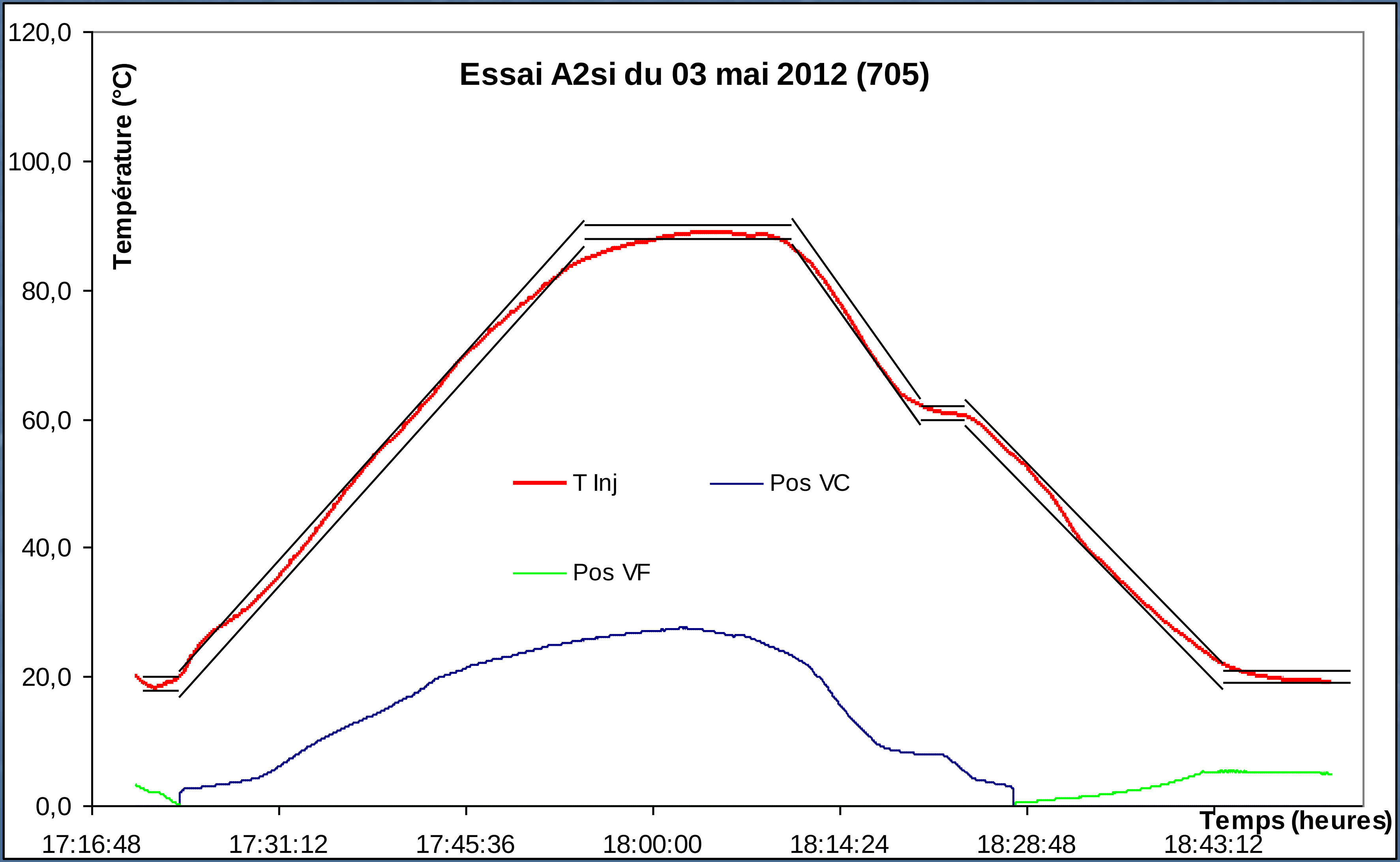
Essai A2si du 17 avril 2012 (673)
Température (°C)
position vanne (%)
65,0
55,0
45,0
35,0
25,0
15,0
Temps (heures)
18:14:24
18:21:36
18:28:48
18:36:00
18:43:12
18:50:24
18:57:36
19:04:48

PFC



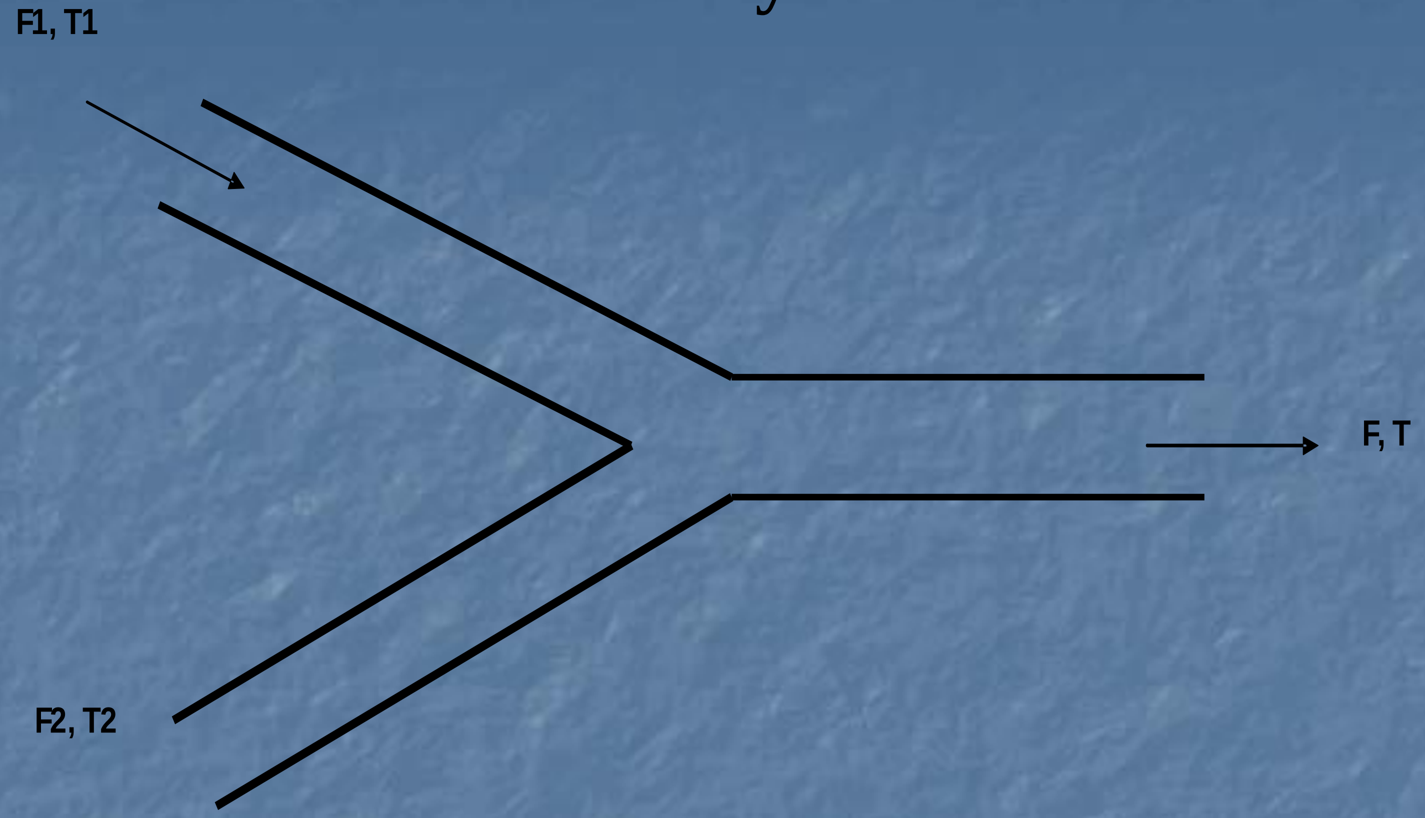
Essai A2si du 18 avril 2012 (676)
Température (°C)
position vanne (%)
100,0
80,0
60,0
40,0
20,0
0,0
T Inj
Consigne
retard +3 mn
Temps (heures)
14:31:12
14:45:36
15:00:00
15:14:24
15:28:48
15:43:12
15:57:36
16:12:00
16:26:24

PFC



Essai A2si du 03 mai 2012 (705)
Température (°C)
120,0
100,0
80,0
60,0
40,0
20,0
0,0
T Inj
Pos VC
Pos VF
Temps (heures)
17:16:48
17:31:12
17:45:36
18:00:00
18:14:24
18:28:48
18:43:12

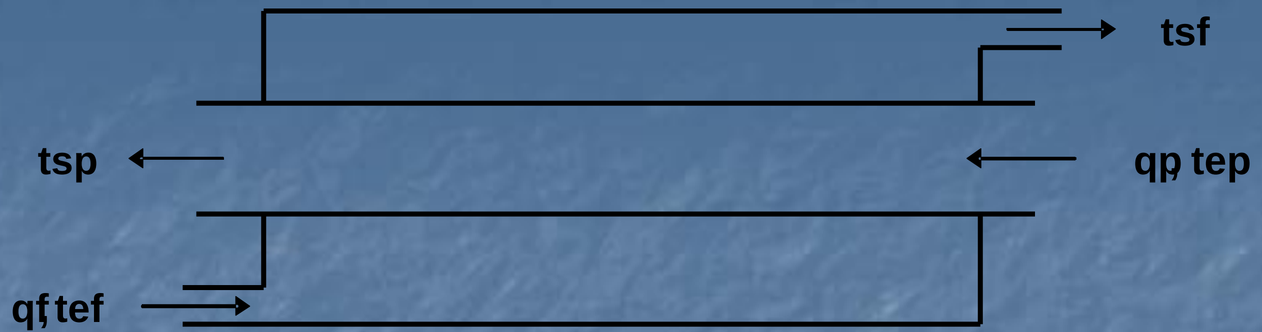
Convexity Theorem



F.T =F1.T1+F2.T2 (enthalpic balance)

T=λ.T1 +(1- λ).T2 with $0 \leq \lambda \leq 1$

Hyperbolic function ! λ = F1/(F1+F2)



$$\Gamma(\mathbf{Qf}) = \frac{1 - \exp[-\mathbf{U.A}(\frac{1}{\mathbf{Fp}} - \frac{1}{\mathbf{Ff}})]}{1 - \frac{\mathbf{Fp}}{\mathbf{Ff}}\exp[-\mathbf{U.A}(\frac{1}{\mathbf{Fp}} - \frac{1}{\mathbf{Ff}})]}$$

Fp, Ff : Thermal flows

$Fp = (\rho.Cp)_p.Qp$ $\quad$ $Ff = (\rho.Cp)_f.Qf$.

SANOFI

VERTOLAY

VITRY sur SEINE

ARAMON

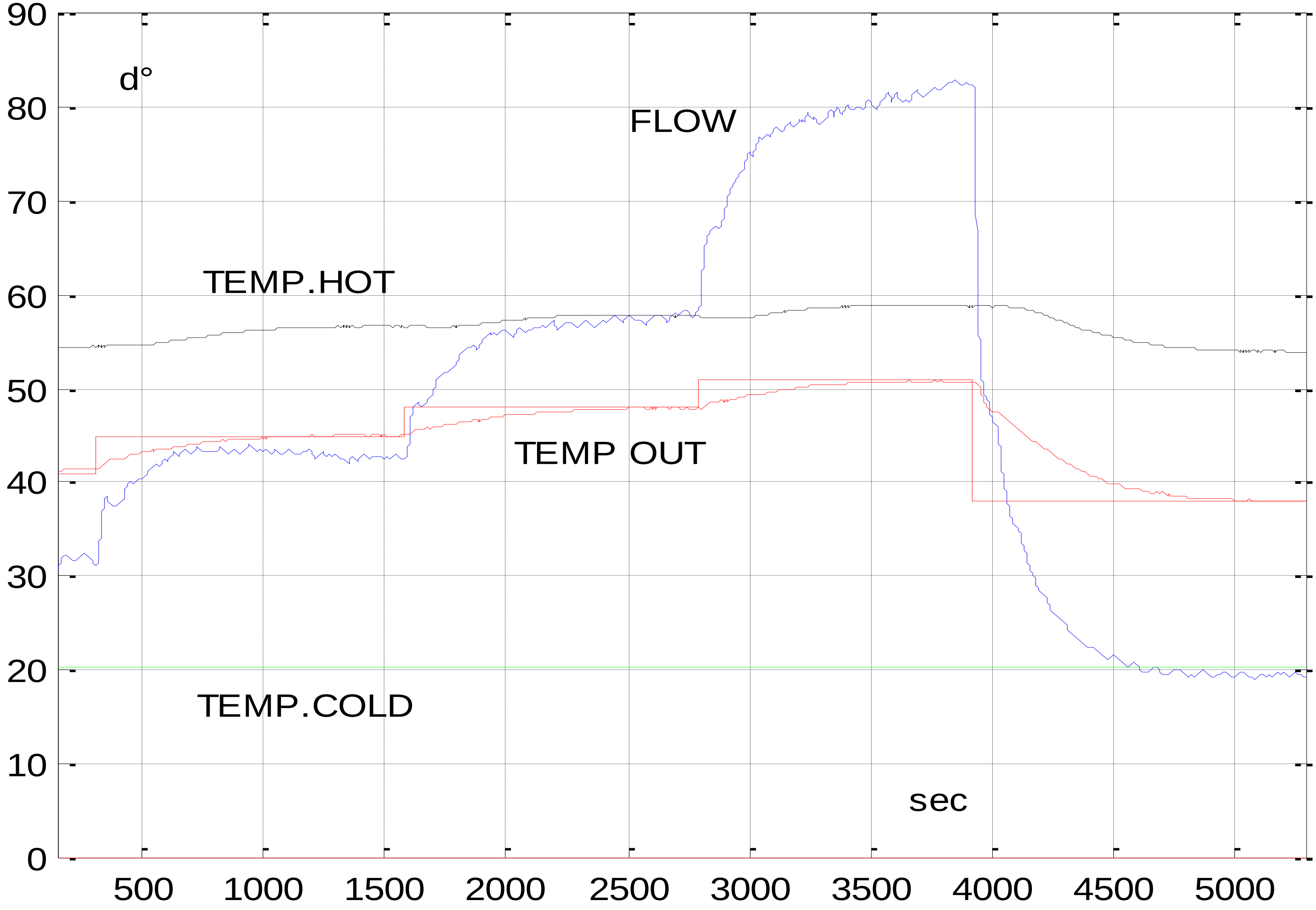
MONTPELLIER

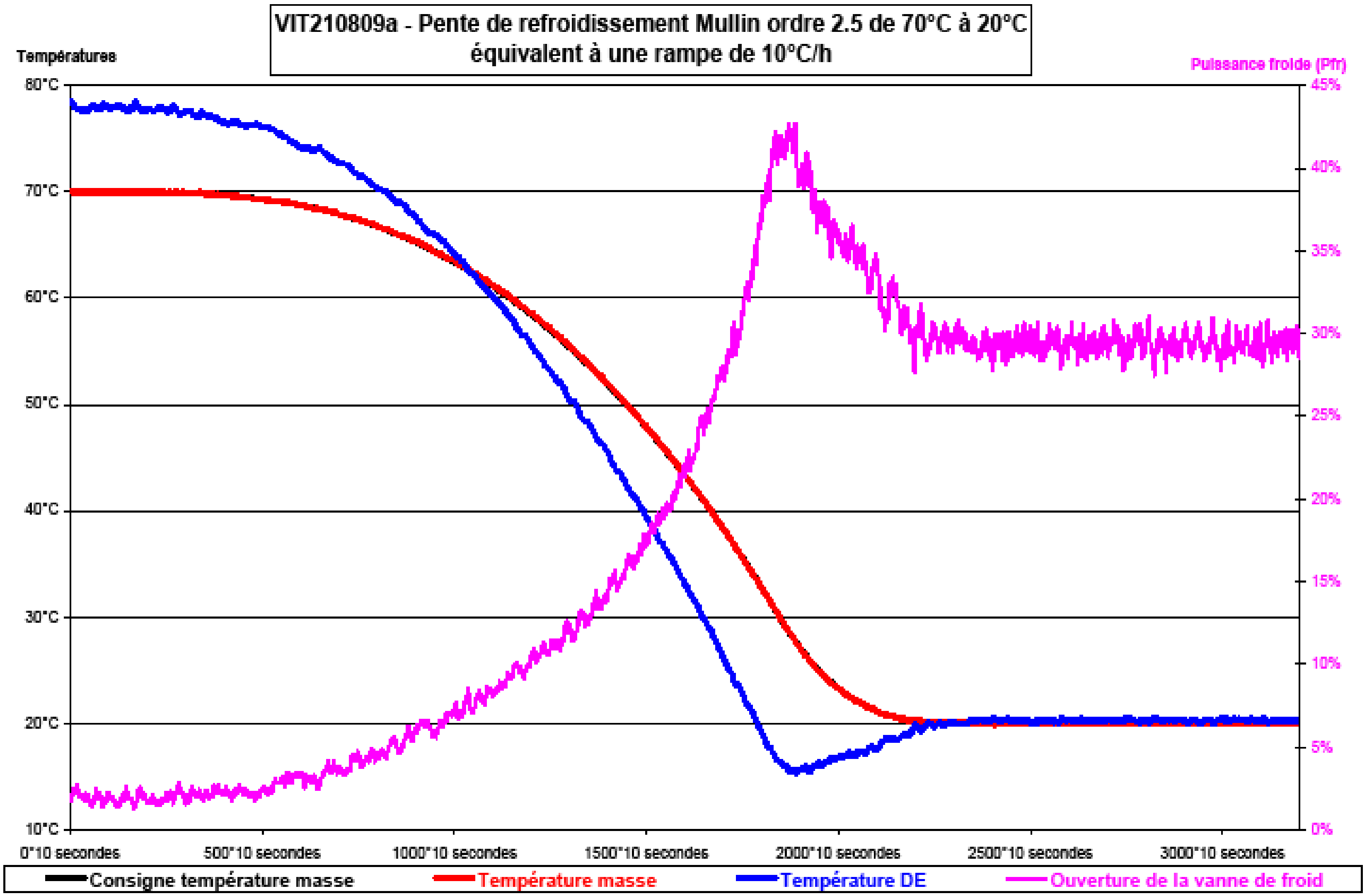
KÖLN

ELBEUF

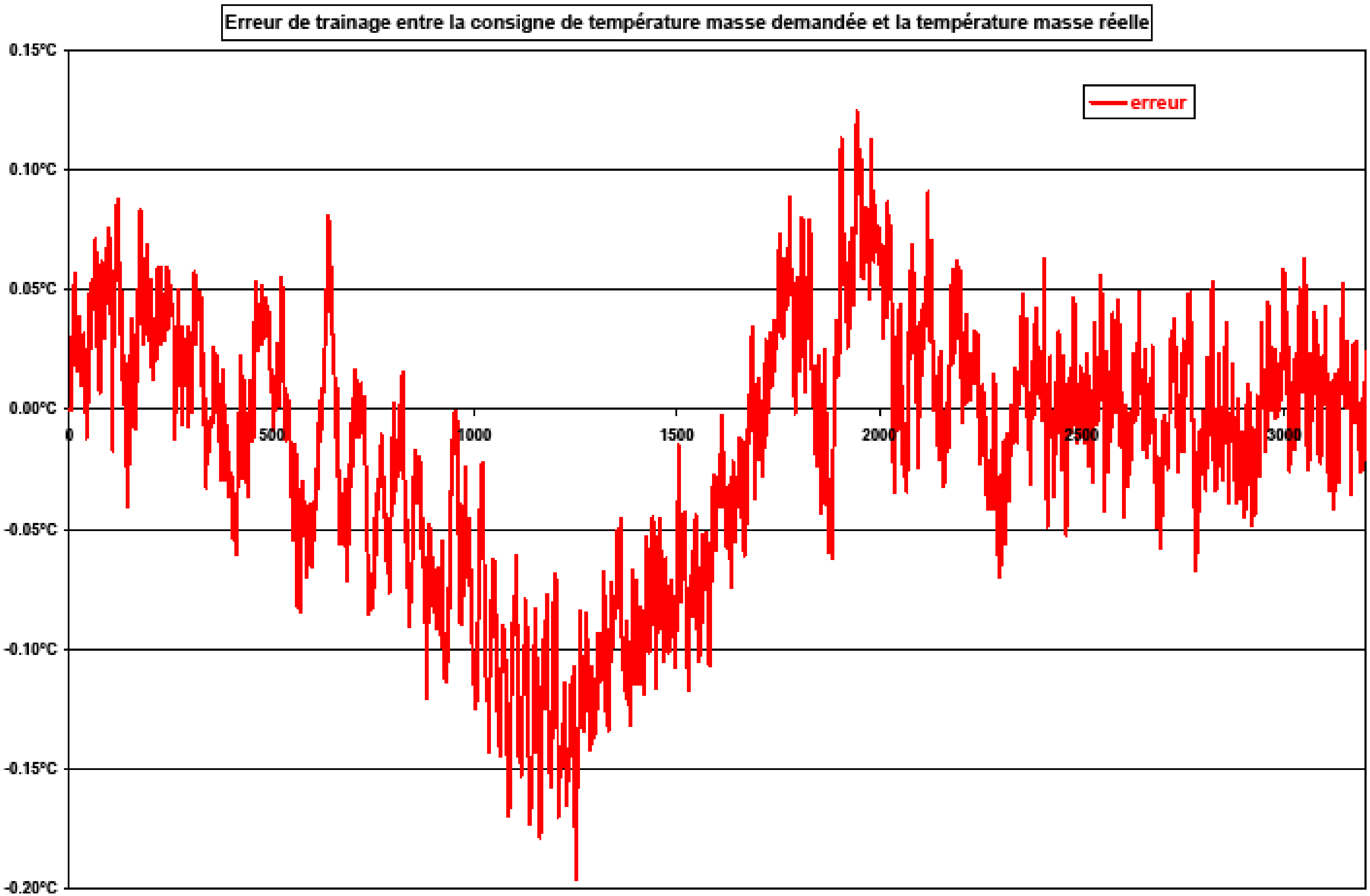
Training of staff: Transfer of Know How

CONVEXITY of HEAT EXCHANGER
Non linear behavior





VIT210809a - Pente de refroidissement Mullin ordre 2.5 de 70°C à 20°C
équivalent à une rampe de 10°C/h
Températures
Puissance froide (Pfr)
80°C
70°C
60°C
50°C
40°C
30°C
20°C
10°C
45%
40%
35%
30%
25%
20%
15%
10%
5%
0%
0*10 secondes
500*10 secondes
1000*10 secondes
1500*10 secondes
2000*10 secondes
2500*10 secondes
3000*10 secondes
Consigne température masse
Température masse
Température DE
Ouverture de la vanne de froid


Erreur de trainage entre la consigne de température masse demandée et la température masse réelle
erreur
0.15°C
0.10°C
0.05°C
0.00°C
-0.05°C
-0.10°C
-0.15°C
-0.20°C
0
500
1000
1500
2000
2500
3000

Conclusion

- Dissemination ? : where is the problem?:
- The technical and economic efficiency of PFC is clearly demonstrated on many different processes
- **TEACHING PFC**:
- Continuous education of :
- Teachers of technical schools
- Industrial operators
- Implementation of PFC in all new PLC's is to be continued