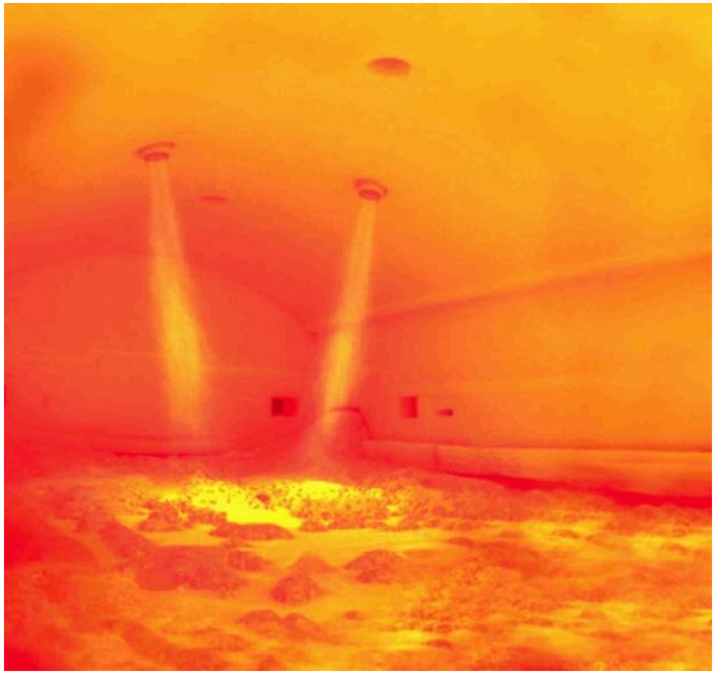
glass melting process => 80% of total energy

=> 50% of total cost



The Comparison of Energy Consumption between the Soda-lime Glass and Borosilicate Glass Furnace

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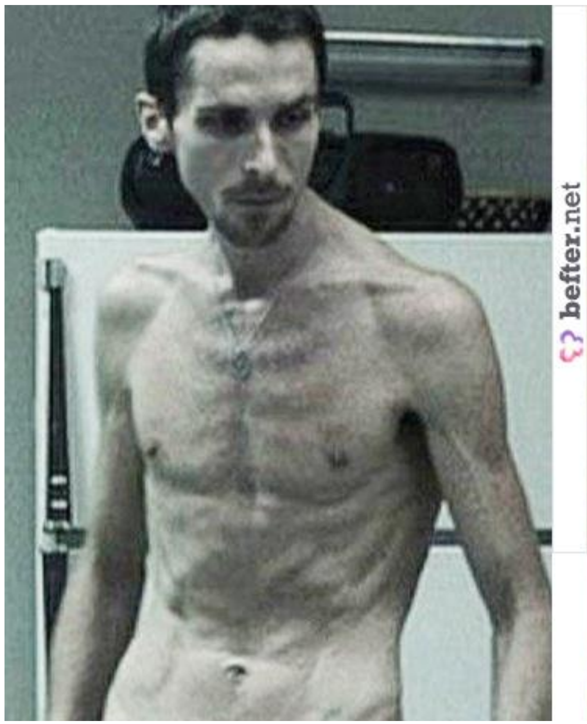
ศูนย์เชี่ยวชาญด้านแก้ว
Thailand Center of Excellence for Glass

กรมวิทยาศาสตร์บริการ
DEPARTMENT OF SCIENCE SERVICE

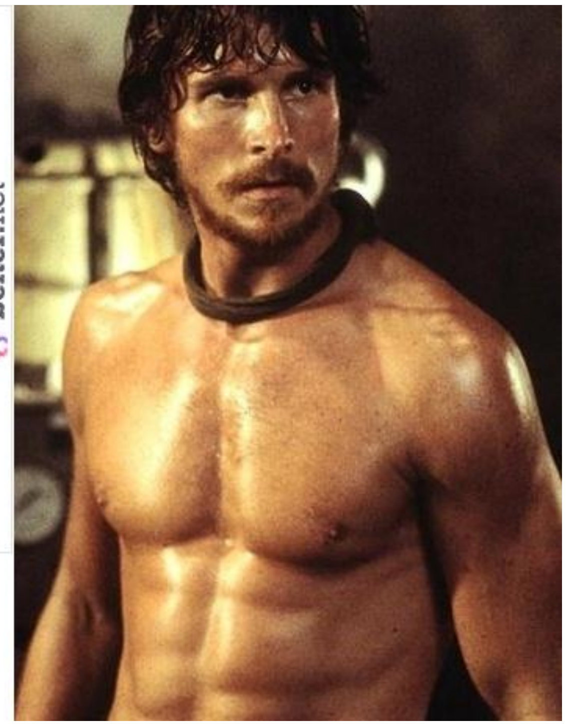
- Mission: To provide scientific and technical supports to the glass industry in Thailand
- Project: Energy reduction glass melting furnace
    - Batch modification
    - Furnace performance assessment

Energy reduction plan

BEFORE

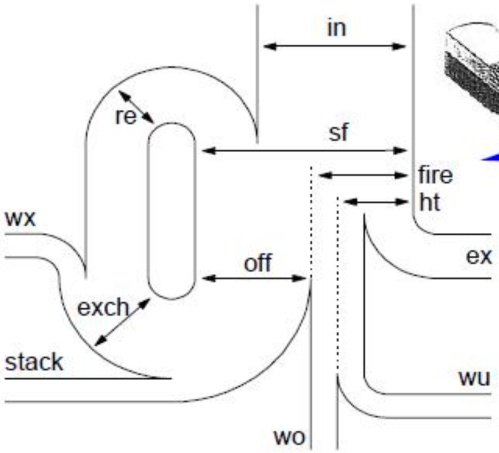


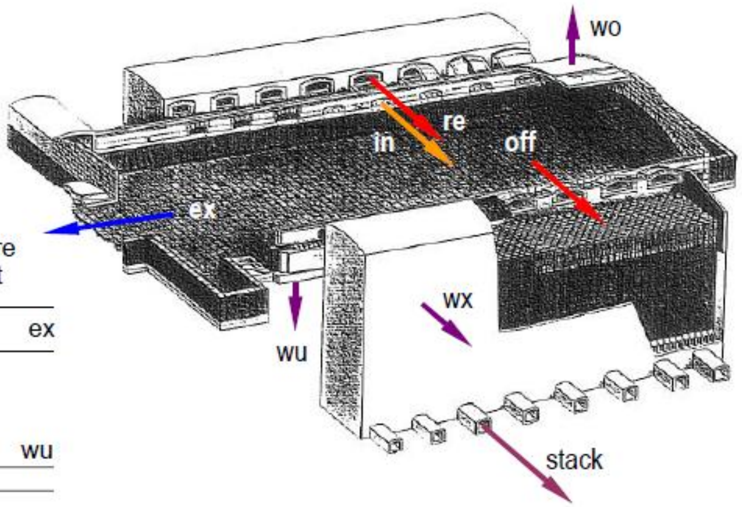
AFTER



Glass furnace performance

Heat balance



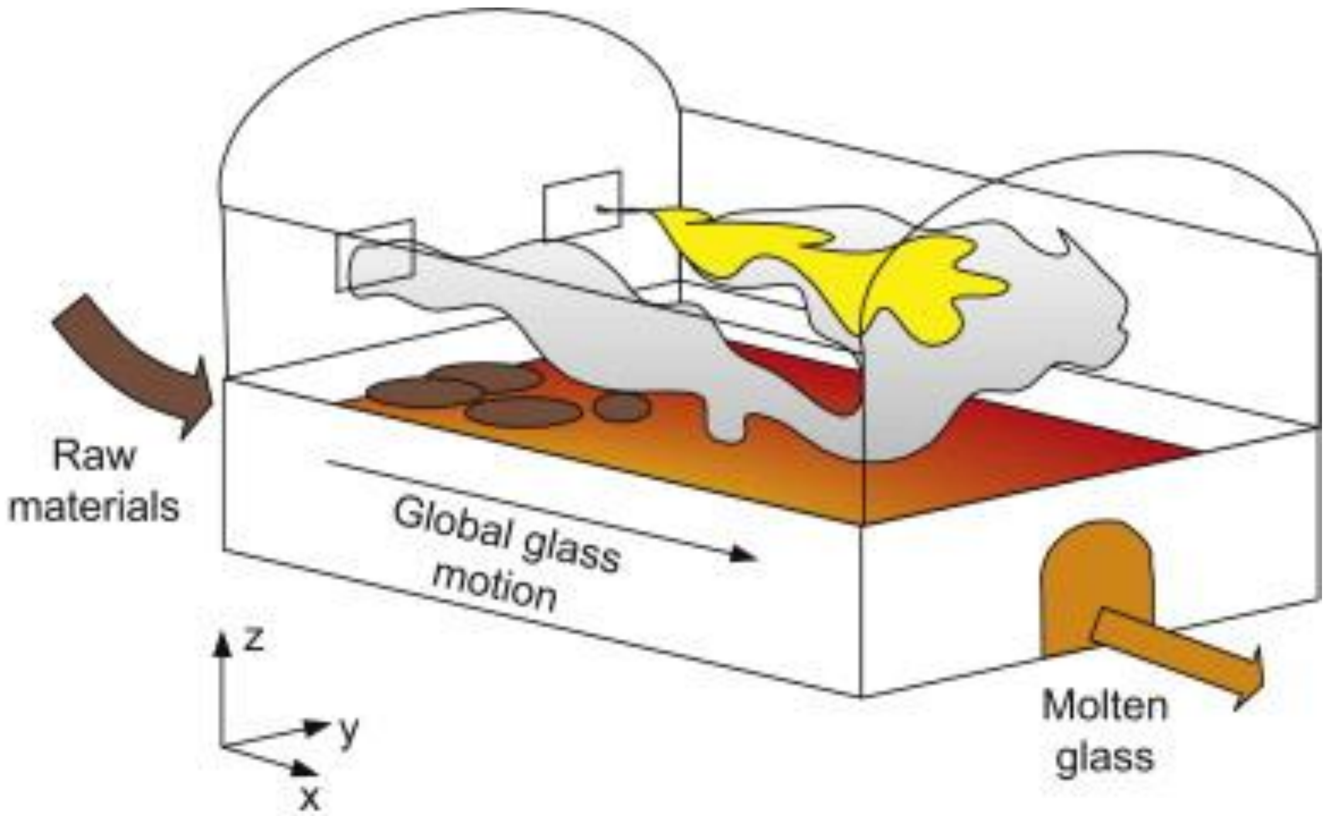


Outline

- Calculations
- Results
- Conclusions

Calculations

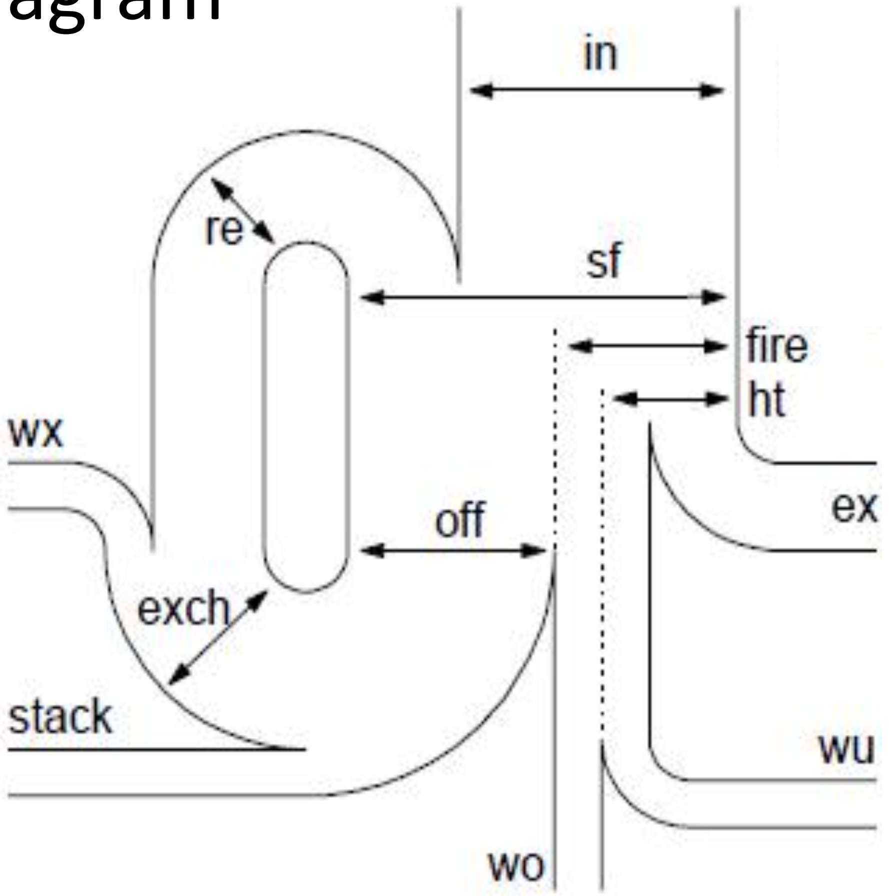
End-port furnace



Source: Olivier Auchet et al. Control Engineering Practice Volume 16, Issue 12, 2008.

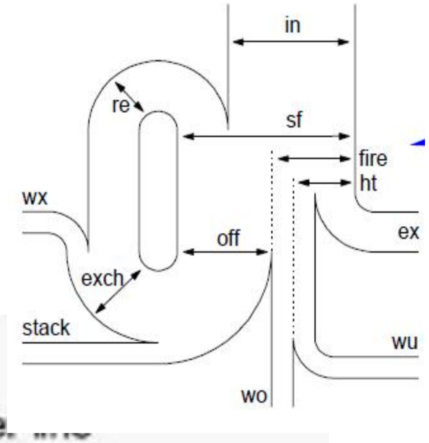
Heat balance

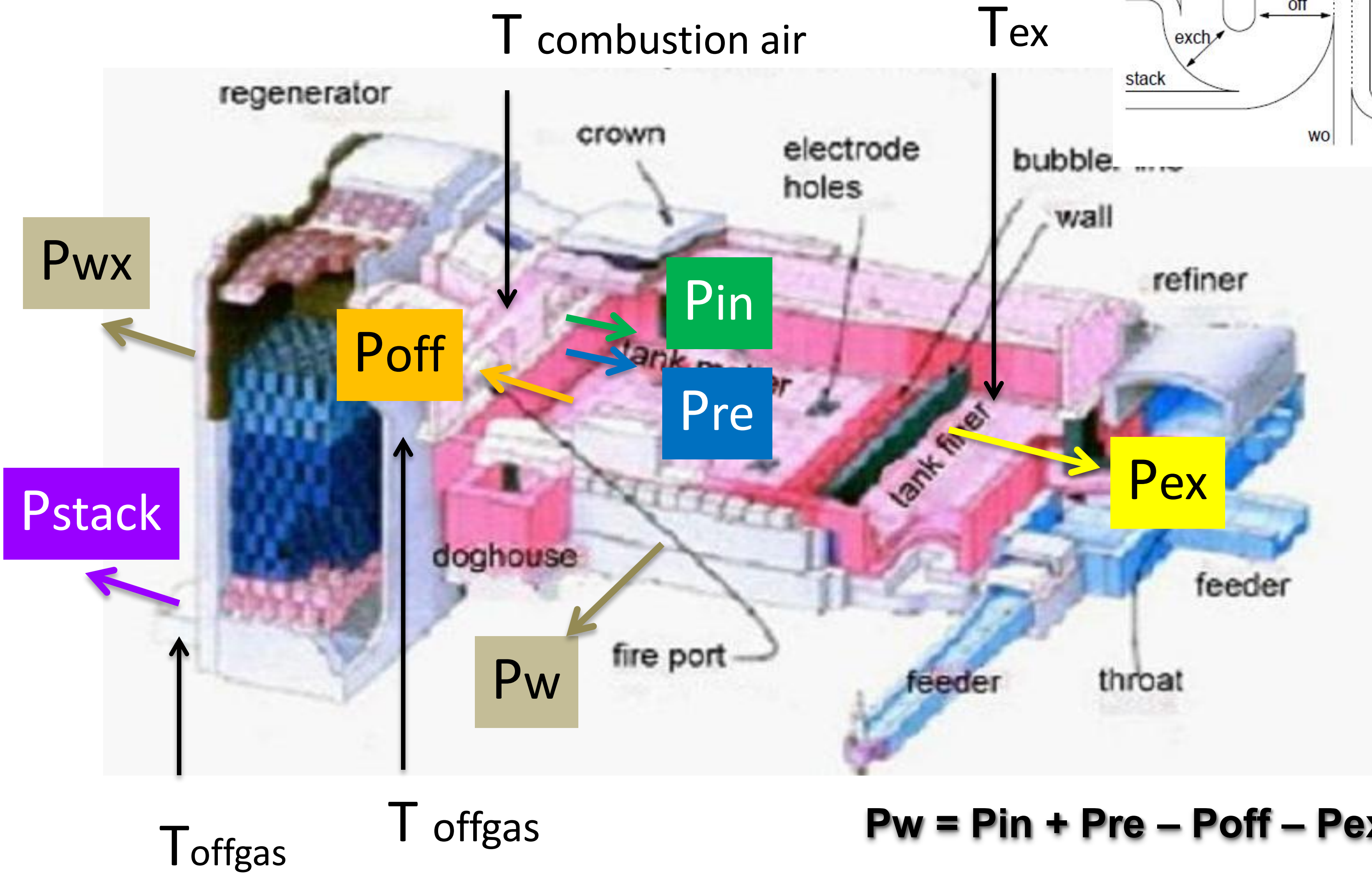
- Sanky diagram



Source : Reinhard Conradt, ICTA 2012

Heat balance





Pw = Pin + Pre – Poff – Pex

Pwx = Poff – Pstack – Pre

Exploited heat (H_{ex})

$H_{ex} = (1-y_c)\ \Delta H^\circ_{chem} + \Delta H_{melt}\ (T_{ex})$

ΔH°_{chem} is the heat required for the batch-to-melt conversion at 298 K.

$\Delta H^\circ_{chem} = H^\circ_{glass} + H^\circ_{gas} - H^\circ_{batch}$

batch (298 K) → glass (298 K) + batch gases (298 K)

$\Delta H_{melt}\ (T_{ex})$ is the heat content in melt at T_{ex} .

$$\Delta H_{melt}\ (T_{ex}) = H_{T,melt} - H^\circ_{glass}$$

$$= H^\circ_{1400,melt} + c_{p,melt} \cdot (T-1400)$$

Batch formula

Data from a factory

y_c is % cullet

$$H_{ex} = (\ 1 - y_c\ )\ \Delta H^\circ_{chem} + H^\circ_{1400,melt} + C_{p,melt}\ (\ T_{ex} - 1400\ )$$

$P_{ex} = H_{ex} \times \text{pull}$

Ref. Conradt R. The industrial glass-melting process. In: Hack K, editor. *The SGTE casebook: Thermodynamics at work*. 2nd ed. Cambridge: Woodhead Publishing Limited; 2008, p. 282-303

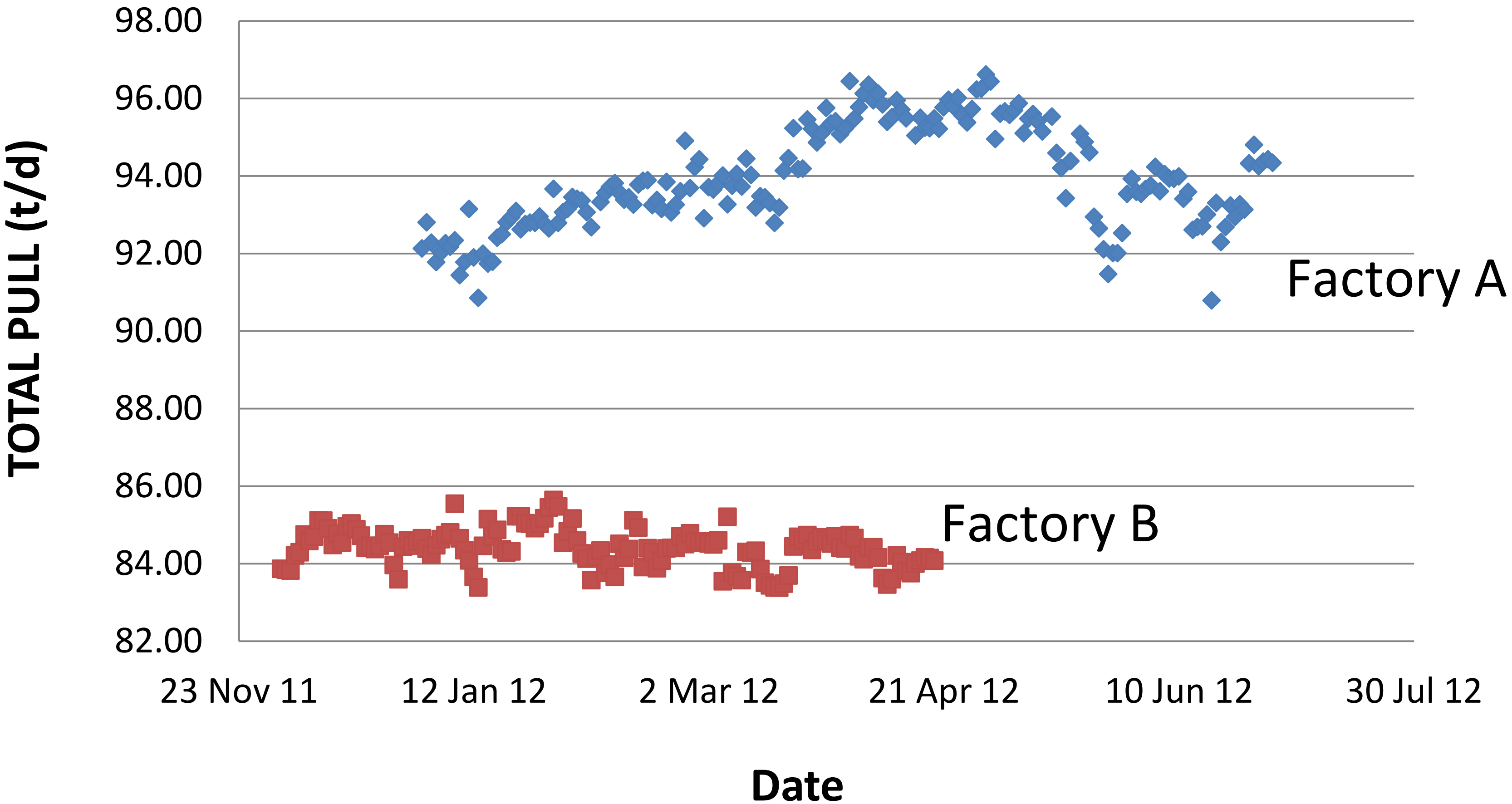
Data

DATE	TOTAL PULL (t/d)	MELT TEMP. (°C) Tex	FLUE GAS TEMP. (°C)		COMBUSTION AIR TEMP. (°C) Tre	AIR/GAS RATIO	FUEL	SECONDARY AIR	ELEC. (If use)	OXYGEN (If use)	% CULLET
			Toff	Tstack			m^3/h	m^3/h	kWh/h	m^3/h	
1 Jun 11	104.74	1342	1321	407	1289	10.60	668	6757	216		20
2 Jun 11	105.52	1333	1322	409	1291	10.60	675	6869	214		20
3 Jun 11	105.74	1340	1333	410	1298	10.60	678	6837	214		20
4 Jun 11	105.65	1340	1330	409	1296	10.61	674	6812	214		20
5 Jun 11	105.65	1342	1328	406	1296	10.60	672	6804	214		20
6 Jun 11	105.74	1338	1328	406	1298	10.60	676	6846	214		20
7 Jun 11	105.00	1341	1330	407	1296	10.60	677	6833	216		20
8 Jun 11	105.62	1339	1324	409	1291	10.61	671	6792	213		20
9 Jun 11	105.91	1339	1321	410	1288	10.60	675	6846	214		20
10 Jun 11	105.48	1336	1322	410	1289	10.60	679	6886	213		20
11 Jun 11	105.54	1344	1326	408	1292	10.60	681	6888	216		20
12 Jun 11	106.29	1344	1328	409	1292	10.60	682	6897	212		20
13 Jun 11	105.37	1346	1339	405	1304	10.60	681	6871	220		20
14 Jun 11	104.25	1346	1332	406	1296	10.59	673	6802	218		20
15 Jun 11	103.88	1344	1327	404	1290	10.60	665	6679	215		20
16 Jun 11	103.12	1341	1321	401	1285	10.60	658	6652	216		20
17 Jun 11	103.19	1340	1322	399	1283	10.61	658	6653	215		20

Furnace data

	Factory A	Factory B
Furnace Type	Regenerative end-port furnace	Regenerative end-port furnace
Area	52 m^2	60 m^2
Capacity	120 ton	200 ton
Total Pull	90.8 – 96.6 (ton/day) 3.78 – 4.03 (ton/hour)	83.4 – 85.6 (ton/day) 3.48 – 3.57 (ton/hour)
Input energy	NG + Electricity	NG
Date of data collection	1 Jan - 30 June 12 (6m)	1 Dec 11 – 19 April 12 (5m)

Total pull (t/d)



Batch data

Raw materials	H° (kWh/kg)*	Amount of Raw Materials per 1 ton of glass (kg)	
		Factory A	Factory B
Silica sand (SiO_2)	4.2112	685	628
Sodium Feldspar ($NaAlSi_3O_8$)	4.1649	51	110
Potassium feldspar ($KAlSi_3O_8$)	3.9635	12	-
Dolomite ($CaMg(CO_3)_2$)	3.4873	193	161
Sodium Carbonate (Na_2CO_3)	2.9608	231	250
Borax .5 H_2O ($Na_2O \cdot 2B_2O_3 \cdot 5H_2O$)	4.5676	-	14
Potassium Carbonate (K_2CO_3)	2.3117		13
[illegible]			[illegible]

* Materials Thermochemistry 6th ed. , O.Kubaschewski et al.

Glass components

components	%wt	
	Factory A	Factory B
SiO_2	72.45	67.94
TiO_2	0.03	0.06
Al_2O_3	1.38	2.10
B_2O_3	-	0.54
Fe_2O_3	0.11	0.09
P_2O_5	0.01	0.01
MgO	3.38	3.67
CaO	7.27	6.53
Na_2O	15.06	17.54
K_2O	0.30	1.28

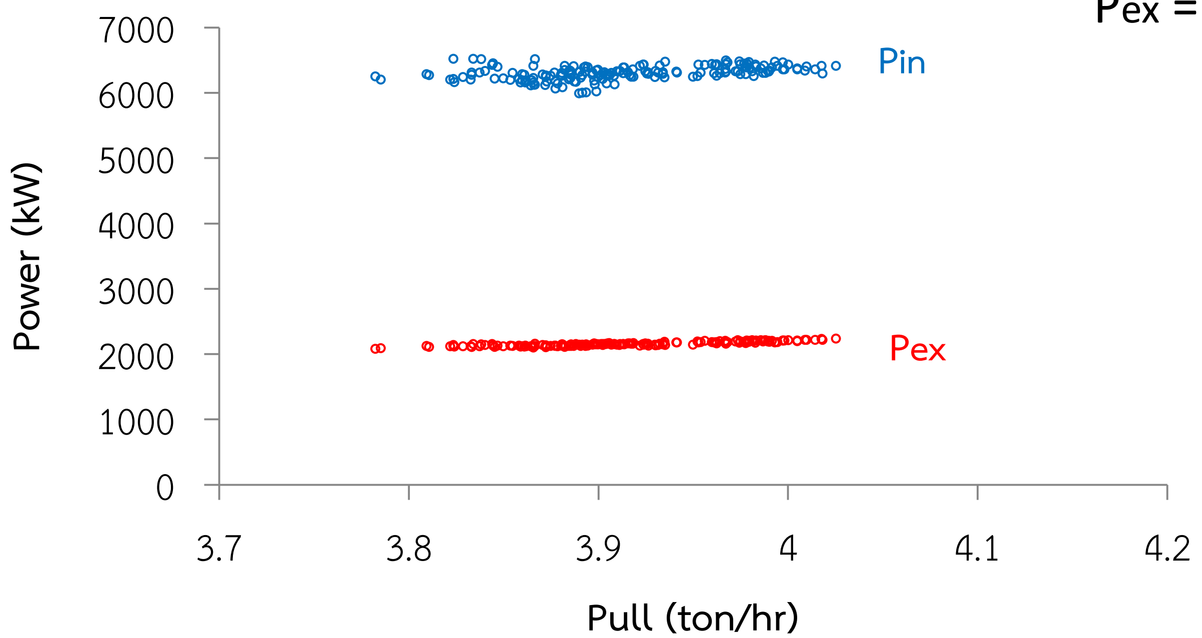
Batch data

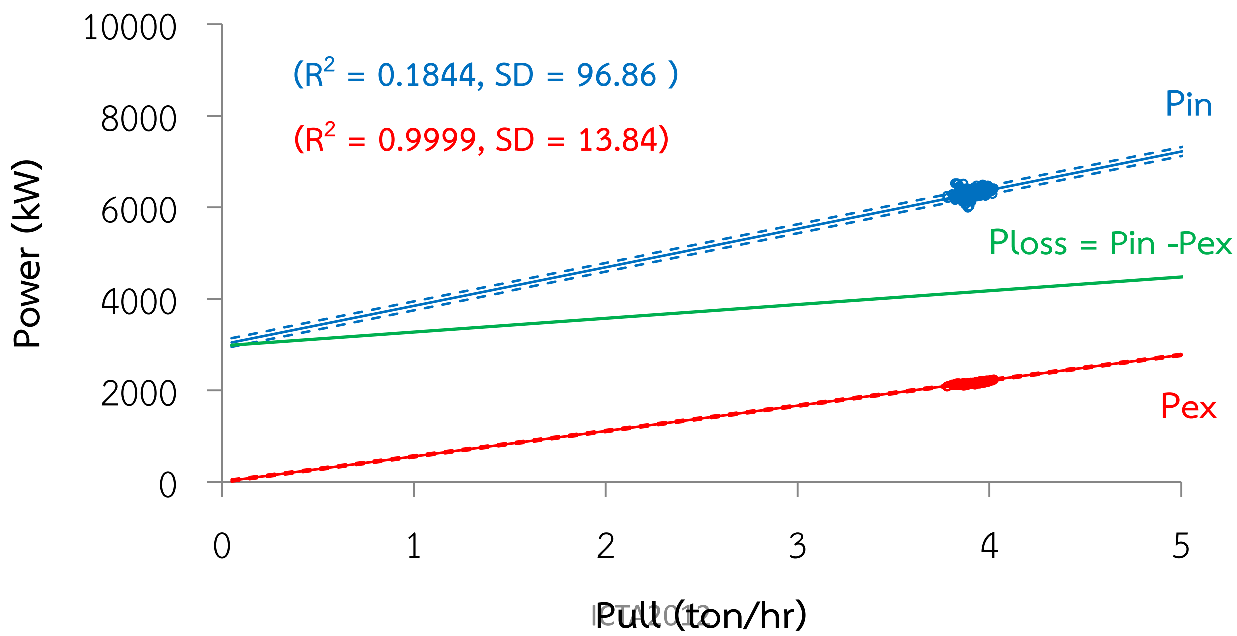
kWh/t	Factory A	Factory B
H°_{batch}	4517.69	4366.34
H°_{glass}	3930.81	3865.61
H°_{gas}	437.34	362.71
ΔH°_{chem}	149.54	138.02

Results

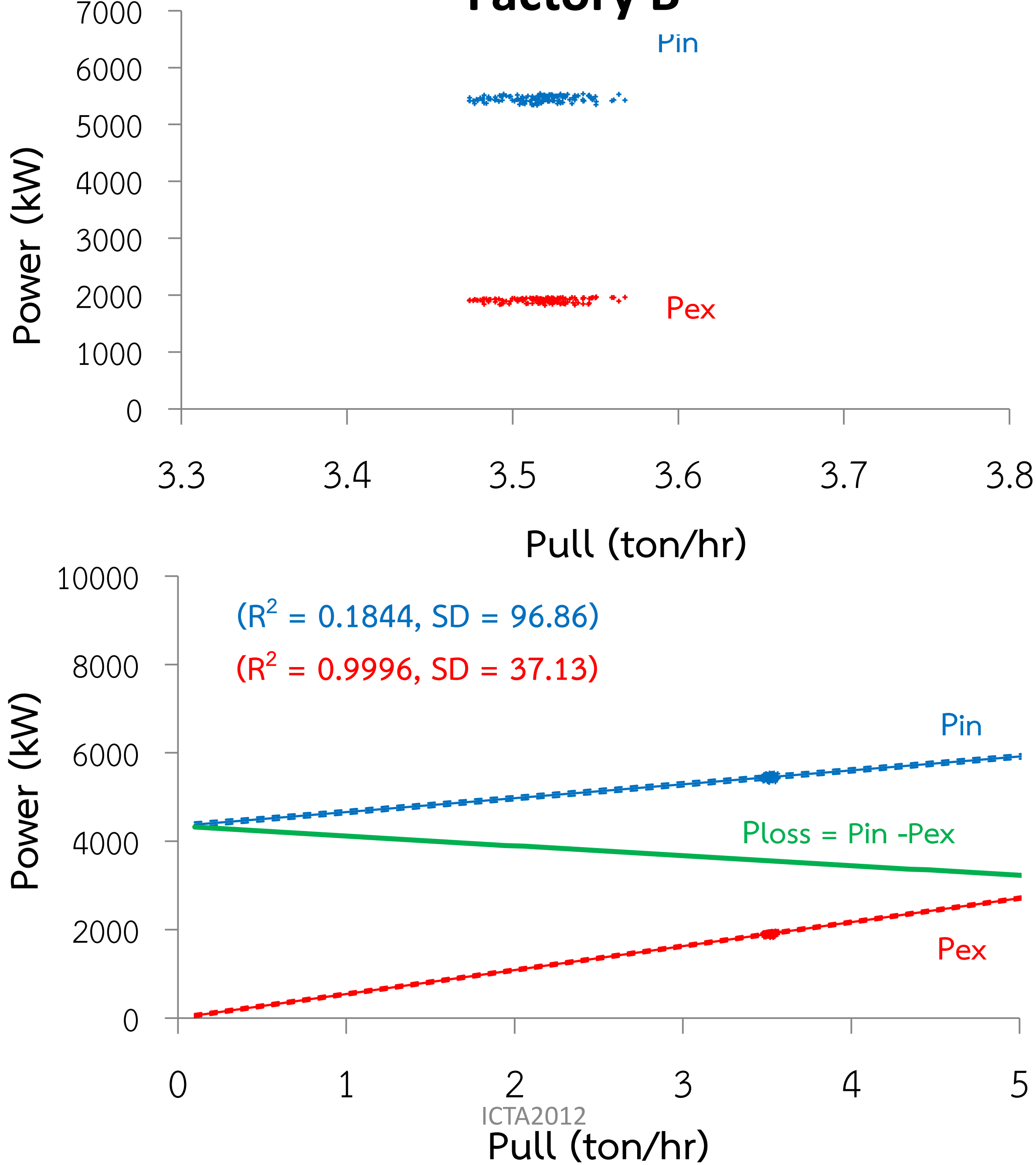
Factory A

$P_{ex} = H_{ex} \times pull$



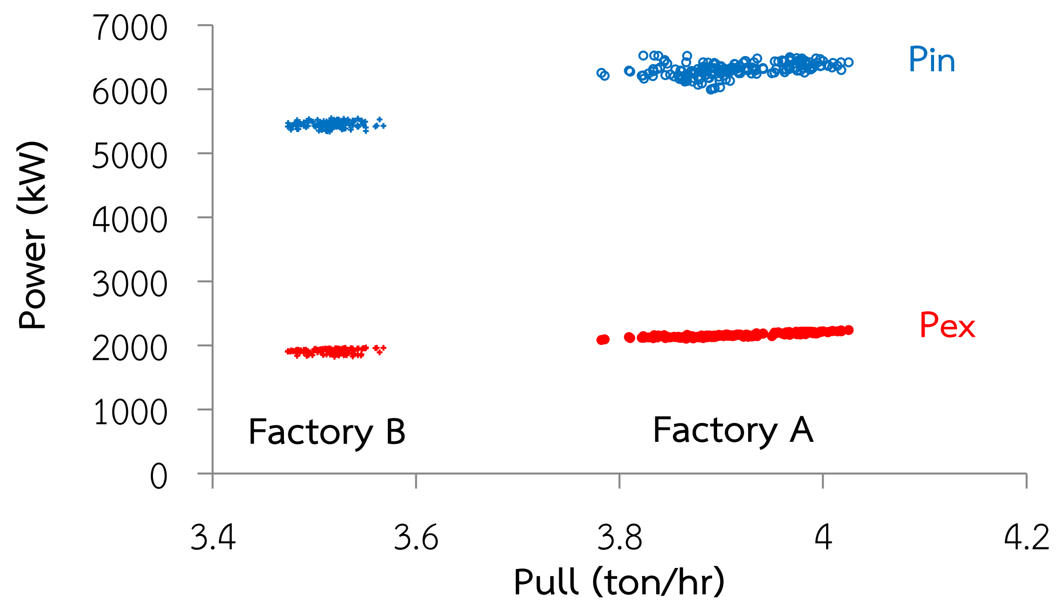


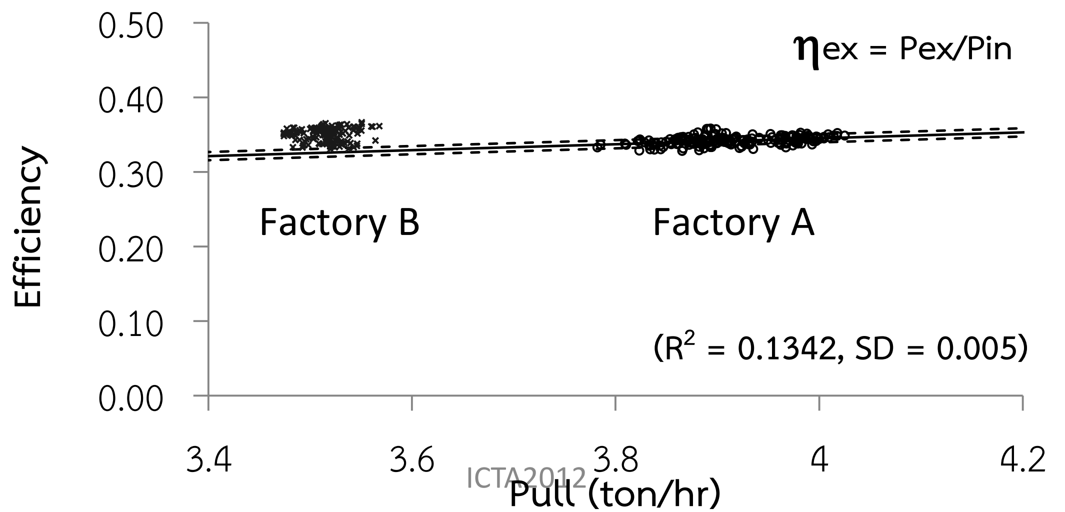
Factory B

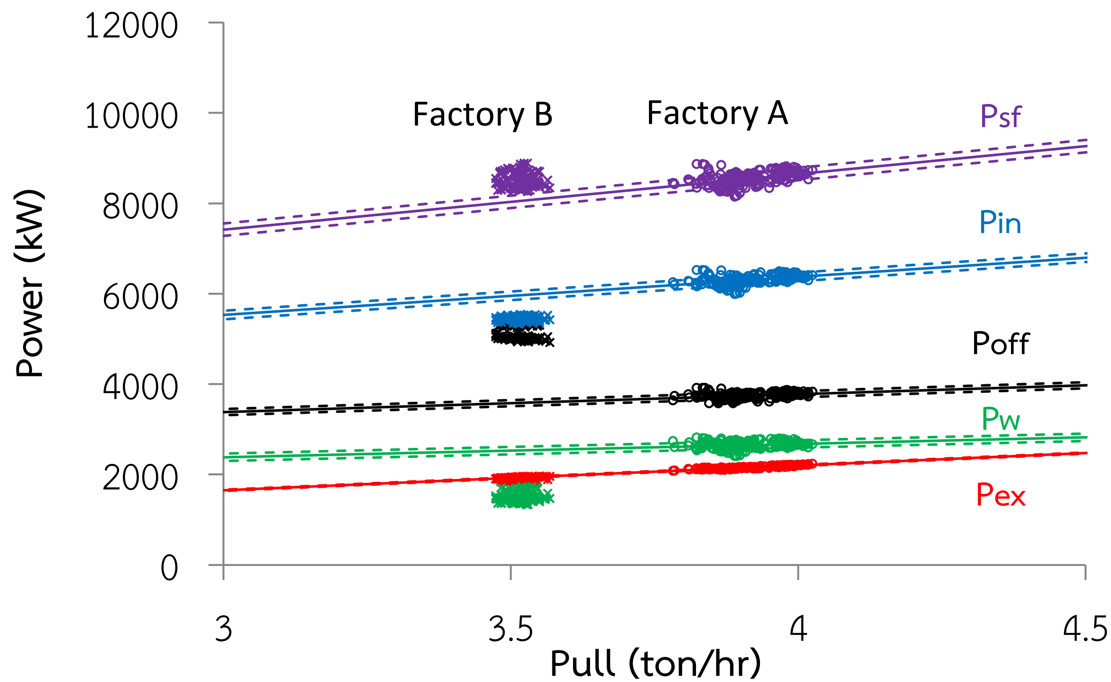


7000
6000
5000
4000
3000
2000
1000
0
Power (kW)
Pin
Pex
3.3
3.4
3.5
3.6
3.7
3.8
Pull (ton/hr)
10000
8000
6000
4000
2000
0
Power (kW)
(R^2 = 0.1844, SD = 96.86)
(R^2 = 0.9996, SD = 37.13)
Pin
Ploss = Pin -Pex
Pex
0
1
2
3
4
5
Pull (ton/hr)

Furnace A and B







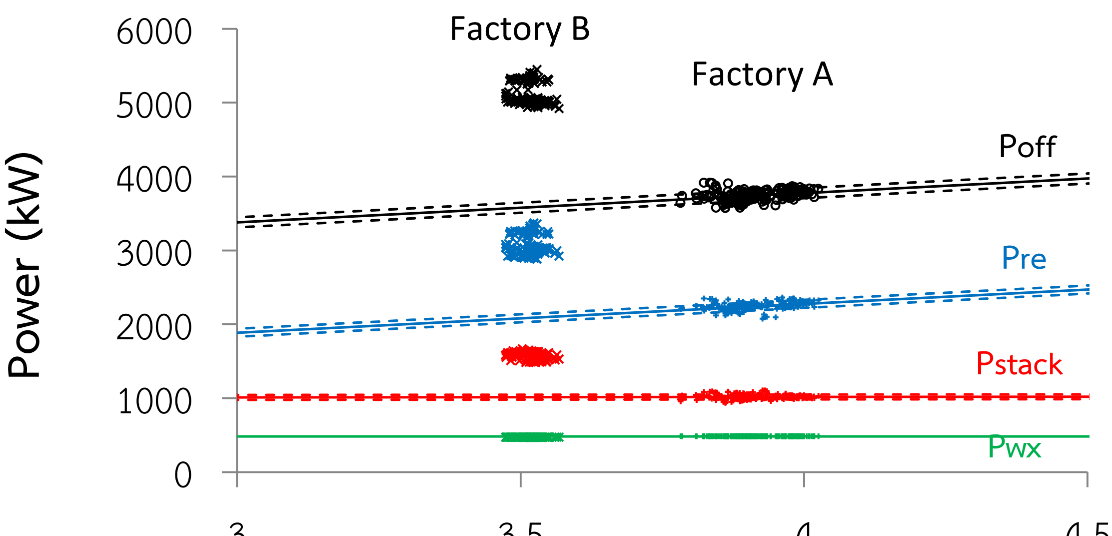
(R^2 = 0.1342, SD = 0.005)

(R^2 = 0.1844, SD = 96.86)

(R^2 = 0.0911, SD = 68.30)

(R^2 = 0.0367, SD = 82.56)

(R^2 = 0.9999, SD = 13.84)



(R^2 = 0.0911, SD = 68.30)

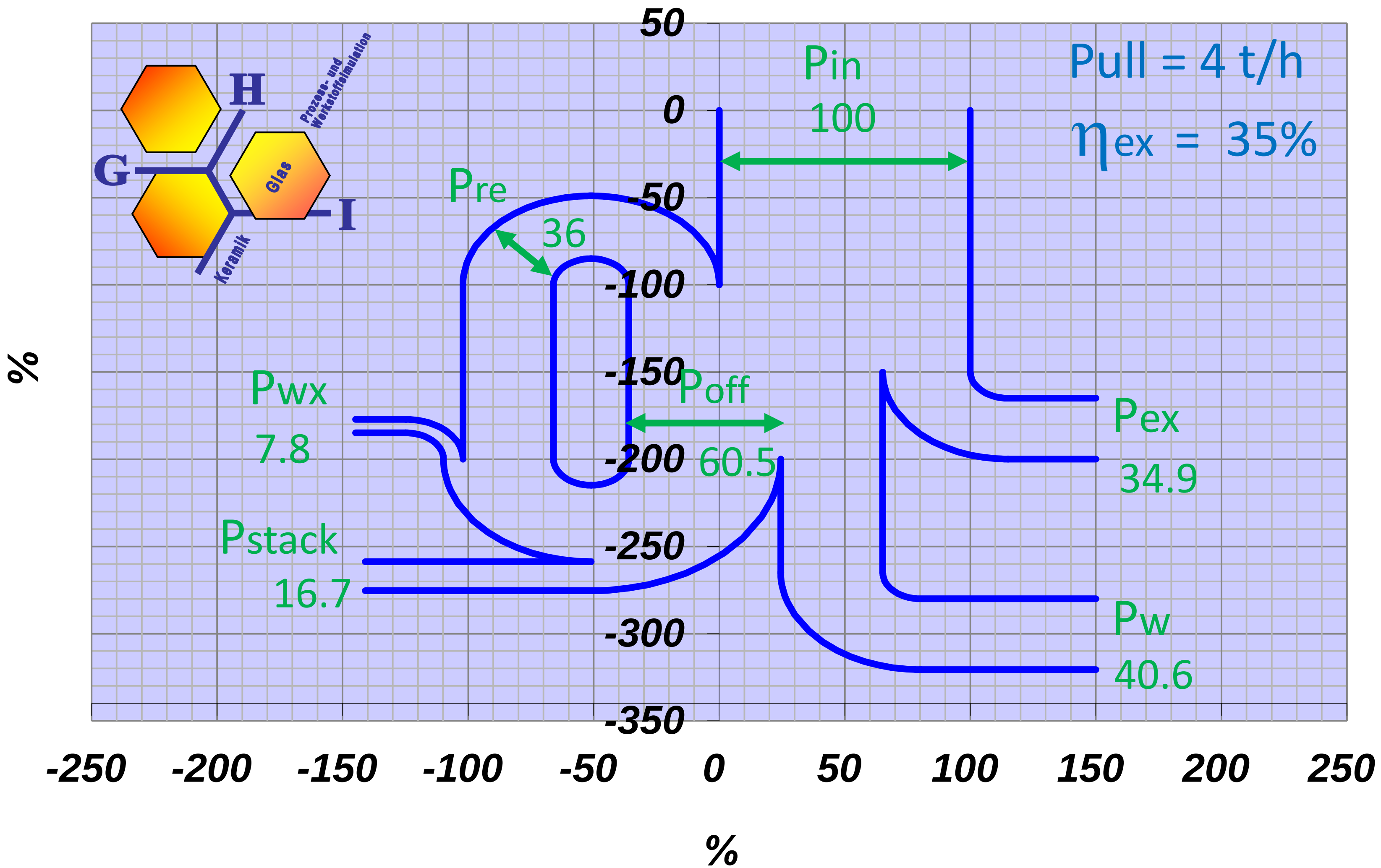
(R^2 = 0.1332, SD = 54.32)

(R^2 = 0.0001, SD = 33.26)

(R^2 = 1, SD = 0)

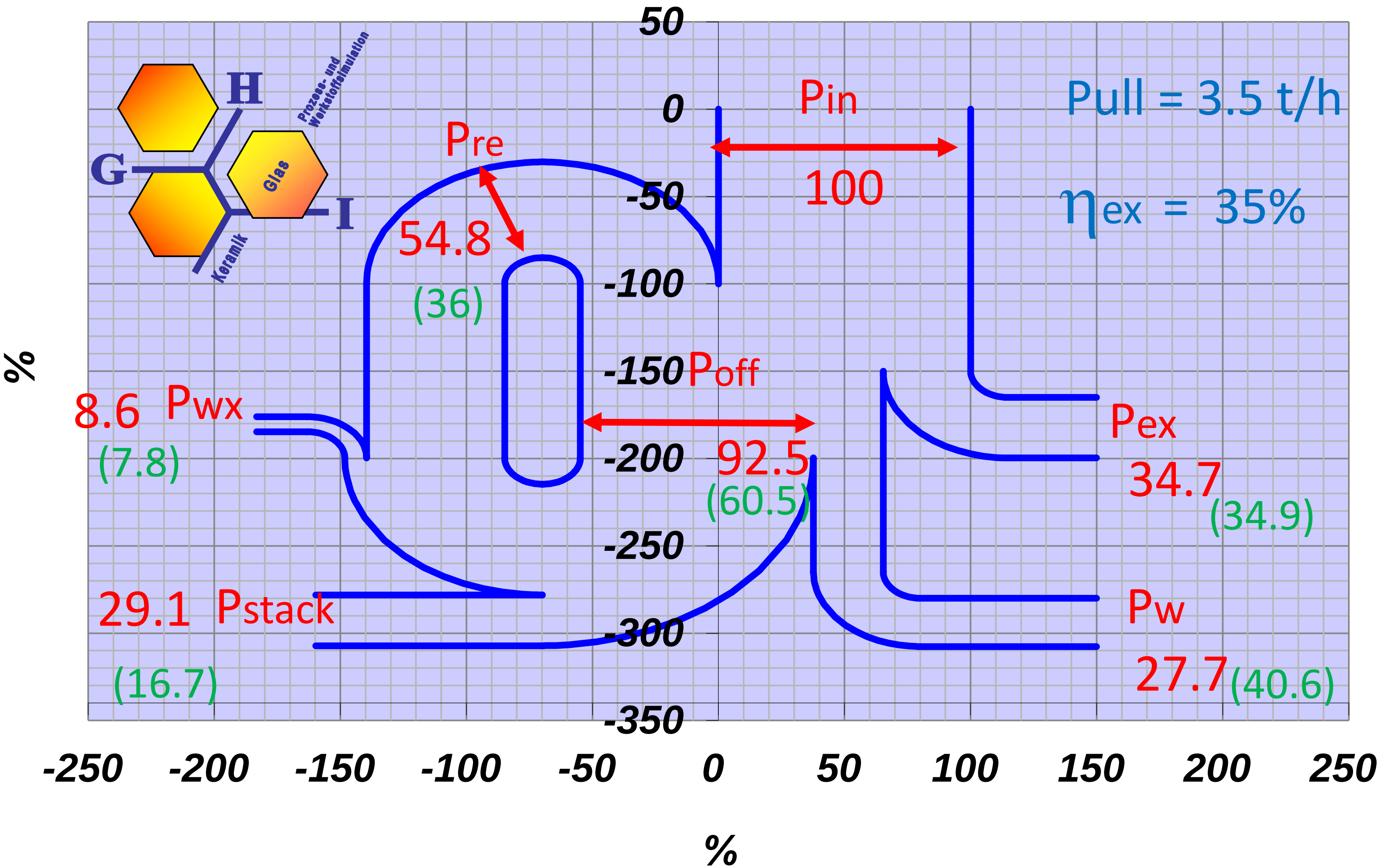
Pre = 0.6Poff

Factory A



Pre = 0.6Poff

Factory B



Pre = 0.6Poff

Conclusions

- Heat balance (furnace performance) can indicate the situation of glass furnace in term of energy consumption.
- Furnace A has 40 - 43% wall losses and 60% heat loss from offgas.
- Furnace B has 25 - 31% wall losses and 92-98% heat loss from offgas.

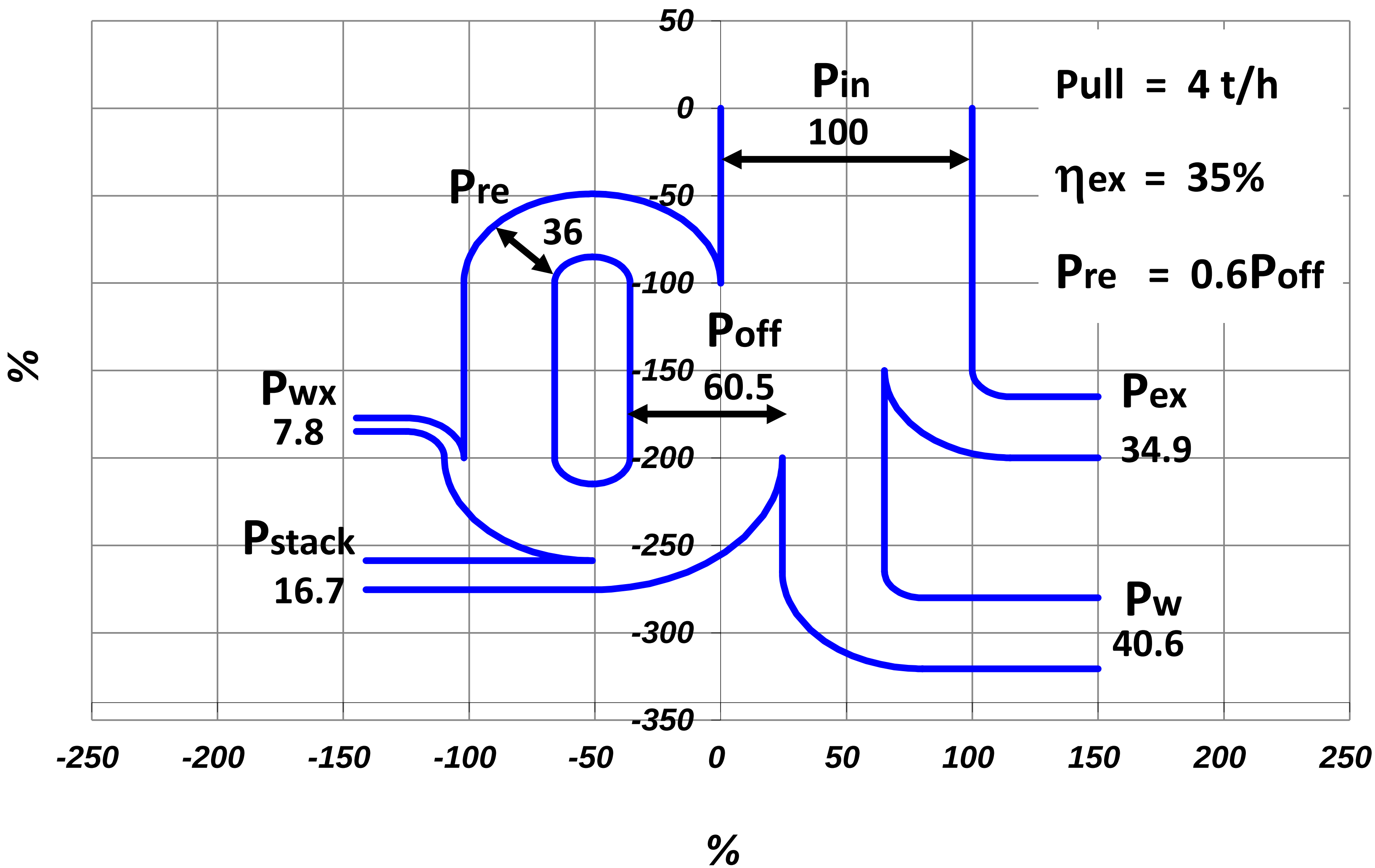
Acknowledgement

Prof. Reinhard Conradt

RWTH Aachen University, Germany

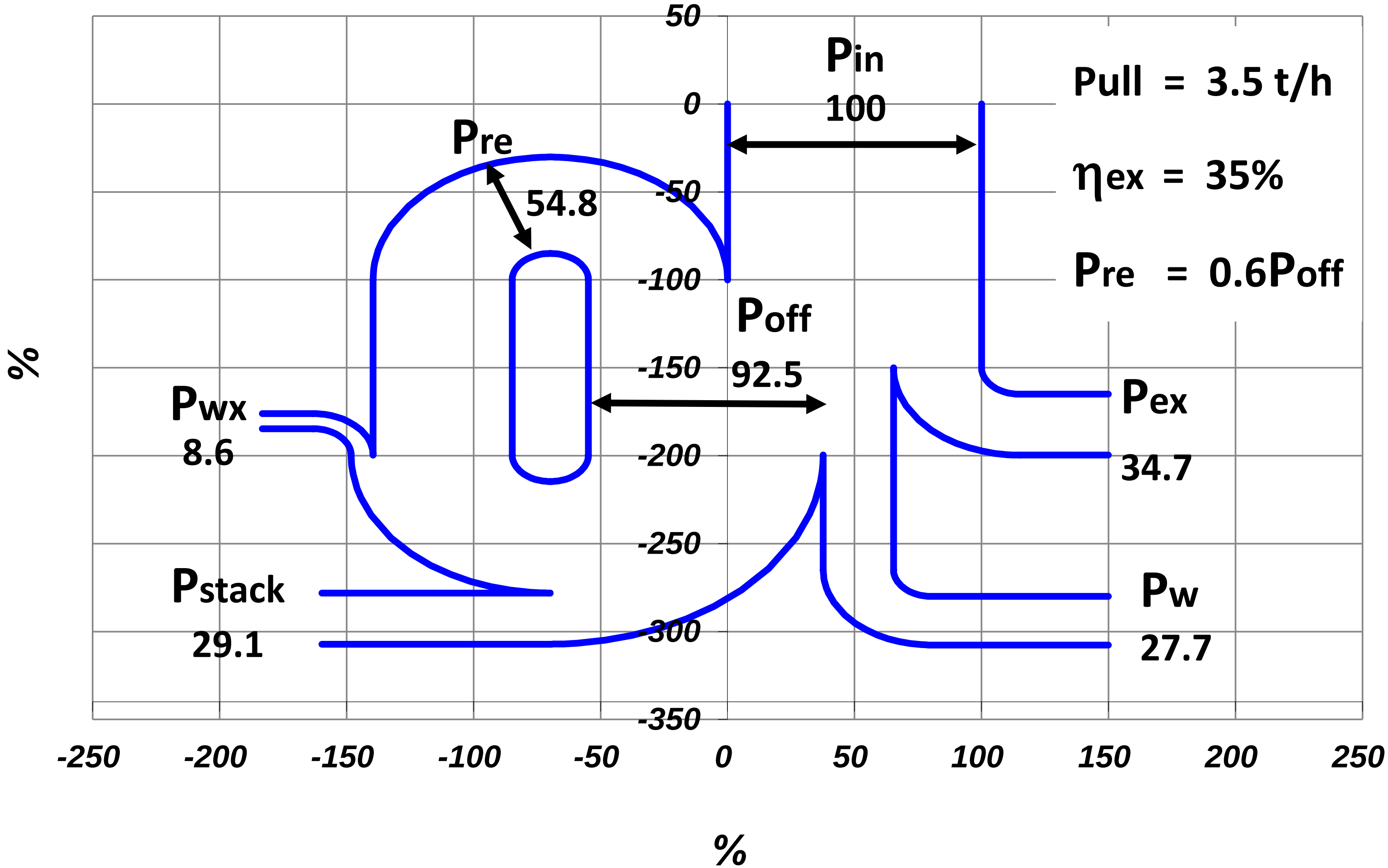
Thank you for your attention

Furnace A



Pin
100
Pull = 4 t/h
ηex = 35%
Pre = 0.6Poff
Pre
36
Poff
60.5
Pwx
7.8
Pex
34.9
Pstack
16.7
Pw
40.6
50
0
-50
-100
-150
-200
-250
-300
-350
-250
-200
-150
-100
-50
0
50
100
150
200
250
%
%

Furnace B



50
0
-50
-100
-150
-200
-250
-300
-350
-250
-200
-150
-100
-50
0
50
100
150
200
250
%
%
Pin
100
Pull = 3.5 t/h
ηex = 35%
Pre = 0.6Poff
Pre
54.8
Poff
92.5
Pwx
8.6
Pex
34.7
Pstack
29.1
Pw
27.7