ISSCT Workshop

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“Technologies for profitable cogeneration”

Cogeneration concepts and power export potential

Boris Morgenroth - IPRO Industrieprojekt GmbH

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Introduction and Objectives

Sugar factories in Brazil, India, Mauritius, Pakistan and Reunion Island have taken the lead in adapting technologies for power export orientated factory concepts.

Specific power export rates of 50 – ~100 kWh/t cane have been achieved. Technologies for increasing the power export from 100 up to 200 kWh/t cane are available - but not all proven at large technical scale or viable.

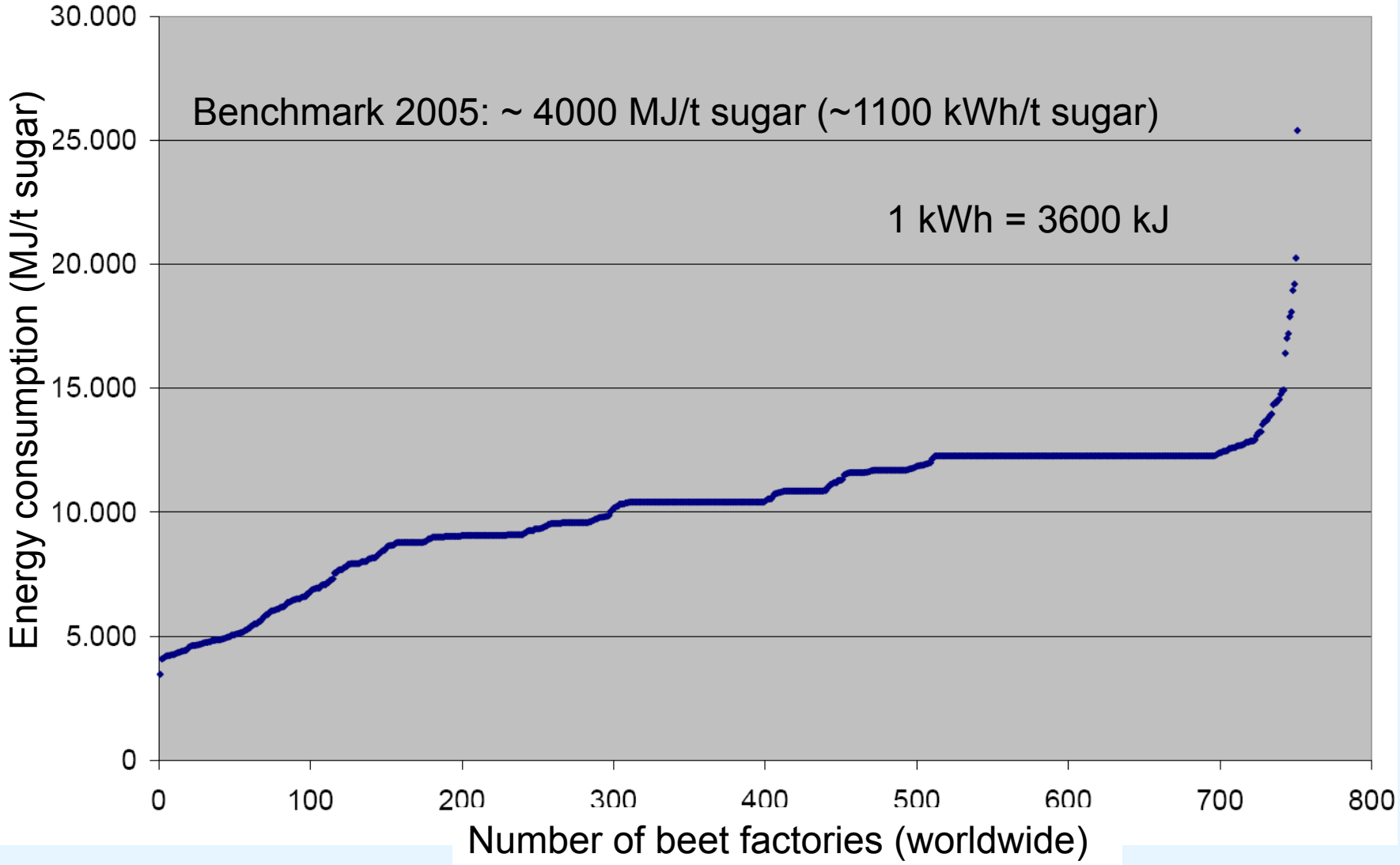
1800 – 2000 cane sugar factories can export 156 – 179 TWh/a – or 20 MW/factory. Prices of 50 – 70 €/MWh (Brazil, India, Pakistan) and carbon credits of 5-15 €/t CO_2 make power export attractive – at least in some countries.

The optimization of the sugar manufacturing process for low steam consumption in the range of 26 – 34 % steam on cane is one important aspect in order to achieve high power export rates. Plants of this type have been implemented in Brazil, Pakistan and India.

Special attention also needs to be directed to the power plant. Apart from high pressure boiler and turbine concepts, drying of bagasse and bagasse gasification in combination with combined cycle systems offer further potential for power export optimization.

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Energy demand benchmarks in the beet sugar industry



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Benchmarks of beet and cane sugar factories

Beet sugar factories (central Europe)

Steam demand: 15 – 22 % on beet (Syrup storage, B-Molasses export)

Power demand: 18 – 28 kWh/t beet

Power export: ~ 0 kWh/t beet (employment of fossil fuels)

Cane sugar factories (highly optimized)

Steam demand: 26 – 34 % on cane (raw sugar, back-end refinery, mill/diffuser)

Power demand: 24 (12*[1]) – 32 kWh/t cane (*[1] with turbine drives)

Power export: 50 – 125 (145*[1]) kWh/t cane (*[1] bagasse steam dryer)

In the cane industry only few factories come close to 26 – 34 % steam on cane yet!

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Power export for selected factories - data base (2002-2010)

Country		Brazil	Guatemala	India	Mauritius
Fibre content cane	%	12.2	12.6	14.5	15.7
Pol content cane	%	14.7	13.5	12.1	12.9
Process steam on cane (during crop)	%	40	39	46	42-45
Sugar recovery	%	50 (ethanol!)	79	83	87
Sugar quality	-	< 100 IU	Raw/partly refined	100 IU	Raw/partly refined
Season length	days	270	160	110	150
Boiler pressure	bar(a)	43 - 65	42 - 60	12 - 86	82
Turbine type	-	E/C	E/C	E/C	E/C
Specific total power export	k W h / t cane	**45**	**41**	**58**	**108**

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Benchmark process calculations for mill and diffuser based plants

Cane crushing rate	10.000 t cane/day
Effective crop length	180 days
Sugar & Fibre content in cane	14%
Imbibition rate	35 or 44% on cane
Bagasse moisture	50%
Sugar recovery extraction	97 or 98%
Exhaust steam pressure	240 kPa(a)
Evaporators	4 or 5 effect Falling film tubular with multistage distributor
Boiler steam pressure/Temperature	10 900 kPa(a) & 535 °C
Sugar colour	< 45 IU in case of the concepts with attached refinery
	350 - 600 IU in case of the raw sugar factory concepts
Factory power consumption for: Refined sugar production Raw sugar production	25 kWh/t cane for diffuser concepts and 30 kWh/t cane for mill extraction concepts 20 kWh/t cane for diffuser concepts and 25 kWh/t cane for mill extraction concepts
Overall sugar recovery	89.5 – 90.5% at 30 % molasses purity

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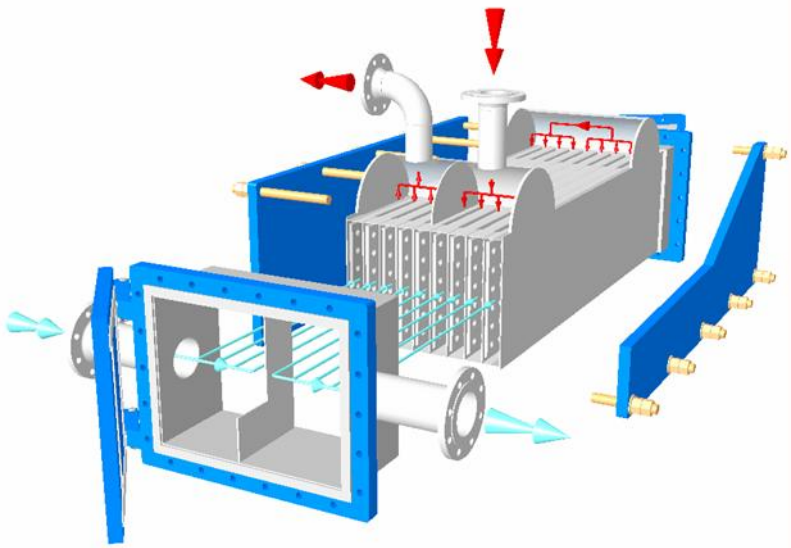
Technologies employed

- Diffuser plus dewatering mills or milling tandem (6 mills)
- Recycling of clarifier underflow in case of the diffuser models
- Defecation in the juice purification
- Partly direct contact heaters and plate/platular heaters for liquid/liquid applications
- Optimum usage of heating with condensate
- Tubular Falling Film Evaporators (FFE)
- Stepwise flashing of condensates by “condensate cigars”
- CIP (clean in place) system for heaters and evaporators
- Minimisation of evaporator condenser loss
- Batch pans for seed massecuite and refinery products R1, R2 and R3
- Continuous pans for the raw house operation
- Syrup/molasses wash layer system for A sugar
- Crystal seed technology in the raw house
- High pressure boilers with 109 bar and 535°C
- Extraction/condensing turbo alternators
- Fully electrified drives (no steam turbines)
- Reasonable degree of automation

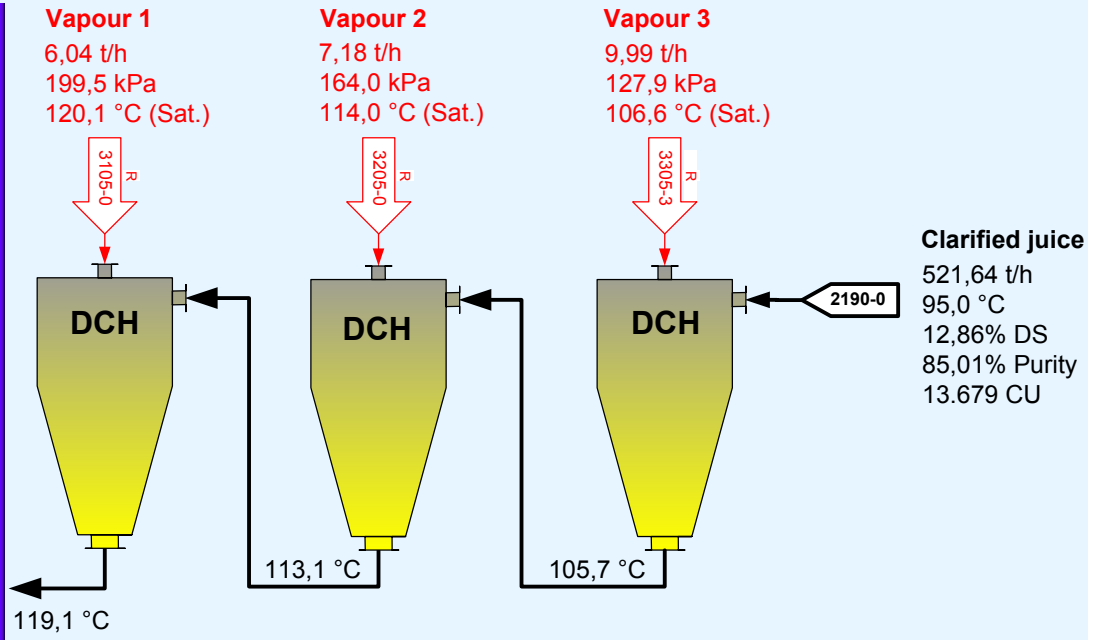


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Tube/plate heaters versus direct contact heaters



Barriquand heater



1. DC heaters are inexpensive and easy to integrate with low space demand
2. Allow an approach temperature of 0.5 – 2 K while tubular or plate heaters require 4 – 8 K
3. Almost no cleaning or down time
4. Constant performance
5. High load flexibility with minimum performance change
6. Drawback is the juice dilution and 2-3 % o.c. higher steam demand

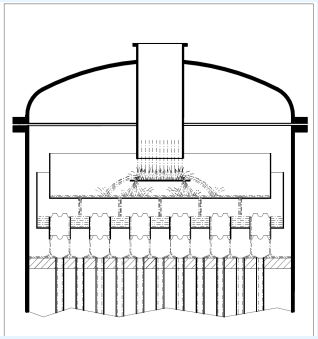
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Falling Film Evaporators



Five effect FFE evaporation plant at Almoiz, Pakistan

- Defecation or sulfitation are both suitable
- Sugar hydrolysis and colour formation are similar or lower than in conventional Robert plants
- Five effect plants of Tubular or Plate FFE have been installed in Brazil (3), India (4), Pakistan (1) in total approx. 250 – 300 FFE including other installations



The most crucial aspects are the juice distributor design and CIP system.

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Results of the diffuser scenarios

		Scenario 1 Diffuser (refined sugar)	Scenario 2 Diffuser (refined sugar)	Scenario 3 Diffuser (raw sugar)
Sugar extraction	%	98	97	98
Imbibition rate	% o.c.	44	35	44
Process steam on cane (during crop)	%	**34.2**	**33.5**	**30**
Condenser loss -> SOC	% o.c.	0.7 -> 33.5	0.7 % -> 32.8	4.8 ->25.2
Excess bagasse for off-crop operation	t	182 015	194 778	221 364
Annual sugar production (pure sucrose)	t	227 866 90.4 % recovery	225 543 89.5 % recovery	228 339 90.6 % recovery
Power production (crop)	MW	34.305	33.38	30.12
Power production off-crop	MW	32.454	34.746	39.49
Total annual power export	MWh	205 525	209 240	220 093
Specific total power export	k W h / t cane	**114**	**116**	**122**

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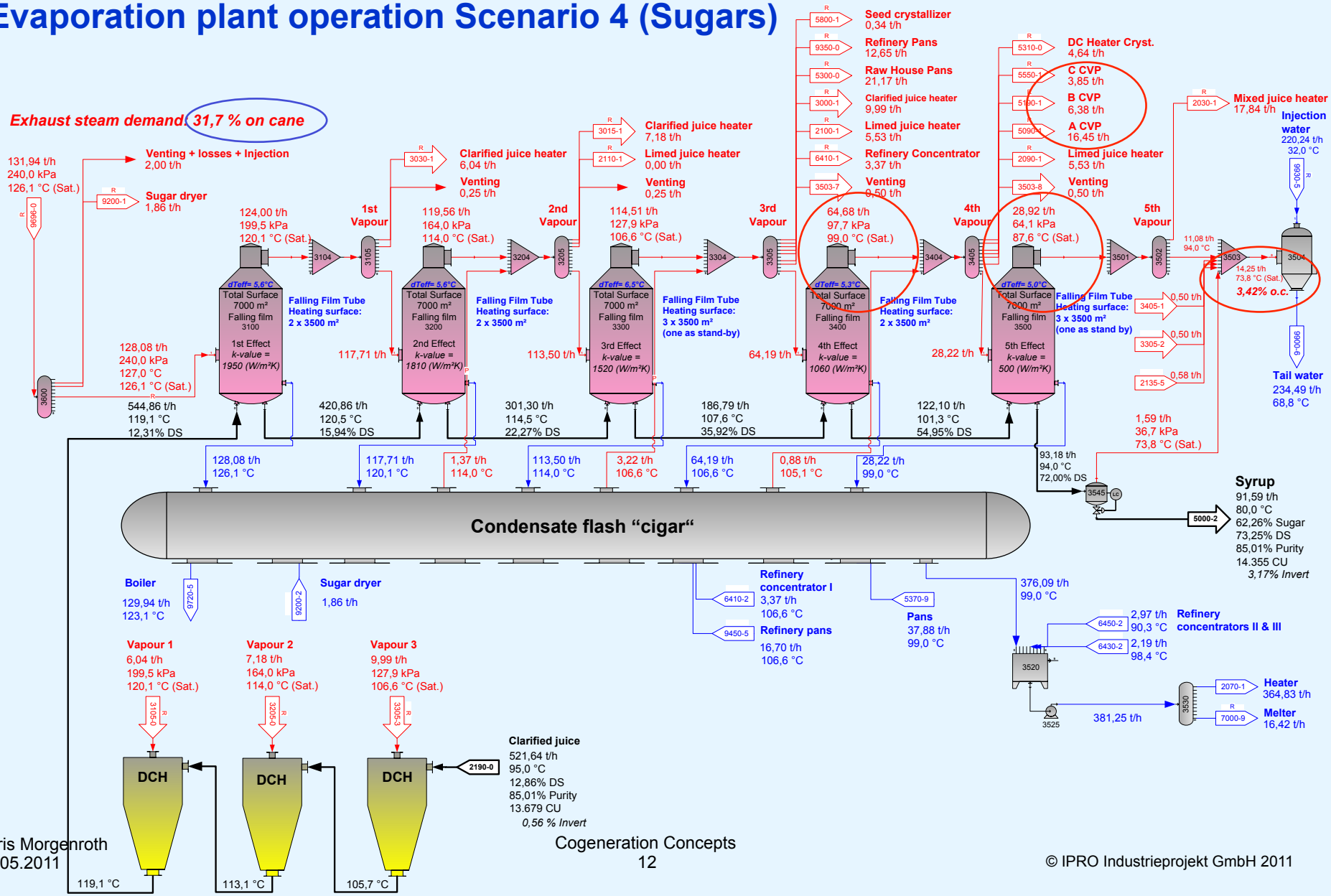
Results of the mill scenarios

		Scenario 4 Mills (refined sugar)	Scenario 5 Mills (refined sugar)	Scenario 6 Mills (raw sugar)
Sugar extraction	%	98	97	98
Imbibition rate	% o.c.	44	35	44
Process steam on cane (during crop)	%	**31.7**	**29.4**	**26**
Condenser loss -> SOC	% o.c.	3.4 -> 28.3	2.2 -> 27.2	4.2 -> 21.8
Excess bagasse for off-crop operation	t	171 420	194 534	221 832
Annual sugar production (pure sucrose)	t	226 860 90 % recovery	224 836 89.2 % recovery	227 117 90.1 % recovery
Power production (crop)	MW	31.61	29.72	26.33
Power production off-crop	MW	31.05	35.17	40.18
Total annual power export	MWh	180 139	185 855	197 046
Specific total power export	k W h / t cane	**100**	**103**	**109**

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Evaporation plant operation Scenario 4 (Sugars)



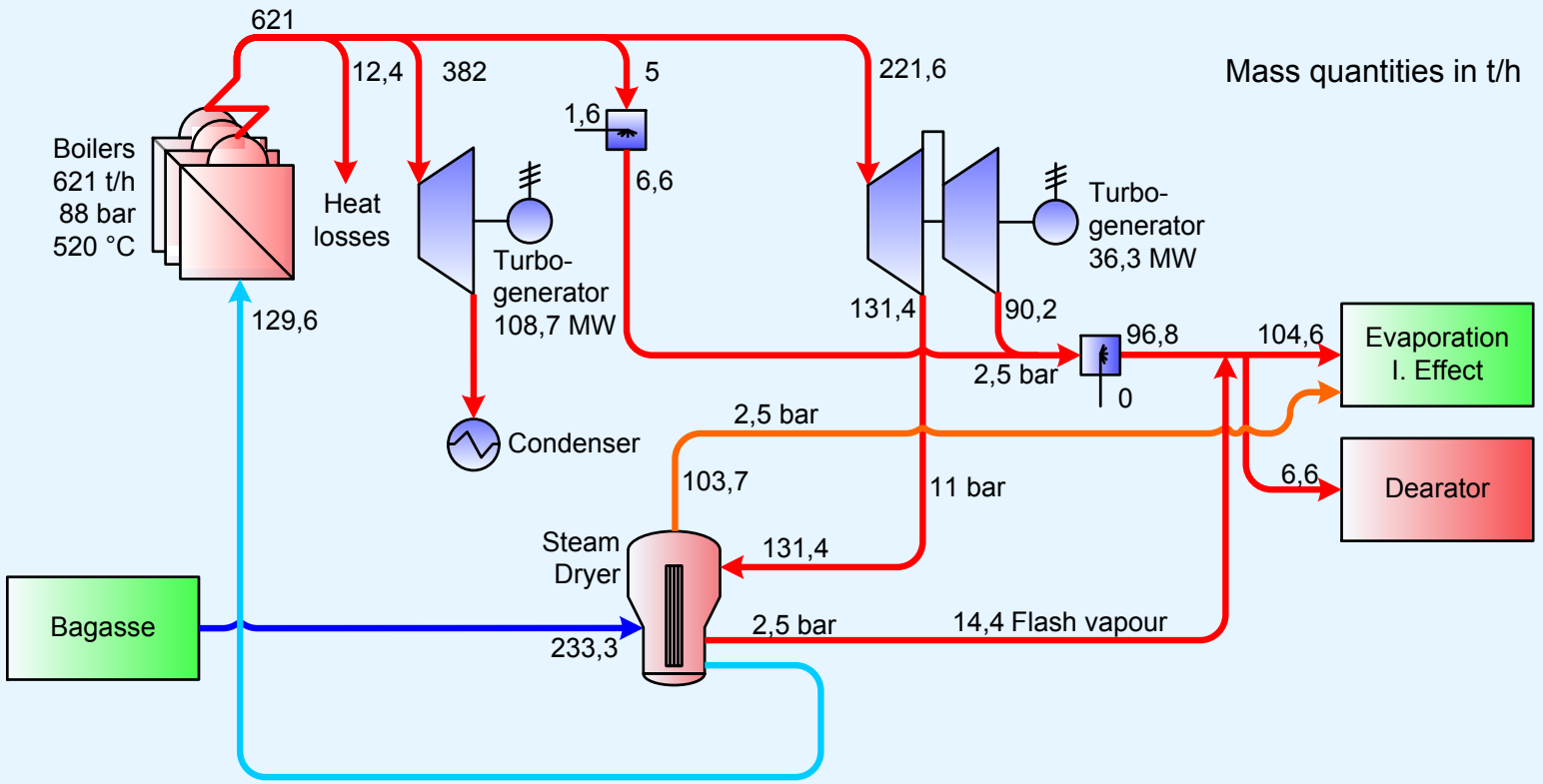
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Impact of bagasse drying on the boiler performance

		Scenario 1	Scenario 2	Scenario 3
		No drying	Flue gas drying	Steam drying
Bagasse moisture	%	**50**	**42.5**	**10**
Energy lost from water in flue gas	%	22.6	18.9	10.3
Total steam generated	t/h	525	554 (+ 5.5 %)	621 (+ 18.3 %)
Boiler efficiency	%	~ 69	~72.7	81.3
Specific power export	kWh/t cane	**124**	**133 (+ 7 %)**	**145 (+ 17 %)**

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Application of bagasse steam drying



Crushing rate	:	20.000 t/d 833 t/h
Crop operation	:	180 d/a

Electricity generation	:	145 MW
Electricity demand	:	24,2 MW
Surplus electricity generation	:	120,8 MW
Sale of electricity	:	522.300 MWh

Integration of a bagasse steam dryer

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Conclusions

The viability of power export depends on the national power policies and prices.

The steam on cane demand can be as low as 27 – 33 % (refined sugar) or 22 – 25 % (raw sugar factories) while diffuser based plants require approx. 2.5 – 4 % more steam on cane compared to mill based plants

Refined sugar production requires approx. 4.2 to 5.7 % additional steam on cane

Diffuser based plants are more power export efficient (plus 13 – 14 kWh/t cane) than mill based plants

Diffuser based plants allow approx. 0.3 – 0.5 % higher sugar recovery as mill based plants (700 – 1200 t/year for the given scenarios)

Critical technologies like Falling Film evaporators as crucial tools for very high steam efficiency have been successfully adapted to the cane sugar industry and proven in practise

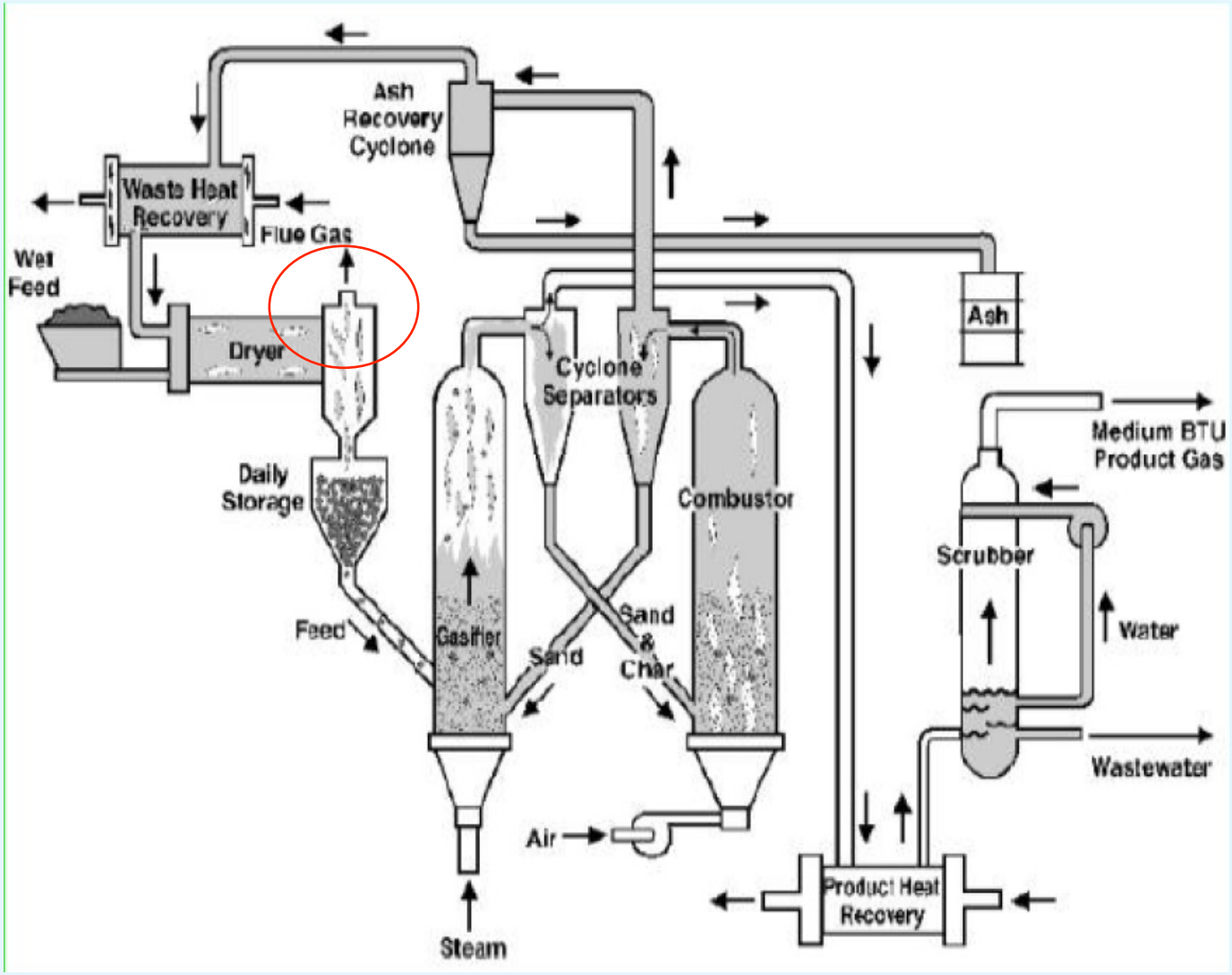
Bagasse steam drying offers potential for future power export maximisation

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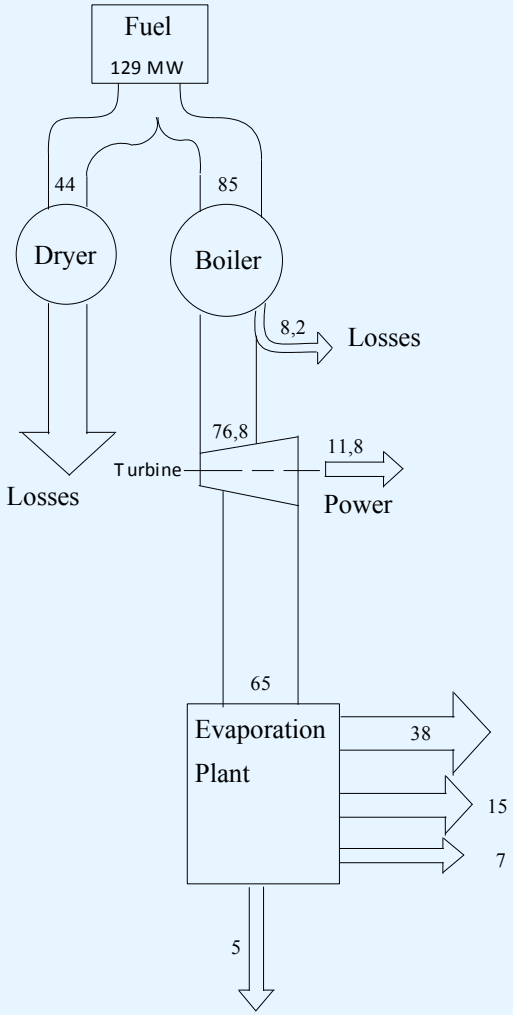
Gasification – a future potential for higher power yields



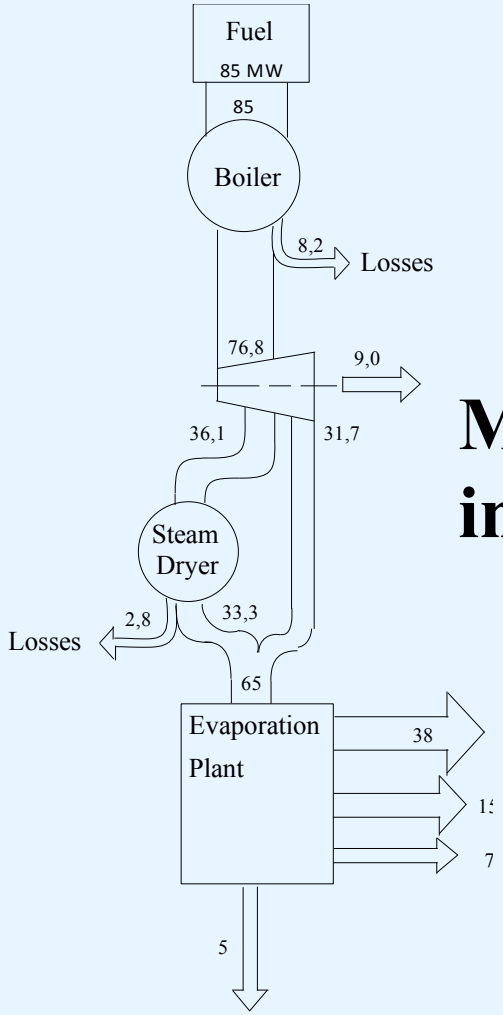
Lavarack & Hobson, 2010

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Modern Cogeneration in Beet Sugar Factories



Energy flows in a factory with conventional high temperature dryer



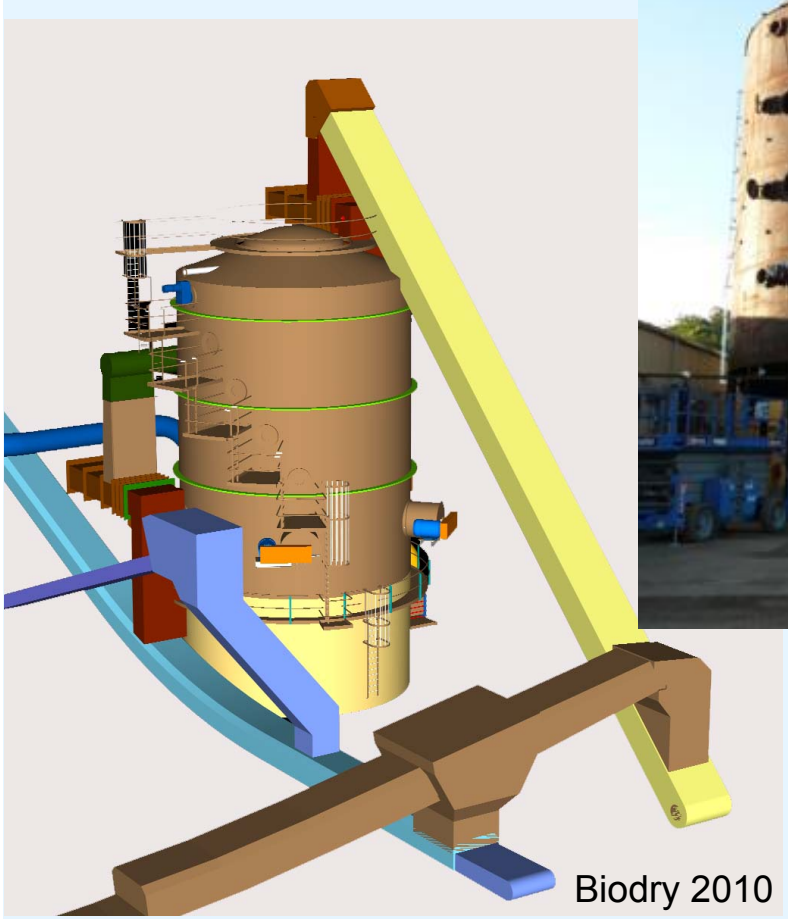
Energy flows in a factory with a steam dryer

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Further increase of power export by employing steam drying of bagasse



By employing bagasse steam drying the power export can be increased further by 15 – 20 kWh/t cane compared to the base models, e.g. up to 145 kWh/t cane.



Bagasse drying is an essential link and pre-requisite for gasification.

Semi commercial dryer unit under installation with 10 t/h water evaporation capacity.

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Impact of bagasse drying on the boiler performance

		Scenario 1	**Scenario 2**	**Scenario 3**
		No drying	Flue gas dry.	Steam drying
Bagasse moisture	%	**50**	**42,5**	**10**
Energy lost from water in flue gas	%	**22,6**	**18,9**	**10,3**
Energy lost dry flue gas	%	5,21	5,20	5,19
Unburnt carbon losses	%	2,5	2,5	2,5
Radiation losses	%	0,3	0,3	0,3
Other losses	%	0,4	0,4	0,4
Gross calorific value	kJ/kg	9.583	11.029	17.295
Total steam generated	t/h	**525**	**554 (+ 5,5 %)**	**621 (+ 18,3 %)**
Boiler eff. (GCV)	%	**~ 69**	**~ 72,7**	**~ 81,3**

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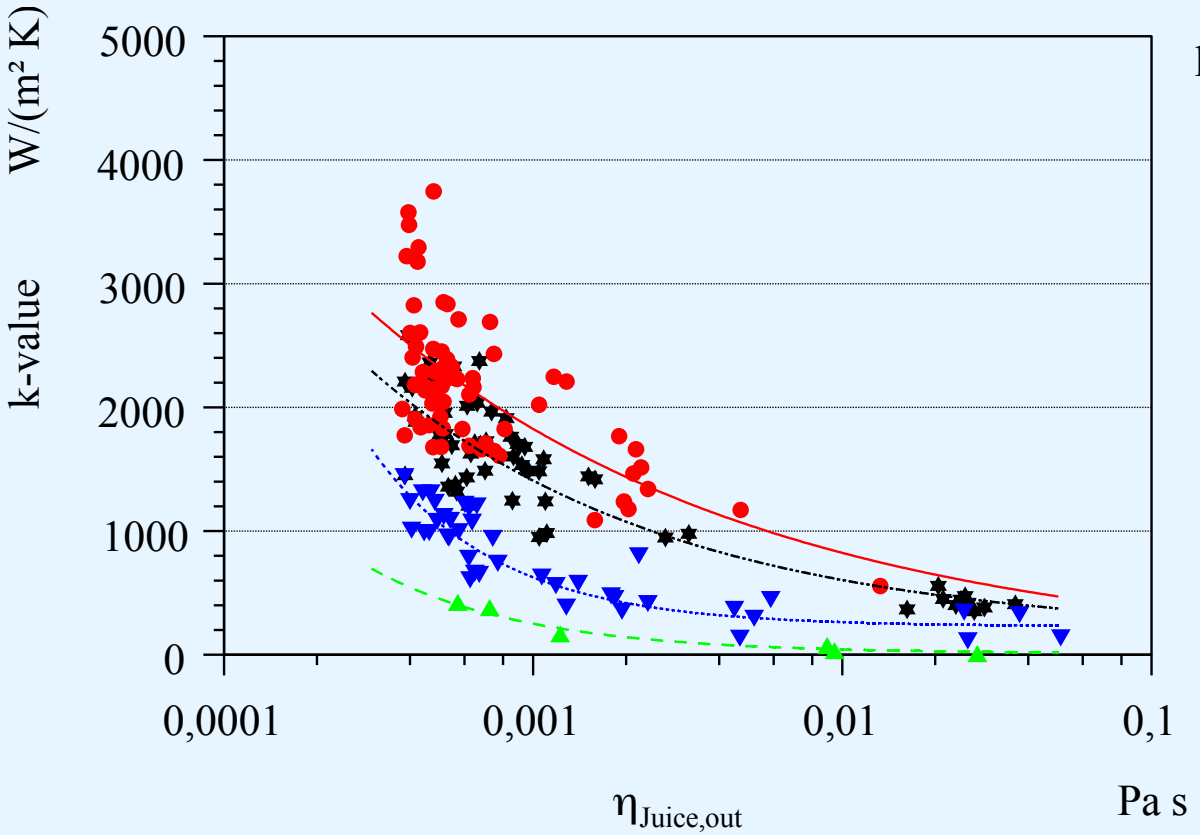
Application of bagasse steam drying

Excess power generated by applying different operational scenarios

		Scenario 1	Scenario 2	Scenario 3
		No drying	Flue gas dry.	Steam drying
Assumed spec. electrical power demand	kWh/t cane	**28**	**29**	**29**
Total Power production	MW	126,6	134,7	145
Excess power production	MW	103,3	110,5	120,9
Specific power production	kWh/t cane	**152**	**162**	**174**
Specific power export	kWh/t cane	**124**	**133**	**145**
Total annual excess power production	MWh	**446.200**	**477.400** (+ 7 %)	**522.300** (+17%)

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Influence of the specific heat flow on the evaporator performance (k-value)



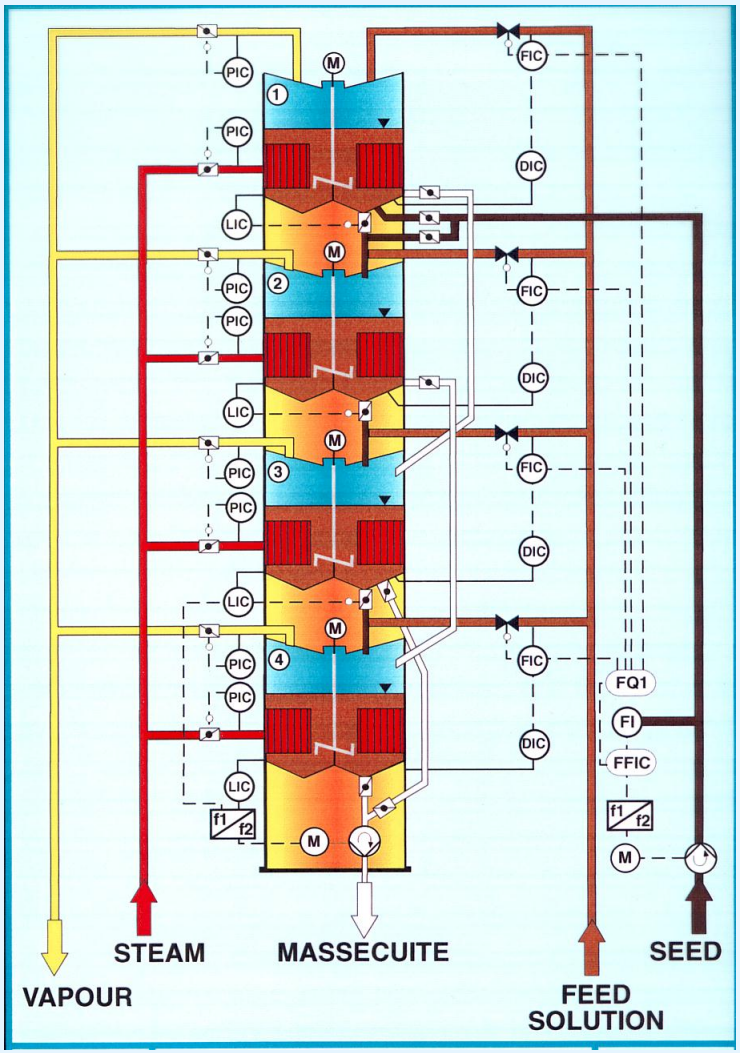
k-values for Robert Evaporators

- k-value for $\dot{q}$ = 12...25 kW/m²
- k-value for $\dot{q}$ = 7...12 kW/m²
- k-value for $\dot{q}$ = 1,5...7 kW/m²
- k-value for $\dot{q}$ = 0...1,5 kW/m²

Robert evaporators do not perform in case of low pressure and temperature differences!

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Discontinuous versus continuous pans



Continuous pans are not crucial for the given concepts.

However, they offer saving in footprint and allow a smoother operation.

Vertical or horizontal systems can be employed.

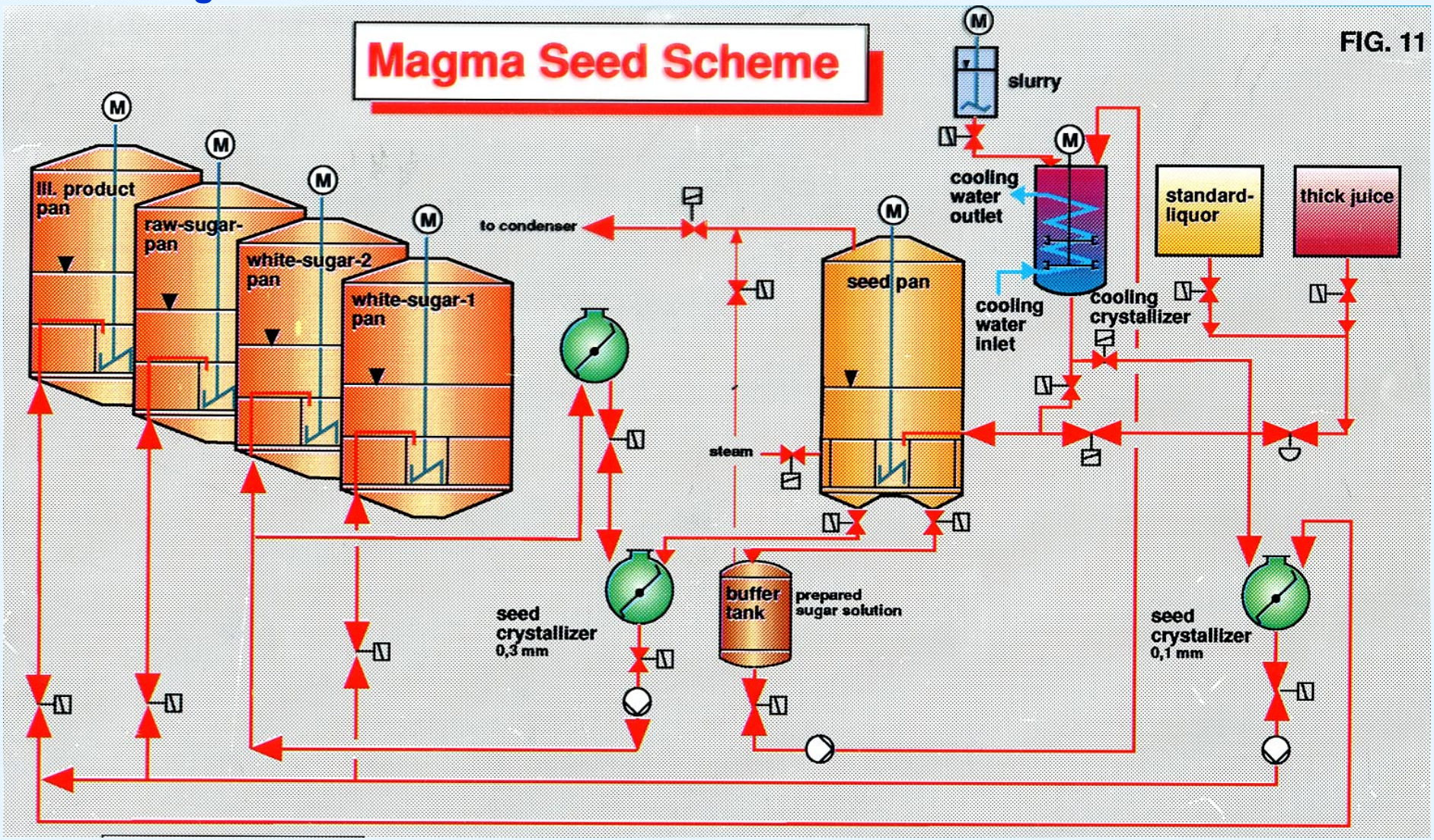
Go for reputed suppliers!

BMA VKT



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Seed magma schemes



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Effect			1	2	3a	3b	4	5
Steam	p_{St}	kPa	230	200	167	167	130	93
	t_{St}	°C	124,8	120,2	114,7	114,7	107,1	97,7
	m_{St}	t/h	158	148	73	72	44	14,5
Vapour	p_{Va}	kPa	200	167	130	143	93	60
	t_{Va}	°C	120,2	114,7	107,1	110	97,7	85,9
	m_{Va}	t/h	155	149	75	62	45	16,4
Juice, in	w_{DS}	%	17,6	23,9	36,4	15,9	49,4	63
	t_J	°C	120,4	120,8	115,8	103,7	108,9	101,5
	m_J	t/h	588	433	284	651	209	164
Juice, out	w_{DS}	%	23,9	36,4	49,4	17,6	63	70
	t_J	°C	120,8	115,8	108,9	110,4	101,5	91,3
	ΔT	K	4,6	5,5	7,6	4,7	9,4	11,8
	$\Delta T_{eff.}$	K	4	4,4	5,8	4,3	5,6	6,4
	k-value	W/(m²K)	3000	2500	1900	2500	1200	700

Crushing rate: 21528 t/d

Heat losses: 1,5 %

q syrup = 88 %

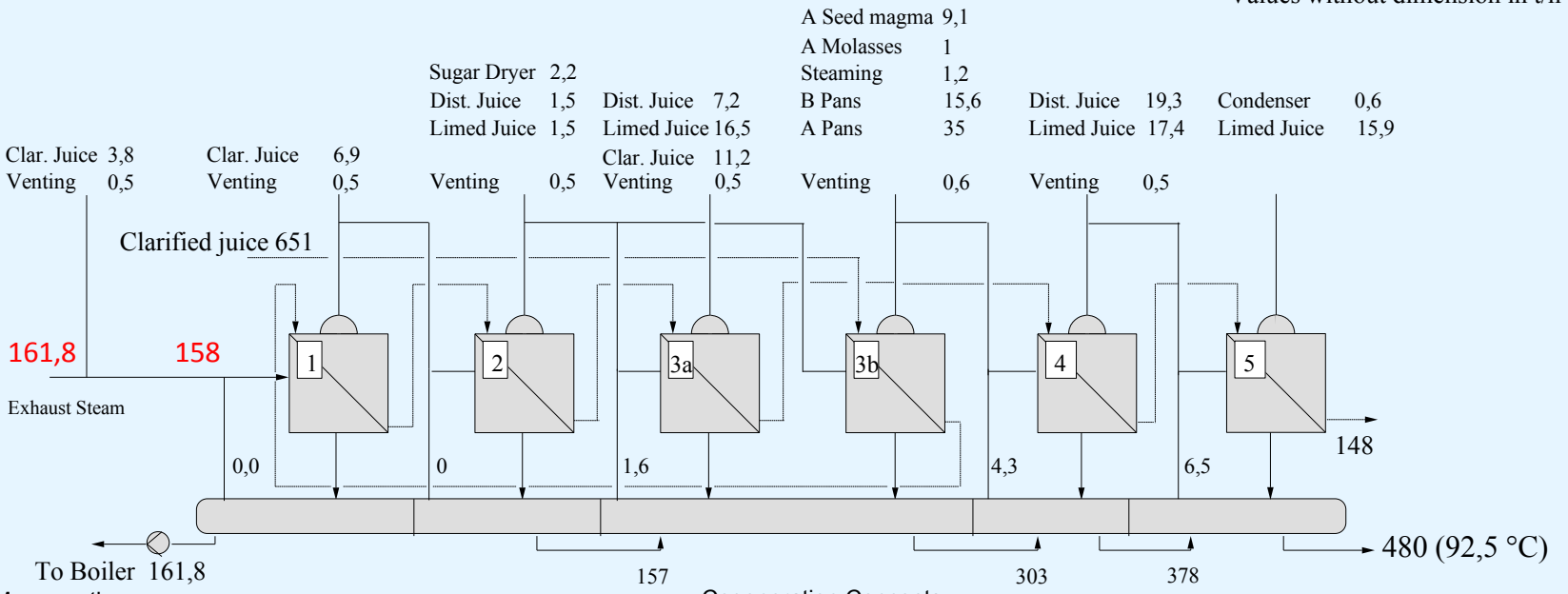
Heating Surfaces

1	8000	m² Plate (2 units)
2	8000	m² Plate (2 units)
3a	4000	m² Plate (2 units former 1st)
3b	4000	m² Plate (2 units former 1st)
4	4000	m² Plate (2 units)
5	2000	m² Plate (2 units)

30000 m² Σ 1,4 m²/t

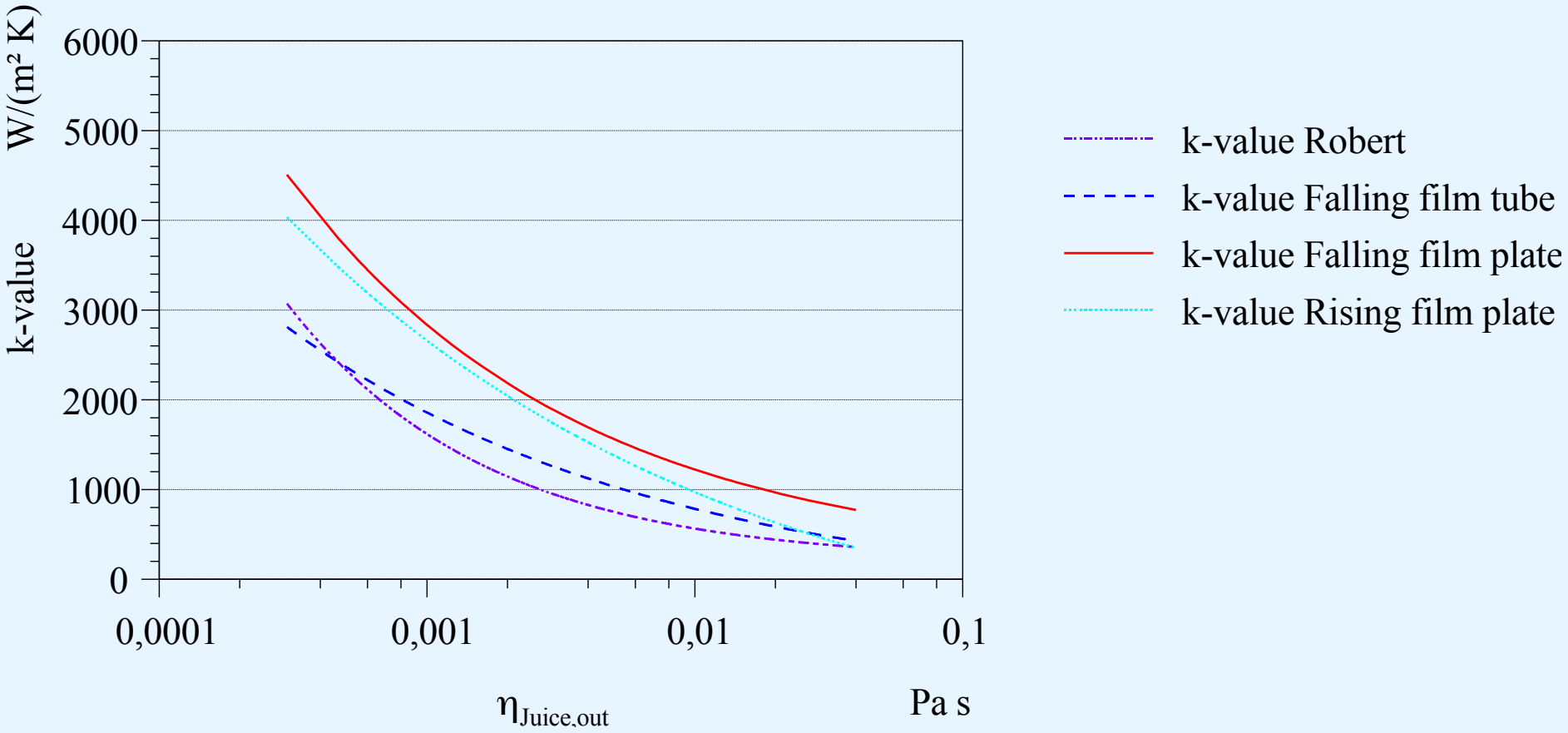
Steam demand: 18 % on Cane

Values without dimension in t/h



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Evaporator performance (k-value) for different viscosities and evaporator types



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