



Process Design For Optimum Energy Efficiency

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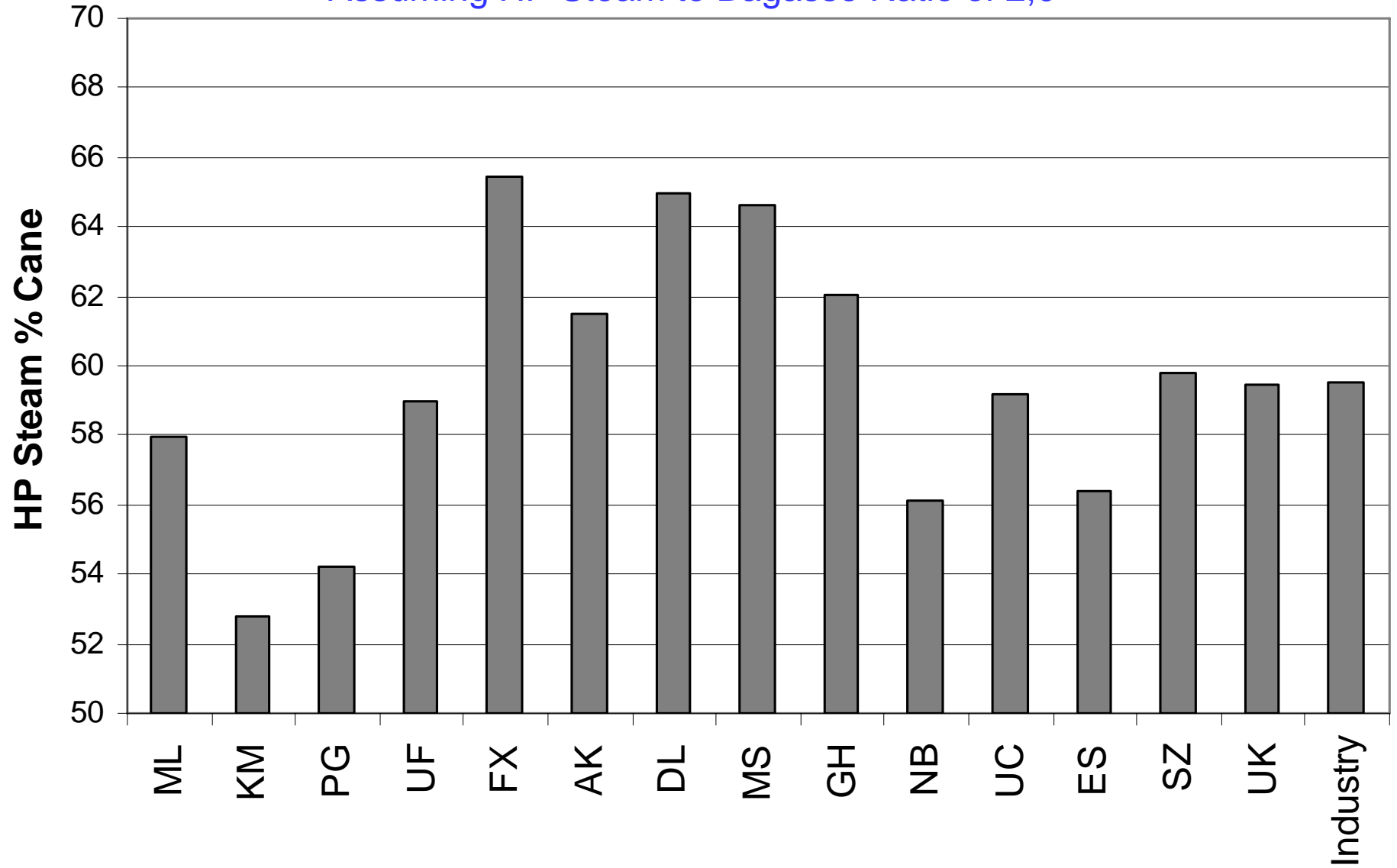
INTRODUCTION

- The average SA sugar factory has a bagasse supply capable of supporting a steam on cane of just under 60%
 - Assuming no bagasse export



2007 Data

Assuming HP Steam to Bagasse Ratio of 2,0



INTRODUCTION

- Traditional factory design focused on achieving a fuel balance :
 - Minimising the purchase of supplementary fuel (coal)
 - Avoiding the generation of an bagasse surplus
 - Hiding it under the GM's office carpet
 - Giving it to the staff at Christmas, etc.
- The emphasis on co-product production and energy export has changed industry thinking



INTRODUCTION

- Traditional steam % cane values ranged between 55 and 60%
- The current energy focus has lowered the target values. The achievable lower limit is currently estimated to be :
 - Reid & Rein (1983) – 37%
 - Singh *et al.* (1997) – 49% (*with back-end refinery*)
 - Broadfoot (2001) – 33%
 - Reid (2006) – 35%
 - Sharma & Peacock (2008) – 38%



INTRODUCTION

- We need to distinguish between HP steam % cane and process steam % cane
 - There can be a substantial difference
 - Low values quoted in the literature refer to process steam only (at steady-state)
- For a non-cogeneration factory, HP steam % cane values of between 45% and 50% are readily achievable under SA conditions



INTRODUCTION

- The lower steam to cane ratios require a decrease in imbibition rate below SA values
 - The sacrifice of sugar recovery in the interests of energy efficiency is currently looking good
(Details to come)



INTRODUCTION

- There is generally no reason why a sugar mill should **have to** continually consume coal during normal operation
 - Unless it is carrying out **substantial:**
 - Export of bagasse
 - Export of energy (steam, electrical power)
 - Supply of utilities to back-end operations (refinery, ethanol plant, etc.)

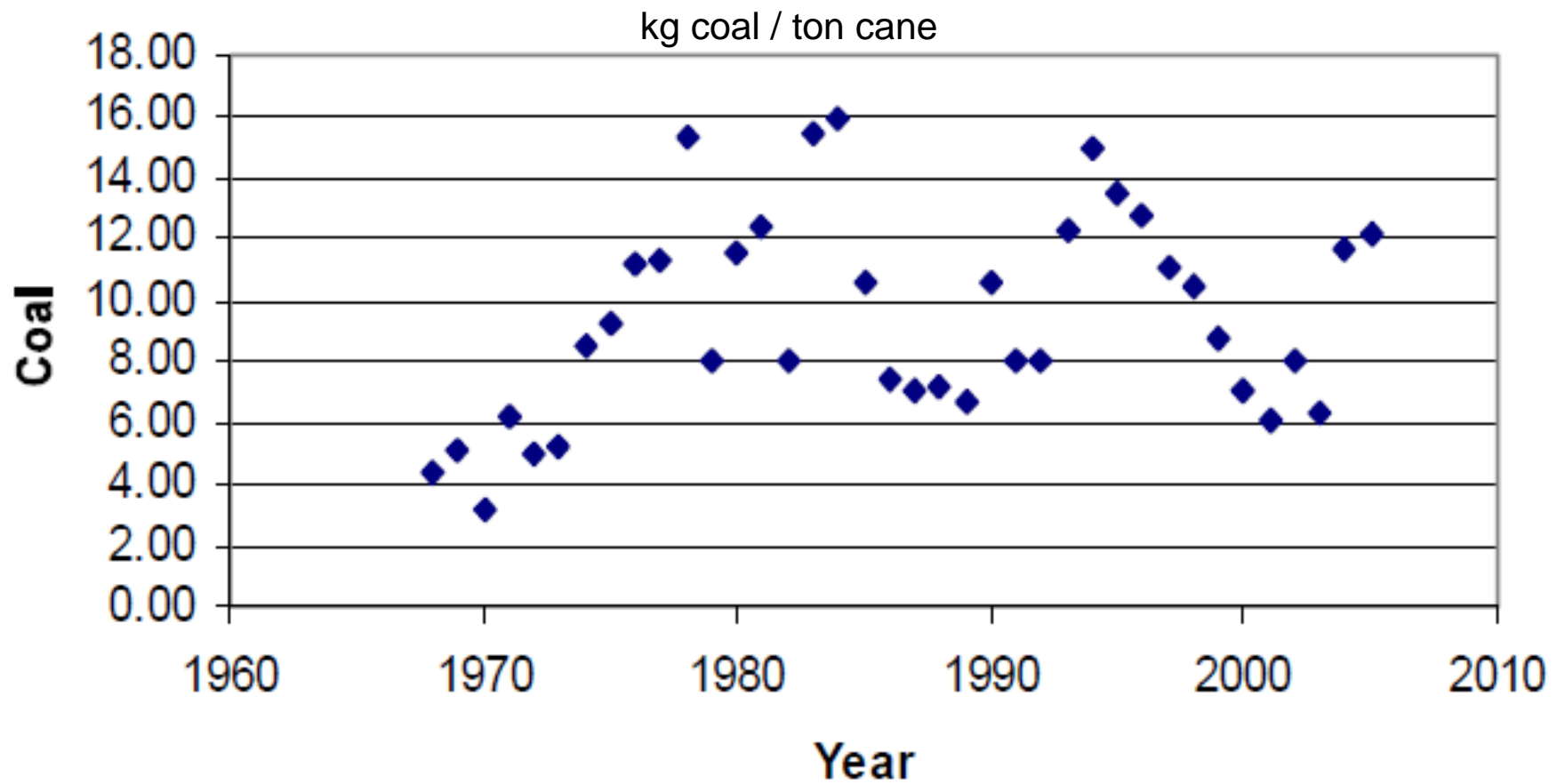


INTRODUCTION

- **However, increasing energy efficiency costs money**
 - Standard factory designs are cheap, but can lead to high operating expenses for supplementary fuel
 - Energy-efficiency generally requires more equipment (particularly heating surface in heaters & evaporators)
- **There is a trade-off between capital cost and operating expenses that needs to be investigated**



Reid, M.J. (2006), "Why do we continue to burn so much coal?", *SASTA*, **80**, 353-363.



INTRODUCTION

- The SA industry continues to burn substantial quantities of coal. This means that either :
 - The trade-off has been investigated by all mills and a conscious decision made to prefer operating expenditure to capital investment (yeah, right), or
 - Some of us haven't bothered to do anything while the cost of coal has dramatically increased



ENERGY
EFFICIENCY

ENERGY EFFICIENCY

- The principles of process energy efficiency in a sugar factory are fairly simple :
 - Reduce the amount of steam / vapour consumption
 - Make use of lower-grade vapours for heating purposes
- The basic principle of vapour bleeding
 - If 1 ton of evaporator bleed vapour from effect “n” in an “N”-effect evaporator station is substituted for exhaust steam, then the saving in exhaust steam consumption is “n/N” tons.



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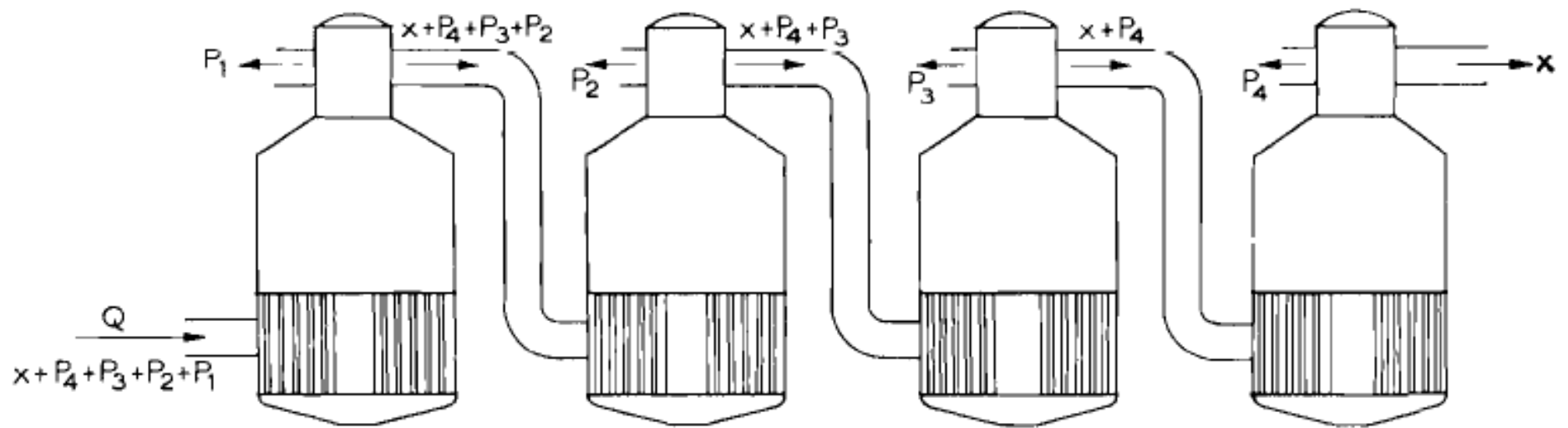


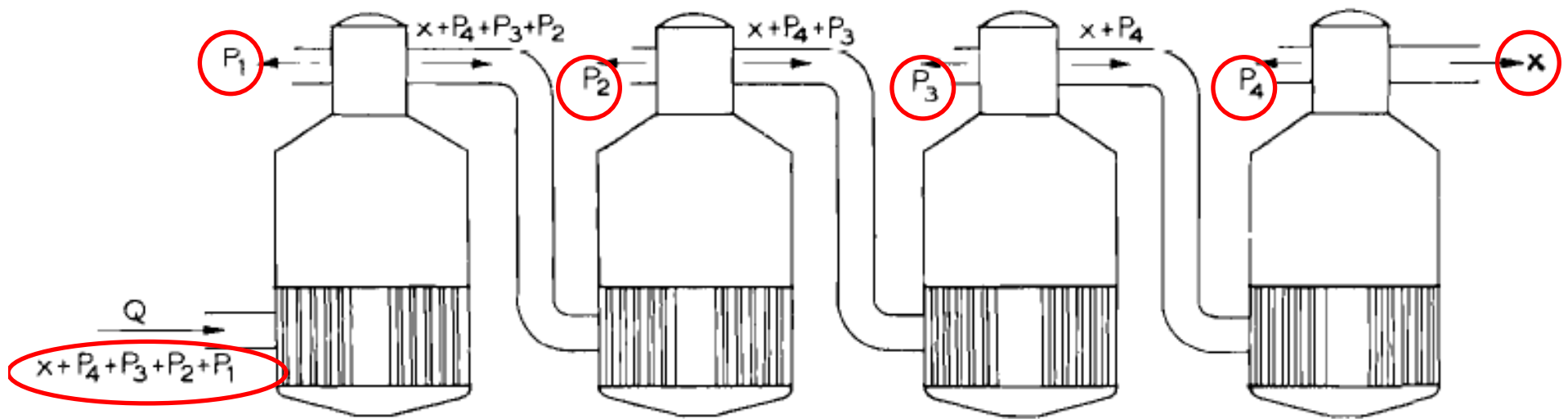
ENERGY EFFICIENCY

- The evaporator station is the heart of the sugar factory energy system
 - It is the largest consumer of process steam
 - It provides the vapour bleed streams used for the other heating duties in the factory
 - Understanding the behaviour of the evaporator station is key to energy efficiency
 - Much like a cornered sugar technologist - It will only take a limited amount of abuse before fighting back



Assuming that 1 ton of steam evaporates 1 ton of water



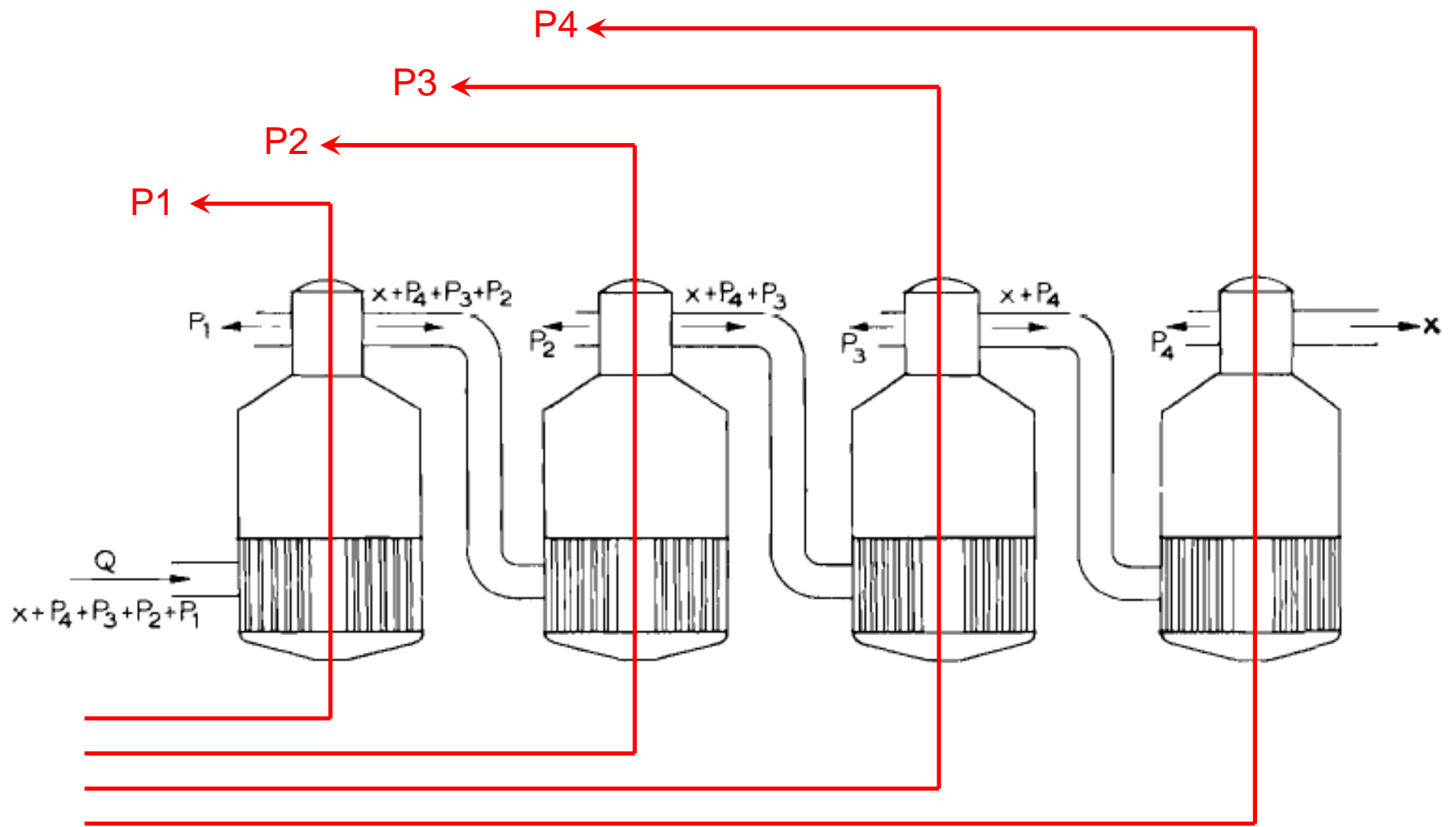


Exhaust IN = Vapour Bleeds OUT
(Including vapour to the condenser)

ENERGY EFFICIENCY

- Saving energy by reducing steam / vapour demand is a no-brainer...
 - Reducing the bleed flow reduces the exhaust demand
- How does the use of low-grade bleeds improve energy efficiency ?



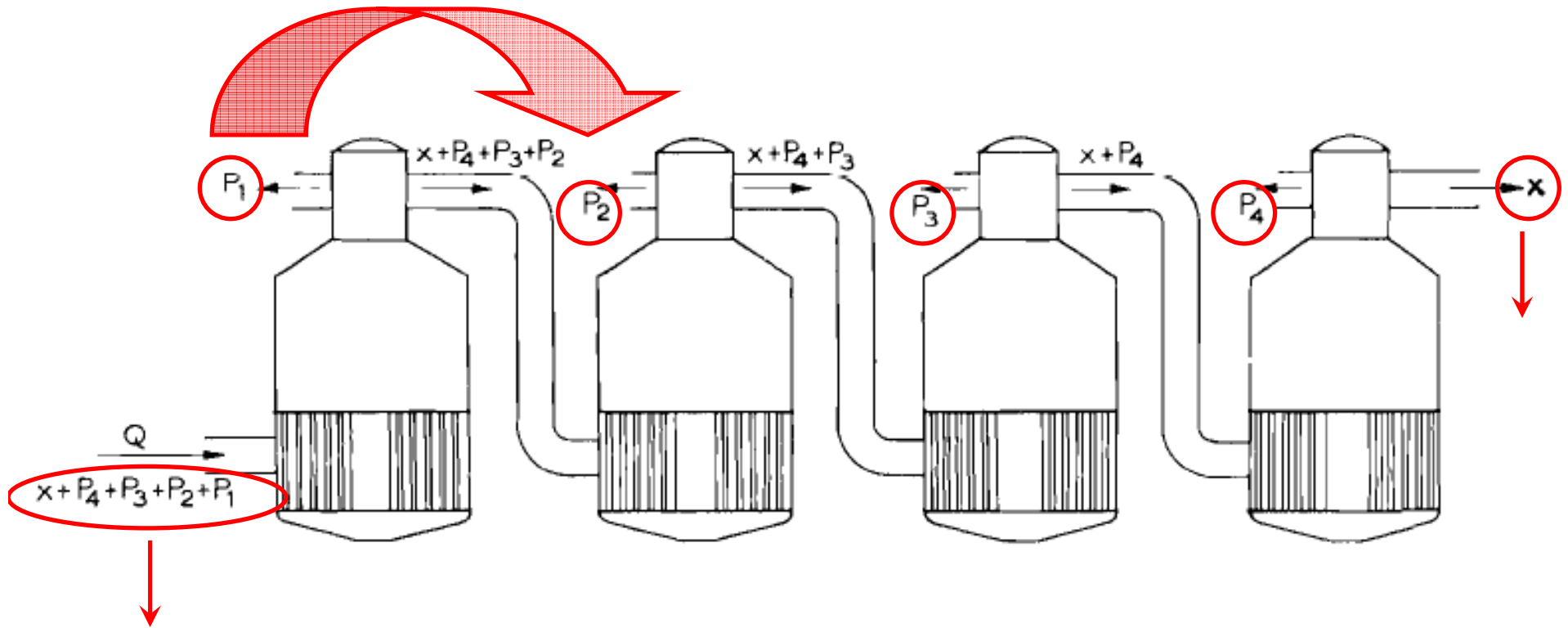


ENERGY EFFICIENCY

- Moving vapour demand to a lower-grade supply of vapour (e.g. from V1 to V2) reduces the **residual** amount of evaporation that needs to be done in the rest of the tail
 - Ultimately, this reduces the amount of final effect vapour entering the condenser “x”



Moving bleed from V1 to V2 reduces "x", which reduces the exhaust steam demand



Exhaust IN = Vapour Bleeds OUT
(Including vapour to the condenser)

ENERGY EFFICIENCY

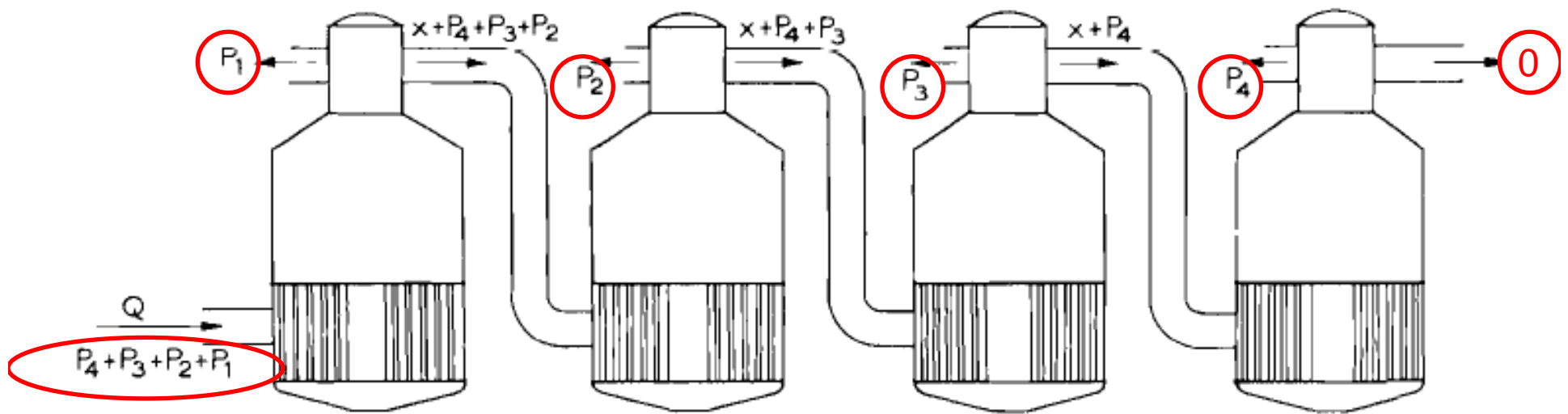
- Energy efficiency reduces to one simple rule ...
- The **only** way to increase process energy efficiency in a sugar factory is to reduce steam / vapour demand :
 - This includes vapour “demand” by the condenser, which is reduced by optimal design of the evaporator station & bleed vapour configuration
 - But there are limits !



ENERGY EFFICIENCY

- You cannot evaporate more water from the juice than you can evaporate from the juice (duh !)
 - The juice can only go to 65 – 70% brix
 - It is easy to over-concentrate the juice by moving most of your heating to low-grade vapour supplies (V2, V3 & V4)
- In this case, there is no vapour left for the final effect condenser ($x = 0$)





Exhaust IN = Vapour Bleeds OUT

(Zero vapour to the condenser = maximum energy efficiency)

ENERGY EFFICIENCY

- **With zero vapour flow to the condenser :**
 - No energy efficiency improvement can be obtained by moving vapour bleeds around
 - Control of the evaporation from the juice becomes more difficult & sensitive to the bleed flow rates (see Sharma & Peacock, 2008)
 - Any increase in bleed flows will require an equal increase in exhaust steam consumption
 - So you can meet it by letting down exhaust steam



PROCESS
DESIGN FOR
ENERGY
EFFICIENCY

PROCESS DESIGN

- Several basic process design options are available for improving energy efficiency
 - Many are described here, with simple cost-benefit analyses for some of the options
 - Several others are available
 - In this investigation, no attempt has been made to carry out structural changes to the operation, such as
 - The boiling scheme
 - The quality of sugar produced
 - Etc, etc



PROCESS DESIGN

- Process design should not attempt to “design in” operational behaviour, such as :
 - Improvements in A-exhaustion
 - Reductions in water usage, etc
- This should only be done where such improvements are easily achieved as a result of equipment or process changes (and can thus be “guaranteed”)



SIMPLE OPTIONS

- A number of simple (& obvious) options exist for increasing energy efficiency. These include :
 - Increasing the number of evaporator effects
 - Two-stage mixed juice heating using V2 & V1
 - Two-stage clear juice heating using V1 & exhaust
 - Using V2 vapour for diffuser heating
 - Using V2 vapour for pan boiling
 - Recycling clarifier mud to the diffuser



SIMPLE OPTIONS

- **Increasing the number of evaporator effects**
 - While there is still final effect vapour passing to the condenser, this will reduce the exhaust steam demand of the evaporator station
 - This happens because the “remaining” evaporation of the juice (after the bleed vapour has been withdrawn) is carried out in more effects. This reduces the flow “x” of vapour to the condenser



SIMPLE OPTIONS

- **Increasing the number of evaporator effects**
 - Requires the installation of additional surface area
 - Quintuple effect evaporator stations are economically viable. Increasing the number of effects beyond this does not generally appear to be
 - There are other ways of reducing the flow of vapour to the condenser



SIMPLE OPTIONS

- Use of V2 vapour for diffuser heating, juice heating and pan boiling
 - Leads to substantial energy efficiency benefits
 - Requires the installation of additional surface area in the evaporator station to supply V2 bleed vapour at a suitable pressure for factory use
 - Typically 120 - 130 kPa(a)



SIMPLE OPTIONS

- **The use of V2 vapour for pan boiling**
 - Is relatively simple in continuous pans, which can typically operate at sub-atmospheric calandria pressures
 - Use in batch pans is facilitated by the use of pan stirrers to assist circulation
 - Unstirred pans may “lose” some of their effective volumetric capacity if they are not designed for good circulation at lower vapour supply pressures



SIMPLE OPTIONS

- No cost-benefit analysis has been carried out for these options
 - They have already been implemented in THS mills
 - They typically have extremely good economic returns and are fairly obvious and widespread

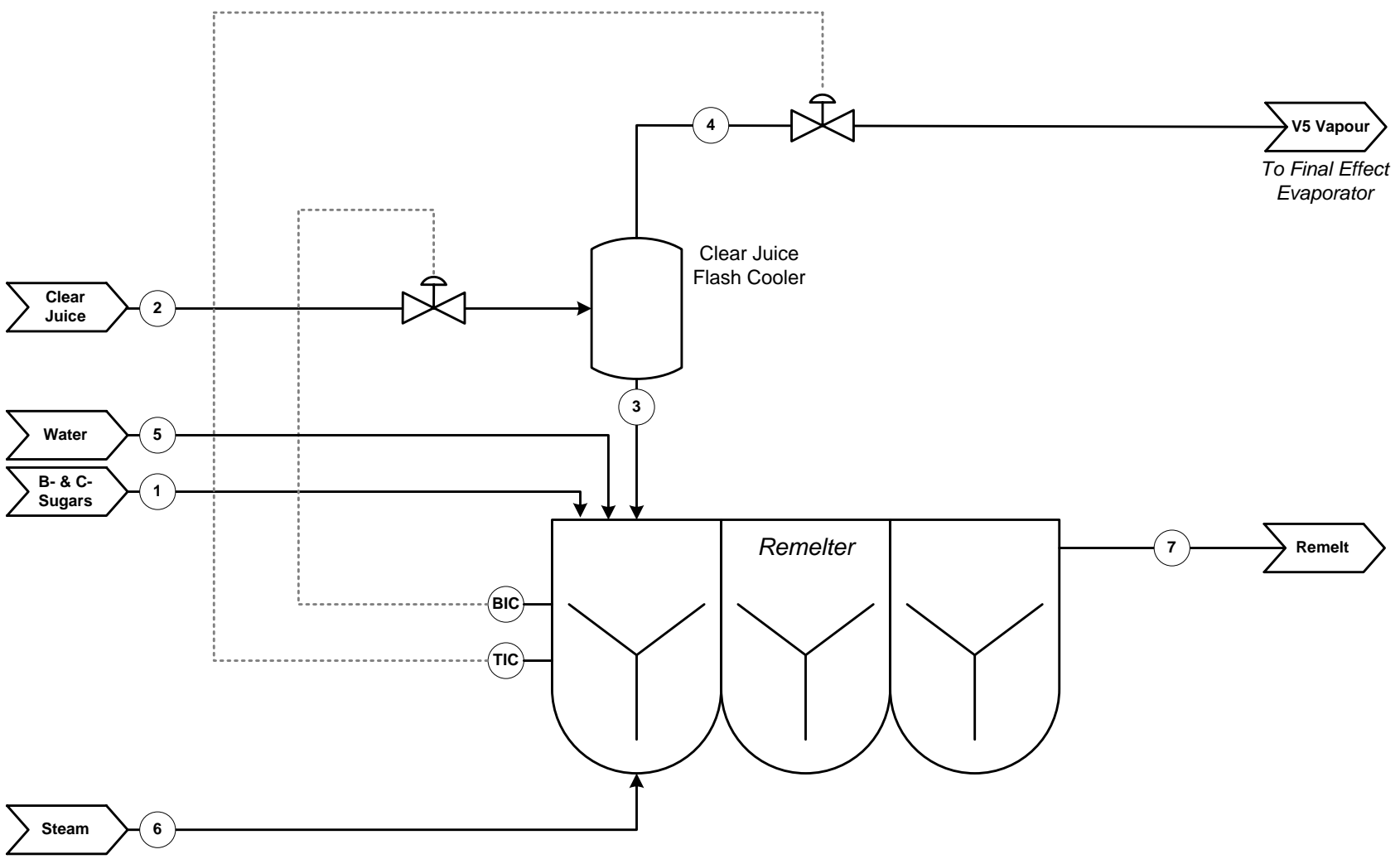


**MORE
"ADVANCED"
OPTIONS**

ADVANCED OPTIONS

- **Using clear juice in the remelter & pans**
 - Clear juice is used as a substitute for water
 - The juice is now evaporated in single effect pan boiling rather than in a multiple effect evaporator station, however:
 - You were going to add water anyway
 - The juice used on the pan floor now bypasses the evaporator station
 - A disadvantage is that it reduces the amount of evaporation to be done
 - There is now less water in the juice available for vapour bleed production





ADVANCED OPTIONS

- **Using clear juice in the remelter & pans**
 - Using clear juice instead of movement water in the A-pans reduces the effective “pan factor”
 - Pan factor is the tonnage of steam used to evaporate each ton of water during pan boiling (typically 130%)
 - Clear juice can also be used for preparing B-magma and in the B-seed pans
 - **Reduces steam / vapour demand through direct reduction as well as impact on condenser losses**



ADVANCED OPTIONS

- Using clear juice in the remelter and pans
 - Reduces HP steam % cane by 1% - 3%
 - Has a very low capital cost implication (estimated to be between R 1 million and R 2,5 million)
 - Piping costs
 - Clear juice flash cooler
 - Instrumentation
 - Payback period between 1 and 2 years



ADVANCED OPTIONS

- **Direct contact press water heating**
 - Heating carried out using low grade V3 vapour
 - Direct contact heating has a low capital cost
 - Water addition into the end of the diffuser has zero effect on energy efficiency
 - It effectively acts like extra imbibition
 - **Reduces condenser losses**



ADVANCED OPTIONS

- **Direct contact press water heating**
 - Reduces HP steam % cane by around 1%
 - Has reasonably low capital cost (estimated to be between R 2,5 million and R 3,5 million)
 - Piping costs
 - Direct contact heat exchanger
 - Instrumentation
 - Payback period around 2½ years



ADVANCED OPTIONS

- **Three-stage mixed juice heating**
 - Mixed juice heating is generally carried out using V1 vapour or a combination of V1 and V2 vapour (two-stage heating)
 - Energy efficiency can be improved by adding a third (primary) stage using V3 vapour
 - **Reduces condenser losses**



ADVANCED OPTIONS

- **Three-stage mixed juice heating**
 - Reduces HP steam % cane by 1% - 2%
 - Fairly high capital cost (estimated to be between R 8 million and R 10 million)
 - Shell and tube heat exchanger/s
 - Piping costs
 - Upgrade of mixed juice pumps
 - Payback period between 4 and 7 years



ADVANCED OPTIONS

- **Four-stage mixed juice heating**
 - Following on from three-stage heating, energy efficiency can be further improved by adding a fourth stage using V4 vapour
 - Only has real potential in a factory with a milling tandem, or where the draft juice temperature from the diffuser is reduced
 - **Reduces condenser losses**



ADVANCED OPTIONS

- **Four-stage mixed juice heating**
 - Reduces HP steam % cane by less than 1% for a diffuser factory
 - Fairly high capital cost (estimated to be between R 6 million and R 8 million)
 - Shell and tube heat exchanger/s
 - Piping costs
 - Upgrade of mixed juice pumps
 - Payback period around 6 or 7 years



ADVANCED OPTIONS

- Using V3 & V4 for juice heating
 - May require evaporator station modifications or the installation of additional surface area in order to boost the pressure of the V3 or V4 bleed streams
 - Depends on the existing evaporator station configuration
 - This will obviously increase the capital cost



ADVANCED OPTIONS

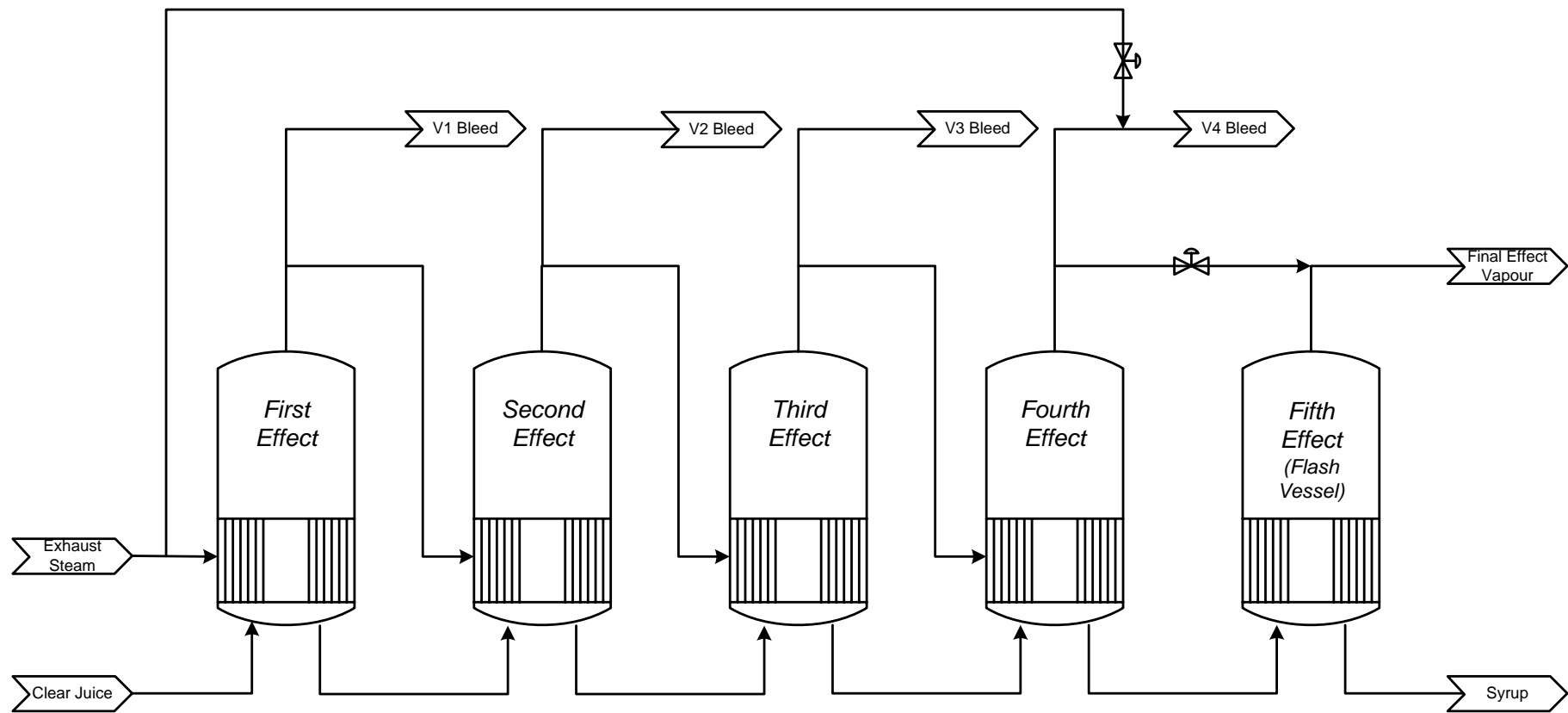
- Using V3 vapour for pan boiling
 - Probably only feasible for continuous pans, due to the low vapour supply pressure
 - Requires evaporator station modifications (and probably more surface area) to supply suitable quantities of V3 vapour to the pan floor at an adequate pressure



ADVANCED OPTIONS

- **Using V3 vapour for pan boiling**
 - Will essentially eliminate the flow of final effect vapour to the condenser, making control of the evaporator station difficult
 - Only quadruple effect evaporator station required (with a 5th effect flash vessel for syrup cooling purposes)
 - Involves a degree of technical risk





ADVANCED OPTIONS

- Using V3 vapour for pan boiling
 - Reduces HP steam % cane by just under 2%
 - Fairly high capital cost (estimated to be between R 16 million and R 20 million)
 - Evaporator station modifications & extra capacity
 - Piping costs
 - Payback period around 7 years



ADVANCED OPTIONS

- **Electrification of turbine drives**
 - Turbines generate substantial quantities of exhaust steam
 - This may limit the ability of a factory to reduce exhaust steam consumption
 - Below a certain point, the turbines will generate more exhaust than the factory consumes, leading to blow-off



ADVANCED OPTIONS

- **Electrification of turbine drives**
 - This leads to unnecessary HP steam production to drive the turbines and to loss of high quality boiler feed water through exhaust blow-off



ADVANCED OPTIONS

- **Electrification of turbine drives**
 - Replacement of knife, shredder, mill & pressure feeder turbine drives with electric motors will result in HP steam savings
 - This is because electric power generated using a turbo-alternator uses around half the steam of motive power generated using a standard sugar industry turbine



ADVANCED OPTIONS

- **Electrification of turbine drives**
 - Reasonably high capital cost (estimated to be between R 8 million and R 20 million)
 - Electric motors
 - Switchgear, transformers, etc.
 - Payback period between 4 and 5 years



ADVANCED OPTIONS

- Further energy savings can only be achieved through direct reductions in steam / vapour consumption
 - Because the condenser losses should be around zero by this stage
 - For example:
 - Reductions in imbibition
 - Changes in operational behaviour
 - Changes in boiling scheme
 - Changes in sugar quality, etc etc



CONCLUSIONS

CONCLUSIONS

- A number of process design options exist to improve the energy efficiency of a sugar mill
- Under current conditions, many of these are economically viable for a mill that burns coal on a continuous basis
 - Economic viability will depend heavily on local conditions
 - Coal cost (increasing rapidly)
 - Existing equipment installed



CONCLUSIONS

- Using the options presented here, an existing mill should be able to reduce its HP steam demand to a value between 45% and 50% on cane
 - Equivalent to a process steam on cane of 40%
 - This is a weekly average value (at 80% OTE)
 - Not a steady-state “best case” value
 - Allows for slow crushing & all stops



CONCLUSIONS

Modification	Typical reduction in HP steam % cane	Estimated capital cost	Estimated payback period
Using clear juice in the remelter & pans	1% - 3%	R1 m - R 2,5 m	1 - 2 years
Direct contact press water heating using V3 vapour	1%	R 2,5 m - R 3,5 m	2½ years
Three-stage mixed juice heating (using V3 vapour)	1% - 2%	R 8 m - R 10 m	4 - 7 years
Four-stage mixed juice heating (using V4 vapour)	< 1%	R 6 m - R 8 m	6 - 7 years
Using V3 vapour for pan boiling	< 2%	R 16 m - R 20 m	7 years
Electrification of turbine drives	Enables reductions	R 8 m - R 20 m	4 - 5 years



CONCLUSIONS

- Some of the more “advanced” energy-saving options have payback periods greater than 5 years when implemented alone
- However, implemented as one large energy efficiency project, the various options in the table have an acceptable combined payback period
 - Particularly for a strategic project such as entry into a large-scale cogeneration market



CONCLUSIONS

- Further reductions in steam consumption are possible, but only by directly reducing the steam / vapour demand of the plant, through such actions as :
 - Operational changes (increased exhaustion, etc)
 - A reduction in imbibition (may be viable already)
 - Changes to the boiling scheme, sugar quality, etc



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