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Application of Process Intensification in starch processing

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Process Research AVEBE
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PI or π

π Contents

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- ***Introduction***
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  - *Case 2: Improved breaking with water*
- ***Stages of process intensification***
  - *Functional approach*
  - *Case 3: Washing and de-watering of starch*
  - *Implementation*
- ***Conclusions***

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π Why process innovation?

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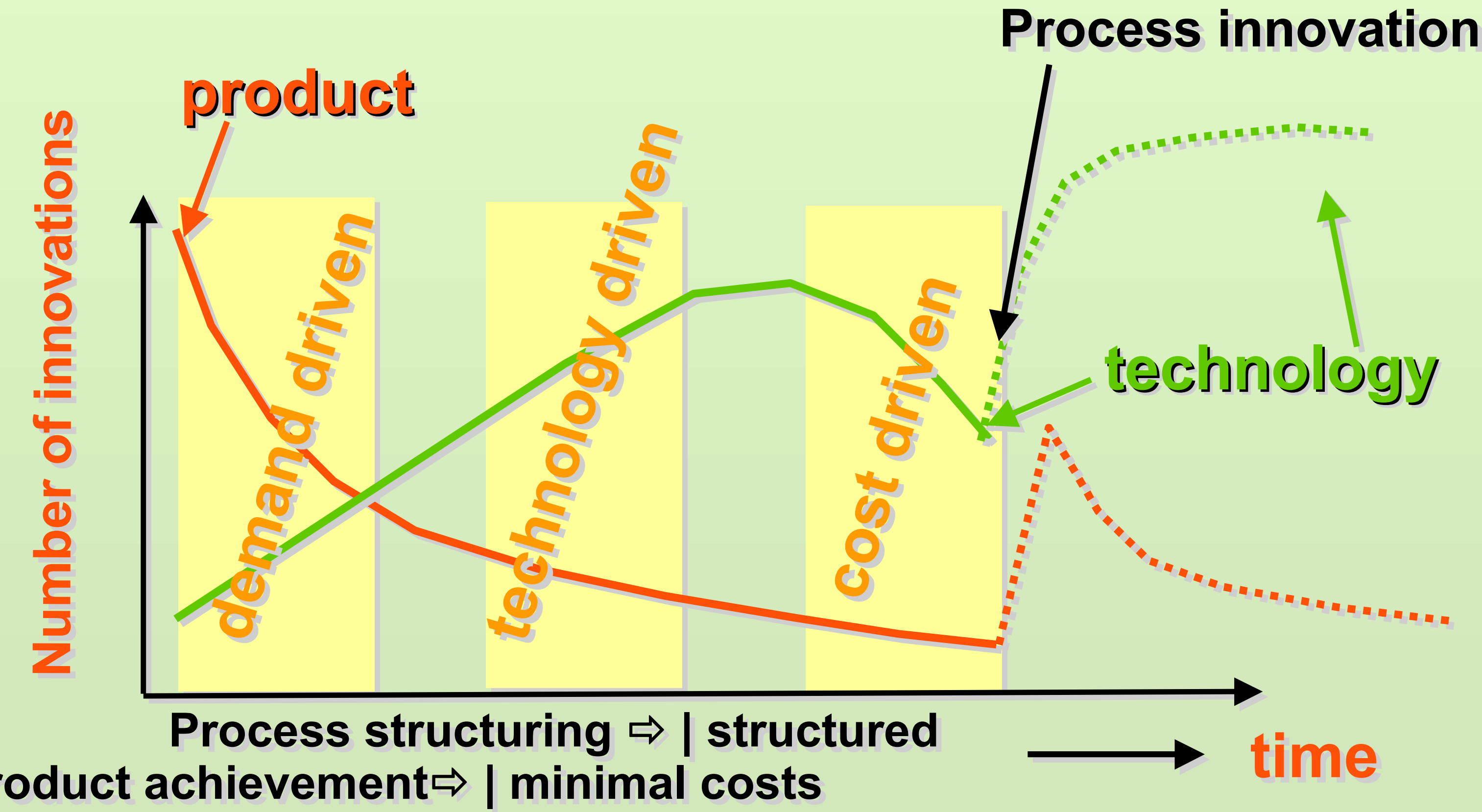
Technology and product innovation are linked.

❖The lifecycle (pull, push, cost) vs. the technology need



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π What is process intensification, PI ?

- ***A redesign method using conceptual stages focussing on functional aspects***

  driven by reducing the size of overall process lines.

- ***This in contrast to e.g. :***
  - *rearranging process units*
  - *optimising single process units*

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History of PI

Concept :

- Pioneered in ICI during the late 1970’s to reduce the capital cost
- Main Plant items : 20% of the cost.
- The balance is incurred by installation costs

A major reduction of equipment size by:

- – "telescoping" of equipment functions
- – eliminating support structure, foundations and long pipes.

Additional benefits:

- – potential by accelerating the response to market changes
- – facilitating scale-up
- – basis for rapid development of new products and processes.

π PI areas

- ***equipment***
  - *multi-functional reactors*
  - *hybrid separations*
- ***energy***
  - *alternative energy sources*
  - *integration of energy and exergy aspects*

π Changes in process design

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- ***Process design depends on business objectives not a goal on itself***
- ***Process design must include (People,Planet,Profit)***
  - *energy, sustainability,*
  - *economic, social factors*
- ***Process intensification is an opportunity.***

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π Classic design

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- ***Hierarchical procedure*** e.g. acc. Douglas (1988)
  - *decomposition to black box*
  - *conceptual design starts with black box then functional sections (unit operations) are added*
  - *early economic evaluation*
  - *hierarchy of decisions*

Creative new technology easily rejected, not implemented

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π Design by Process Systems Engineering

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Systems approach vs unit operation approach

- ***Process analysis***
  - *decompose process into functional blocks*
  - *tasks prevails over equipment*
- ***Process synthesis***
  - *black / gray box & early economic evaluation*
  - *build process systematically & document all alternatives (QFD principle)*

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π PI must be combined !

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Pre-work done by using :

- ⌧Root Cause Analysis (RCA),
- ⌧Failure Mode and Effect Analysis (FMEA)
- ⌧Theory of Constraints (TOC)
- ⌧TRIZ (by Altshuller)
- ⌧Quality Function Deployment

These tools can be used to find and to work on the real problem.

G.Poppe and B.Gras, Innovation Quotient, http://www.triz-journal.com/archives/2002/02/c/

Altshuller, The 40 TRIZ principles.

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π Examples of process intensification

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- **Novel technologies,**
  - ***hybrid systems, combined unit operations***
  - ***oscillatory flow***
  - ***micro channels***
- ***The use of alternative solvent & energy systems***
- ***Novel equipment*** */ reactors*

(separations , reaction)

- Reactive distillation
- Multifunctional reactors
- Dryer-granulators

- Microwave heating
- Eutectic freeze crystallizer
- scCO_2
- Static mixers,
- Monolithic catalysts,
- Micro reactors
- Compact heat exchangers,
- Spinning-disk reactors,
- HIGEE separators

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π Small to overcome a.o. heat and mass transfer limitations

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- Hi Gee separators

  Increase driving forces Higher mass transfer performance by centrifugal techniques. Ramshaw at ICI early 1980's

- Integrated Reactor-Heat Exchangers (HEX Reactors) vs STR

  Fast exothermic or endothermic reactions e.g. liquid-liquid extraction reactor

  Hickson & Welch: reaction time 28 h to 15 minutes

  Dow Chemical UK: reaction time 4 h to 4'. 120 T/year in 25 cc reactor.

- Spinning tube-in-tube (STT) Holl technologies
- Spinning disc reactor (SDR) by Glaxo Smith Kline (C. Ramshaw, J.R. Burns)
  - high heat transfer rate 10 kW/m2K
  - small reactor volume
  - high yield > 99.9 %, no by products (93 %reduction)
  - increased conversion rate 100x

Ref. a.o. Stankiewicz & Moulijn, Chem. Eng. Progress, Jan 2000.

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π Examples of PI in starch processing

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- ***Examples of PI in starch industry are rare :***
  - *dominated by incremental improvements*
  - *traditional industry*
  - *mature technology*

- ***General examples:***
  - *extrusion processes*
  - *membrane processes (FAIR-CT98-9154)*

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π Functions or tasks in processes

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- **_Basic functions_**
  - *chemical change*
  - *concentration change*
  - *separation*
  - *phase transition*
  - *temperature change*
  - *pressure change*
  - *form change*
- **_Example_**
  - *biochemical reactions*
  - *adding solvents*
  - *membrane*
  - *evaporation*
  - *cooling*
  - *pumping*
  - *extrusion*
- **_Many other functions!_**

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Various functions of water in starch processing

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- ∝ Dissolve
- ∝ React
- ∝ Carry
- ∝ Dilute
- ∝ Absorb & Transport heat
- ∝ Swell
- ∝ Break
- ∝ Reduce viscosity
- ∝ Product component

BUT:

- minimise use
- good quality water is becoming scarce and expensive
- mind water quality and microbial aspects

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π Case 1 : model based process redesign

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Rajaram & Corbett *UCLA* Cerestar (Cargill 2002):

5 year iterative process redesign flows and control on wheat starch plant at Sas van Gent the Netherlands.

Trigger : environmental regulation

Benefits:

- Energy consumption were reduced by 30% (50.4 MWH per day)
- Fresh water 50% and (2500 m^3 per day)
- Annual cost savings were 3 $ million.

Indirect:

- Better deeper understanding of the drivers of process performance.
- Less environmental impact ➔NO investment of $100 million for expansion of the wastewater facility.

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Ref: K.Rajaram, C.J. *Corbett* Achieving Environmental and Productivity Improvements through Model-Based Process Redesign Forthcoming in *Operations Research.*

π Case 1: basic process for modelling

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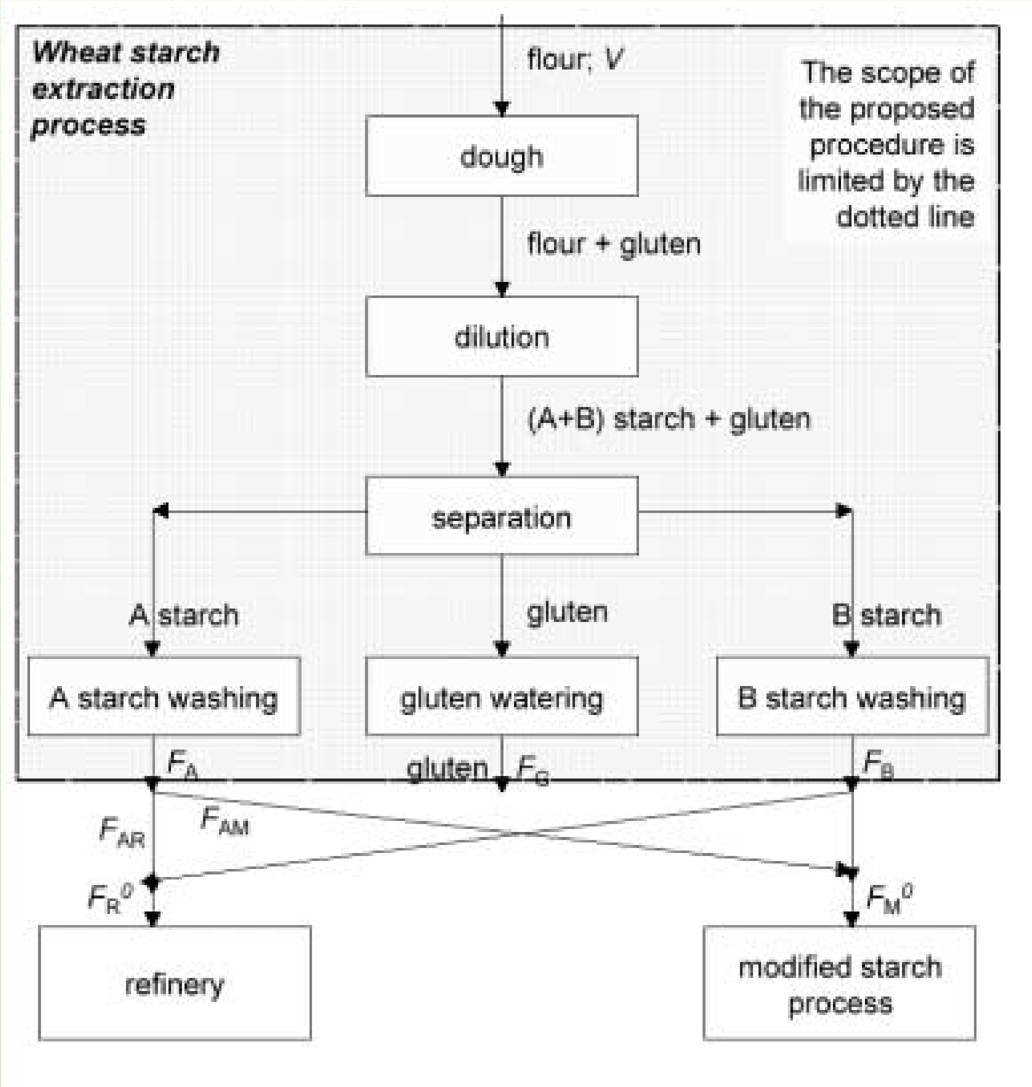

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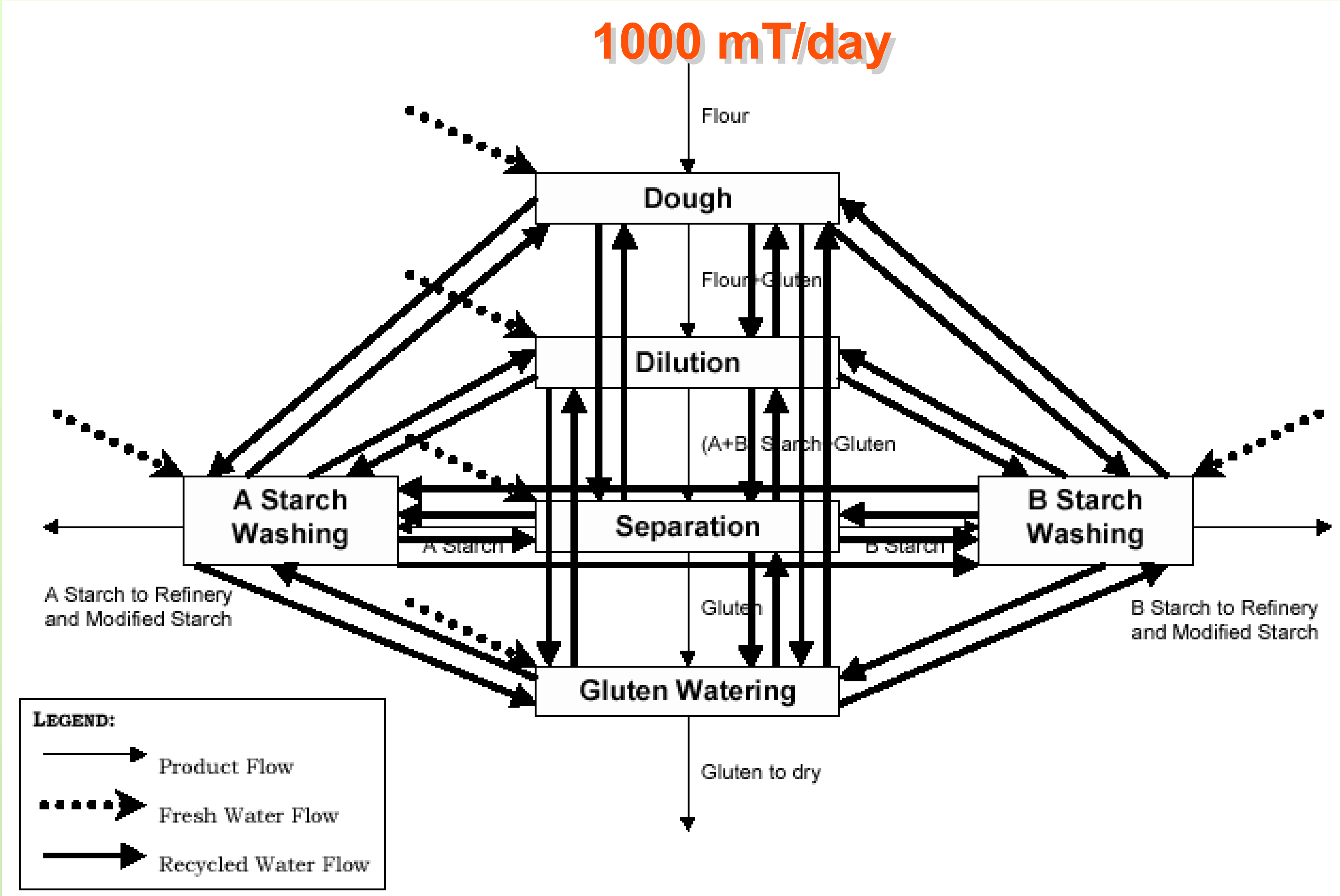
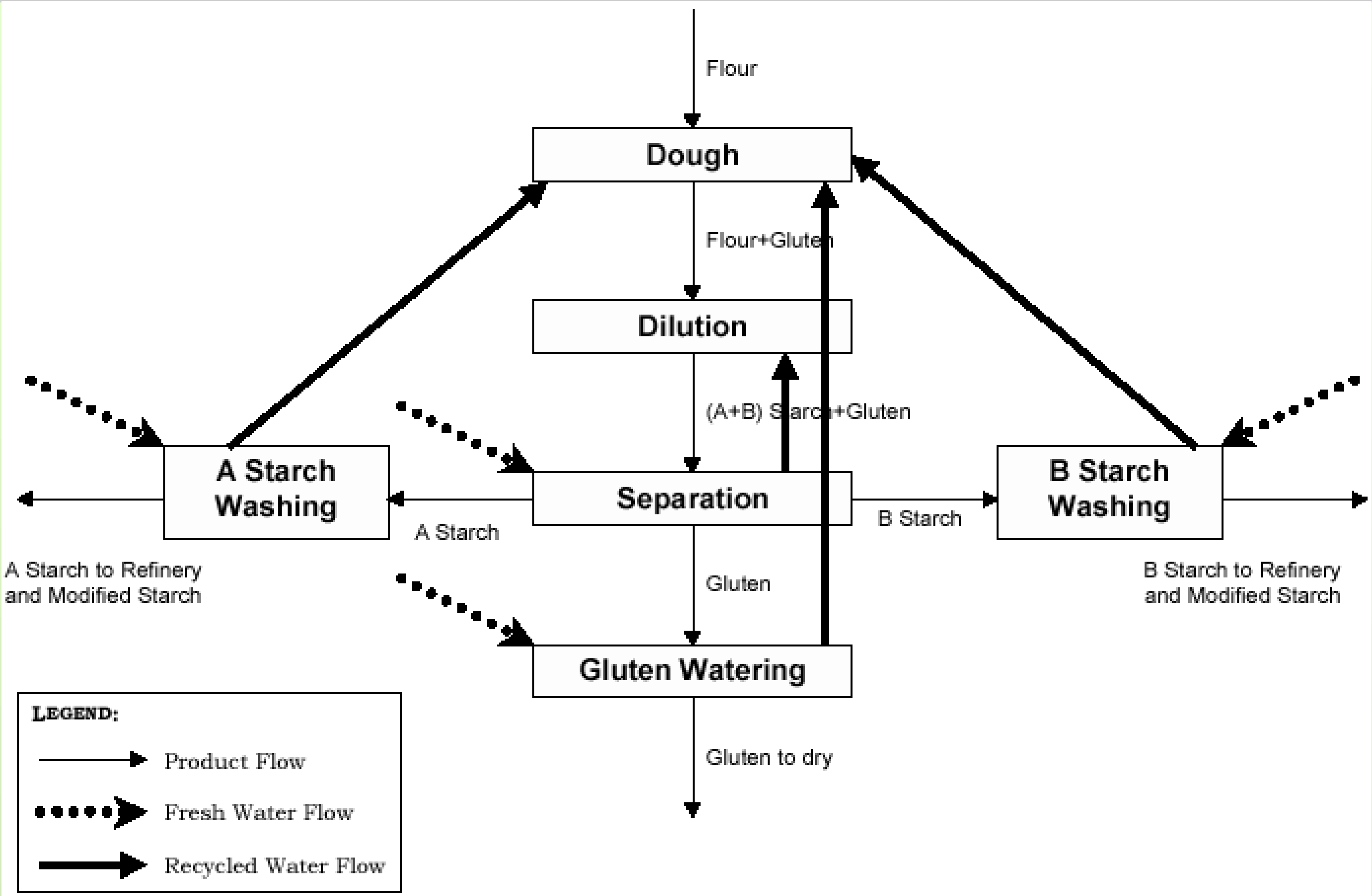
π Case 1: Flows before redesign



NB : mind the fresh vs recycled water flows

Case 1: Flows after redesign cycles



Reduction control variables: 90 ⇨ 18
75% reduction of links

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π Case 2: Functional Cryogenic breaking

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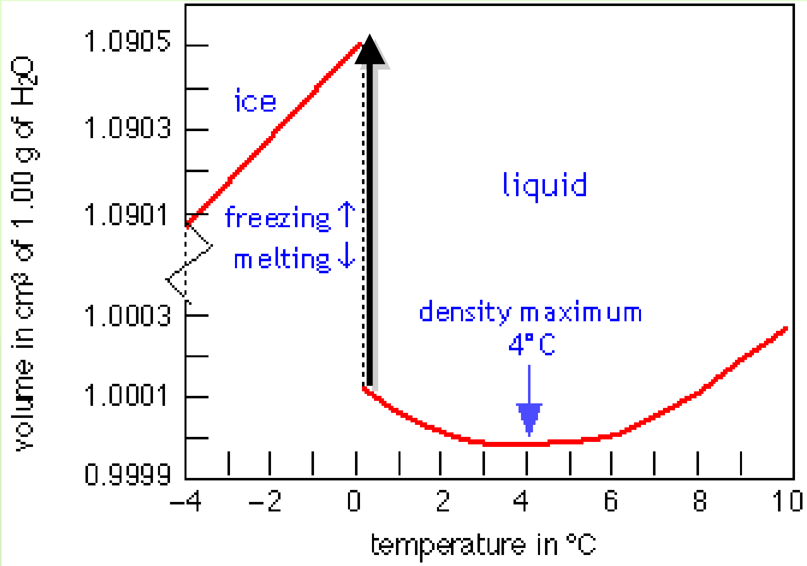
The principle in Cargill patent ***US 6368649 B1***

- Use unique function of water.
- Use water where it is needed.



- Short steeping with water
  - water content 16 to 25 % within 15-60 minutes
  - excess water removed
- Cold shock using cryogenics (liquid N_2 / CO_2)
  - freezing of water in capillaries
- Impact mill
  - starch free coarse fibres jump off
  - easy separation germ and gluten

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π Case 2: Cryogenic breaking

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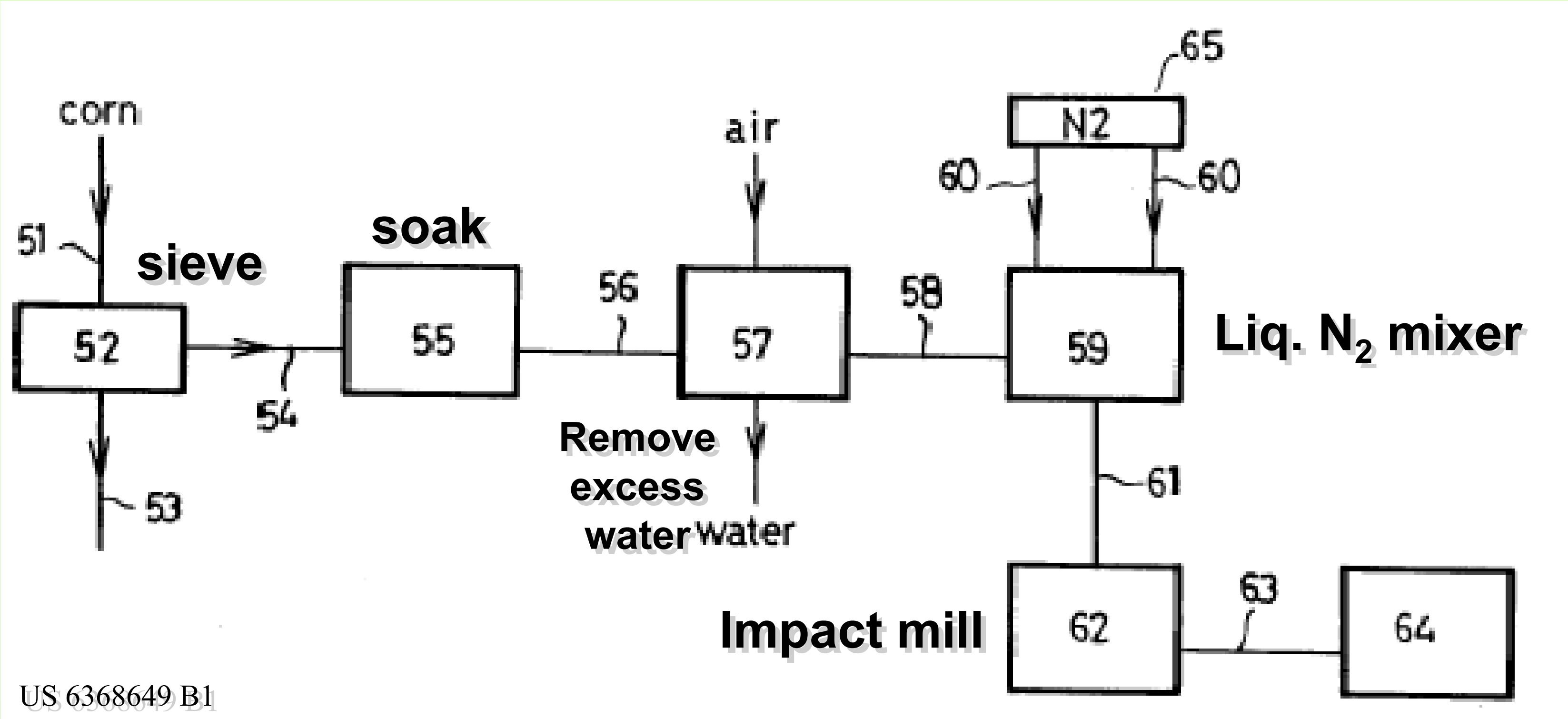

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π Wet corn processing old vs proposed

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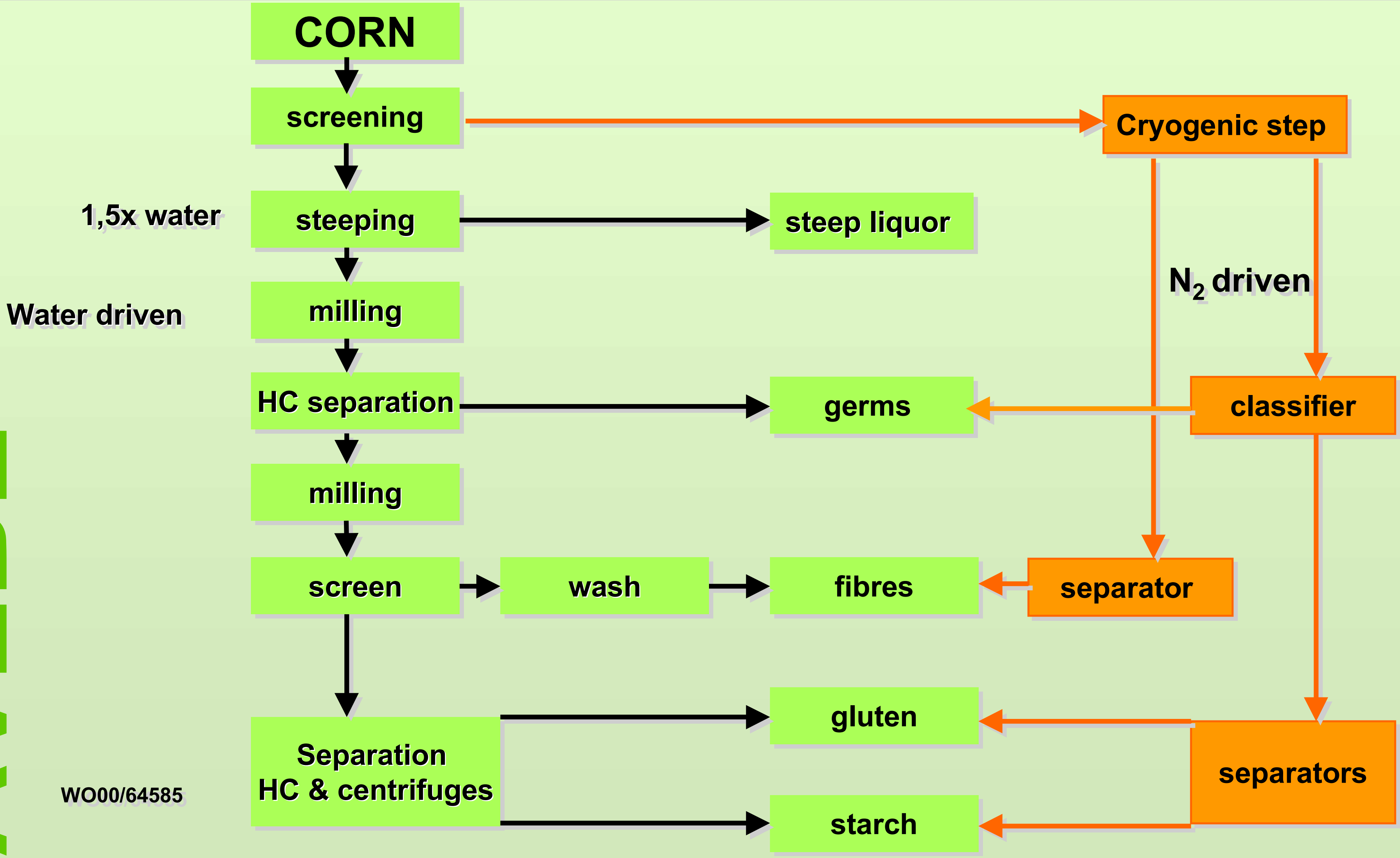

WO00/64585

π Stages of process intensification

1 Functional description of the process (line)

2 Setting theoretical maximal performances for each function

3 Recombining functional elements

4 Optimisation of functional elements to meet the theoretical performance (modelling)

5 Selected concept

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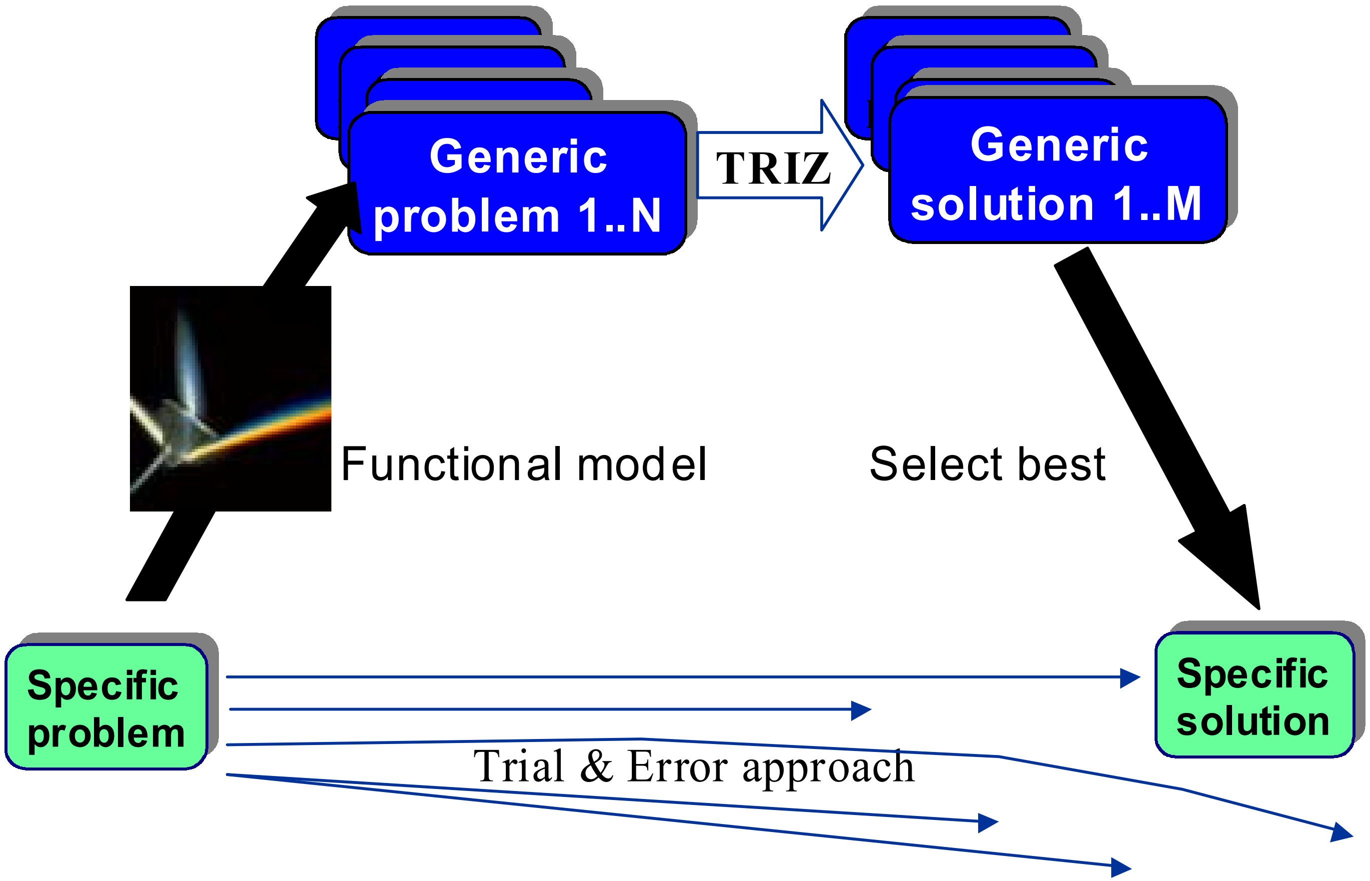
The analogy with the TRIZ methodology



π Basic tools within TRIZ

Resources

functional model

Trends of evolution	Contradictions
Segmentation	40 Principles

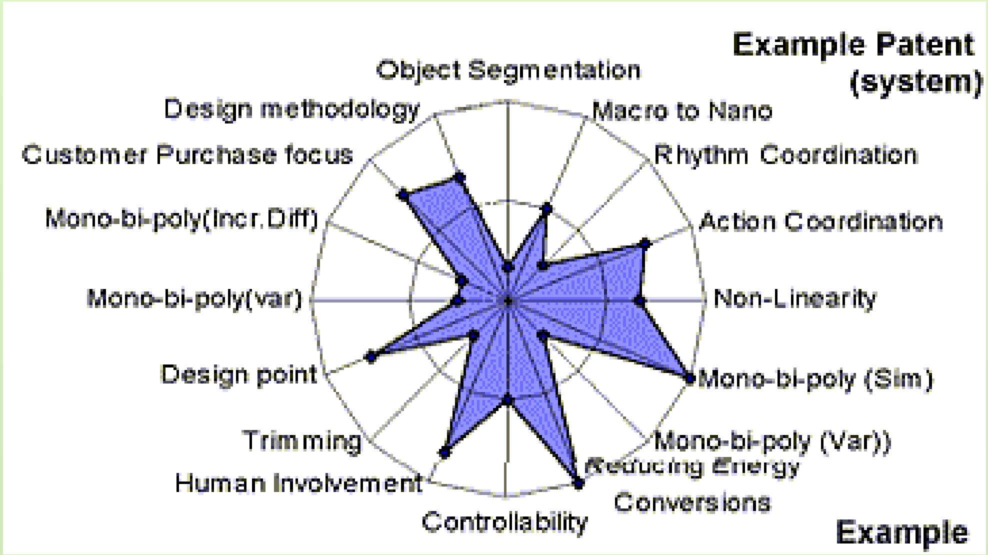
concepts

π Powerful tools

- ❒ ***Trends***

Solid ⇨ Liquid ⇨ Aerosols ⇨ Gas ⇨ Field

- ❒ **Evolutionary Potential Diagrams**



- ❒ See: Creax.com

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Case 3: Redesign washing and dewatering

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Process: Potato starch modification in Suspension

Reaction → Separation → Drying

Reaction

potato starch
reagent
catalyst
swelling inhibitors

modified starch

Separation

modified starch

⇕

side products
reagents residues
swelling inhibitor

Drying

purified derivative

20% moisture

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π The sub-system: Separation Process

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Washing process

Function:

- ***Remove of Impurities***

Dewatering process

Function:

- ***Reduce the amount of water***

NB

- ***Product specification is made in final drying step → Costs!***

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Washing Process

Present Situation

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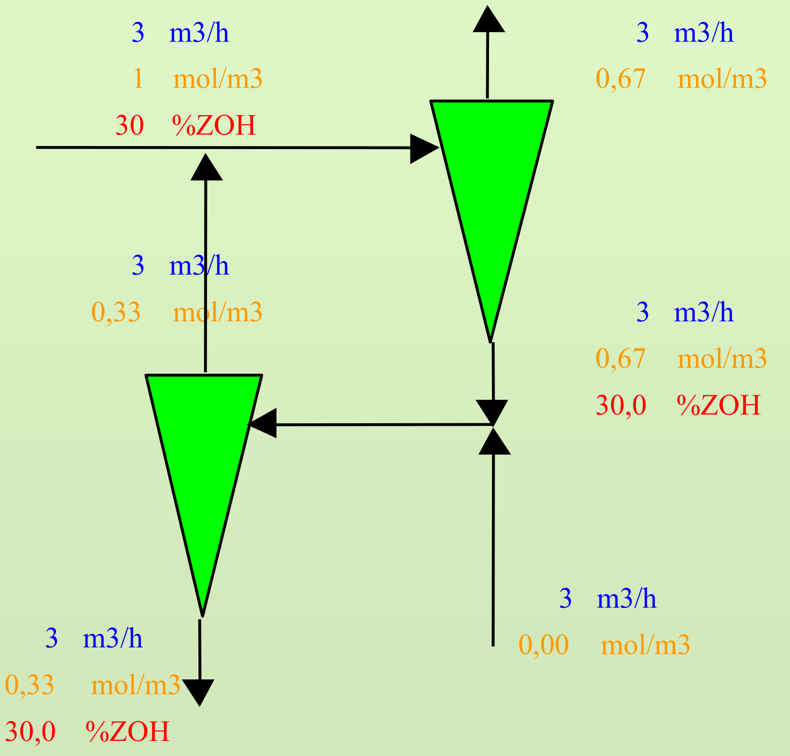
Hydrocyclones

Washing ratio (6-stage):

3-5 kg / kg ds

- high energy demand
- high investment
- losses of starch
- maintenance



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Dewatering Process

Present Situation

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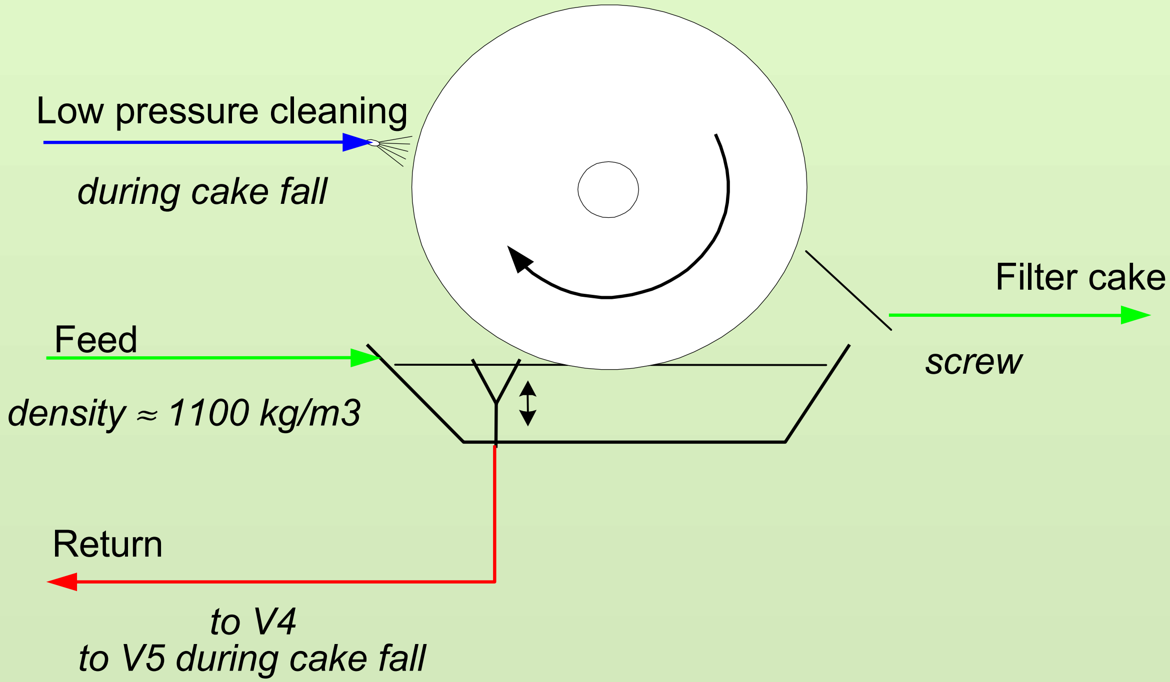
Rotary vacuum filter

38% - 40% moisture

- Low energy demand
- Less maintenance
- Reliable
- Low investment



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Targets, the problem

- ***Minimum amount of Wash Water ?***
- ***Maximum amount of Dry Substance ?***
- ***Smaller more, reliable equipment***
- ***Process suitable for GMP***

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π PI stages

1 Functional description of the process (line)
2 Setting theoretical maximal performances for each function
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5 Selected concept

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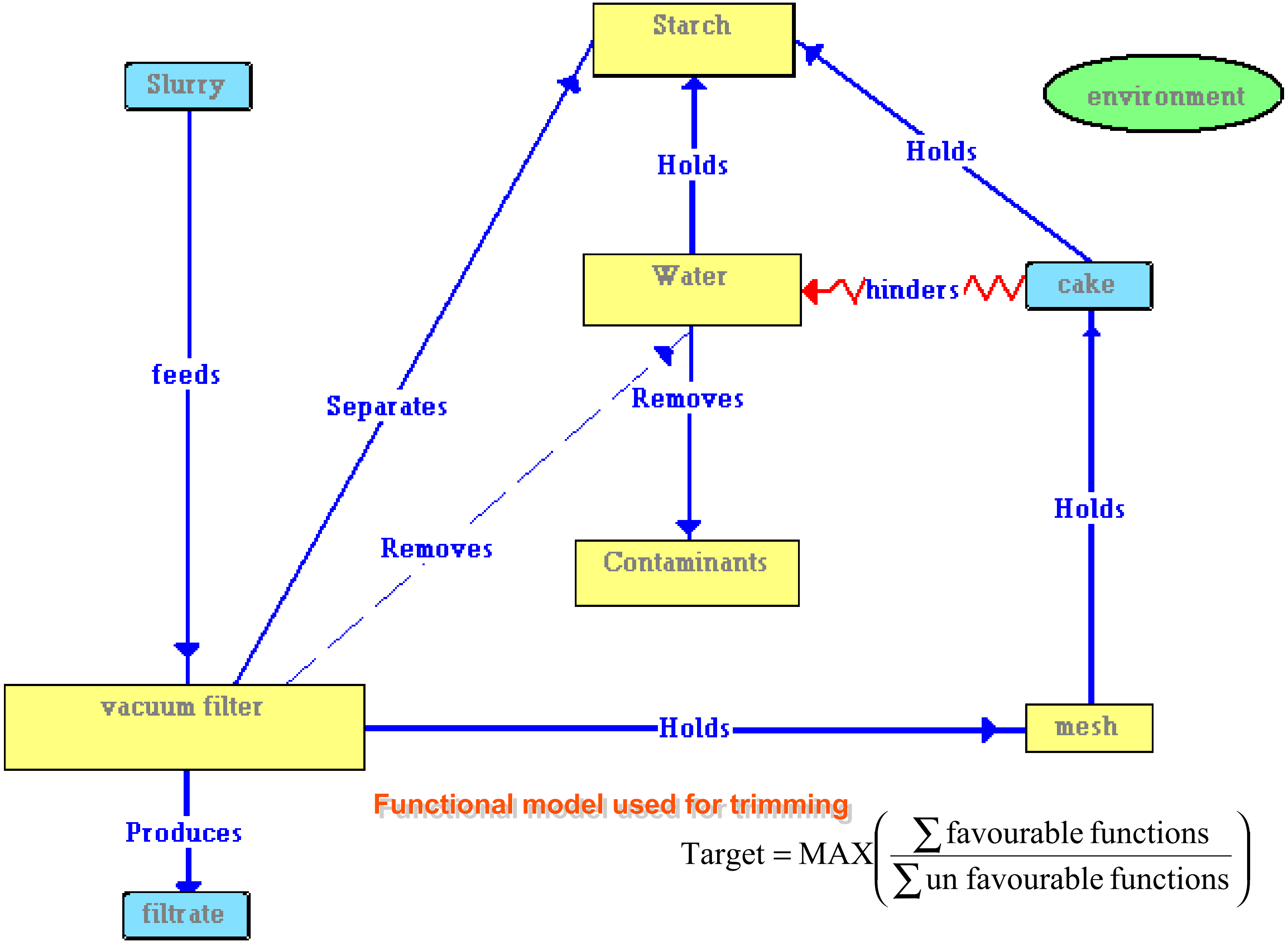
Simple functional model of washing & dewatering



Functional model used for trimming

$$\text{Target} = \text{MAX}\left(\frac{\sum \text{favourable functions}}{\sum \text{un favourable functions}}\right)$$

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π TRIZ principles

- ***Technical contradictions indicate :***
  - *Consolidate and combine processes*
  - *Make one continuous process*
  - *Use thin films*

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π PI stages

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π Modelling: water in starch

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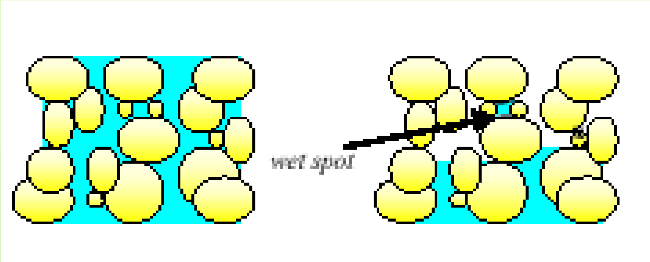
Residual Moisture, W_{rm} ,consists of various water locations

- absorbed fixed
- adsorbed small
- pendular < 0.076 vol%
- wet spot
- capillary



$$W_{rm} = \boxed{W_{abs} + W_{ads} + W_{pendular}} + W_{wetspot}(S) + \boxed{W_{cap}}$$

The capillary water model is essential:

$$W_{cap} = f(psd, \Delta P, H, \eta, R_m, \varepsilon, \gamma.\cos\phi, t)$$

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π Fundamental Approach

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- ***Washing model***
  - *Removal of impurities*
  - *Wash ratio*
  - *Ratio: absorbed water vs external water*
  - *Thickness of Filter cake*
  - *Water ratio for 90% removal: HC: 10 vs VF: 2*
  - *Fast kinetics*
- ***Dewatering model***
  - *Dewatering kinetics*
  - *Slow kinetics*

π Model elements

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- ⊕ Raw material
- ⊕ Pressure difference
- ⊕ Cake thickness
- ⊕ Screen resistance
- ⊕ Surface tension

negligible loss of starch

low resistance

Surfactant : improved dewatering

replacing of centrifuges / pressure filters

π PI stages

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π Combined washing and dewatering

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- *100% removal with Wash Ratio < 1.0*
- *Kinetics of washing much faster than dewatering*
- *Investment limited*
- *Design equipment with combined functions using the model*

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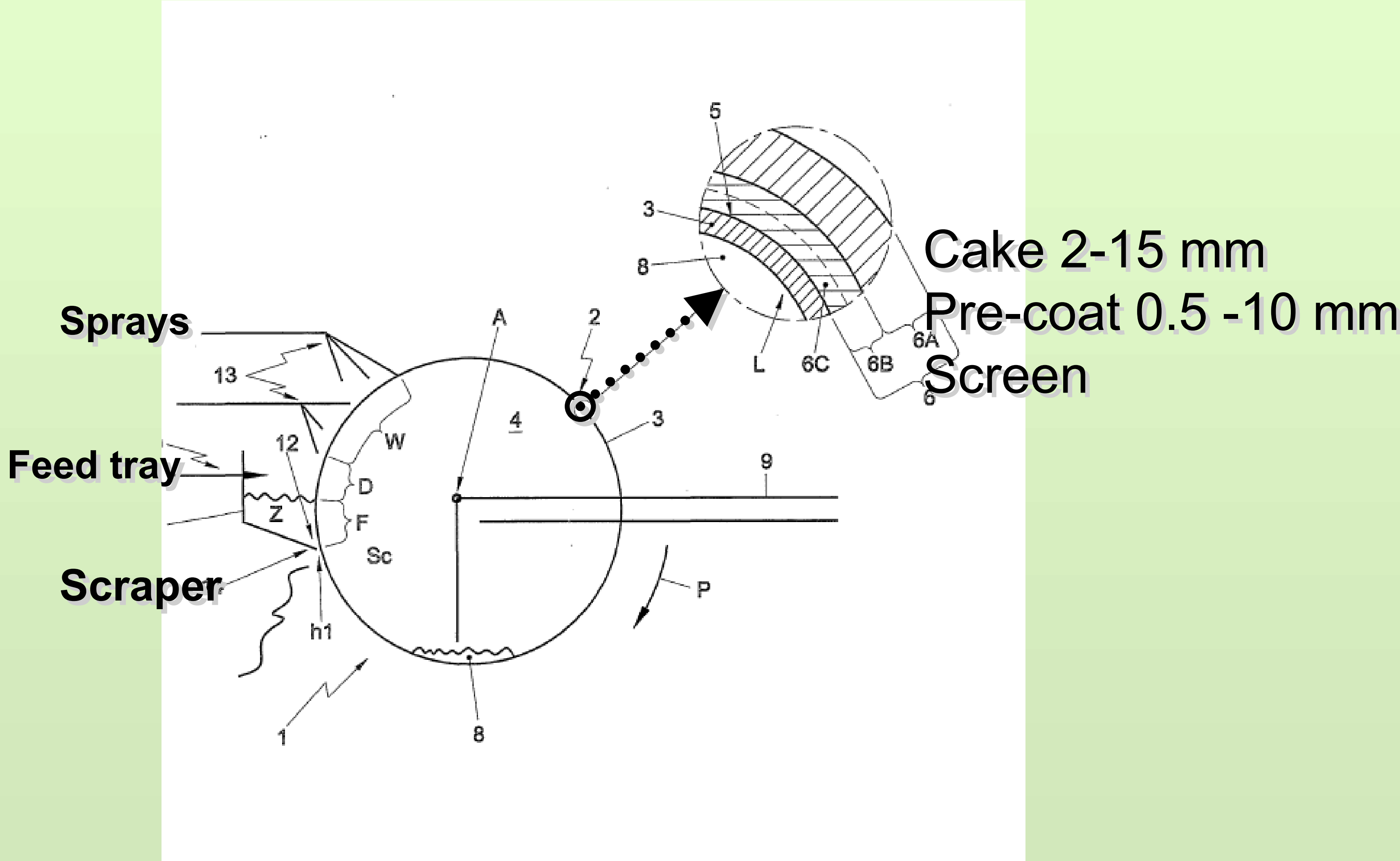
π Vacuum filter scheme



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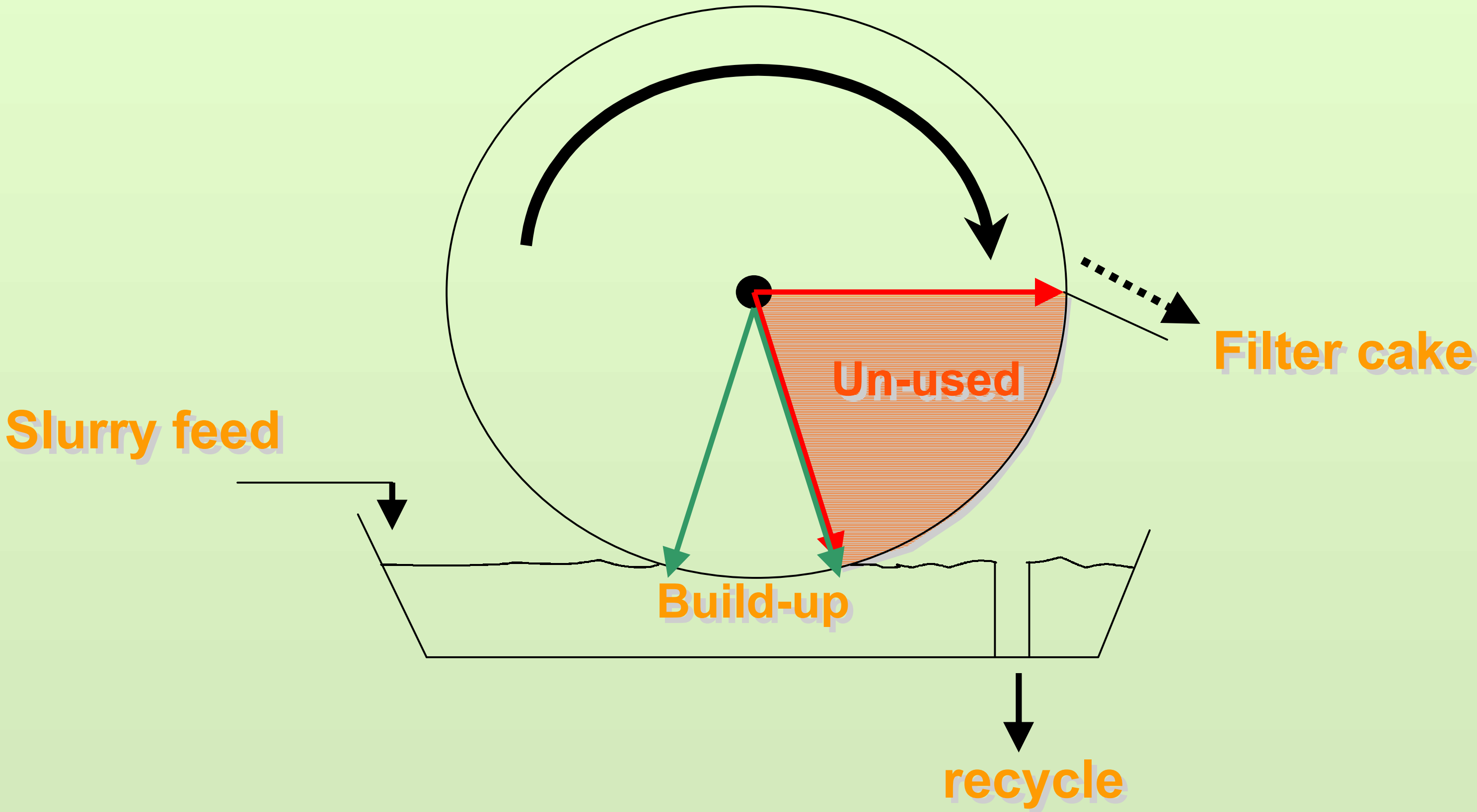
Utilisation of filter surface



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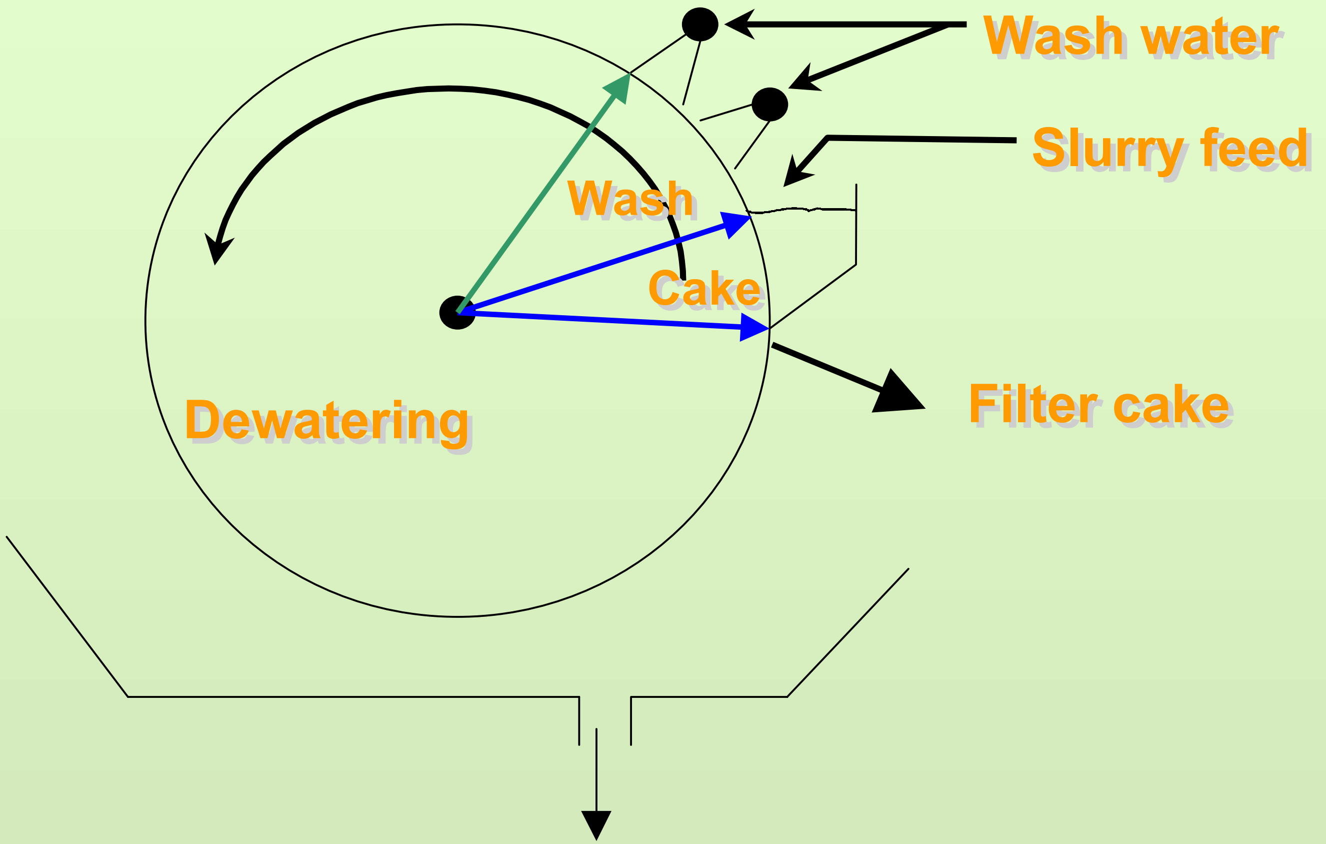
Improved design washing & dewatering



π PI stage

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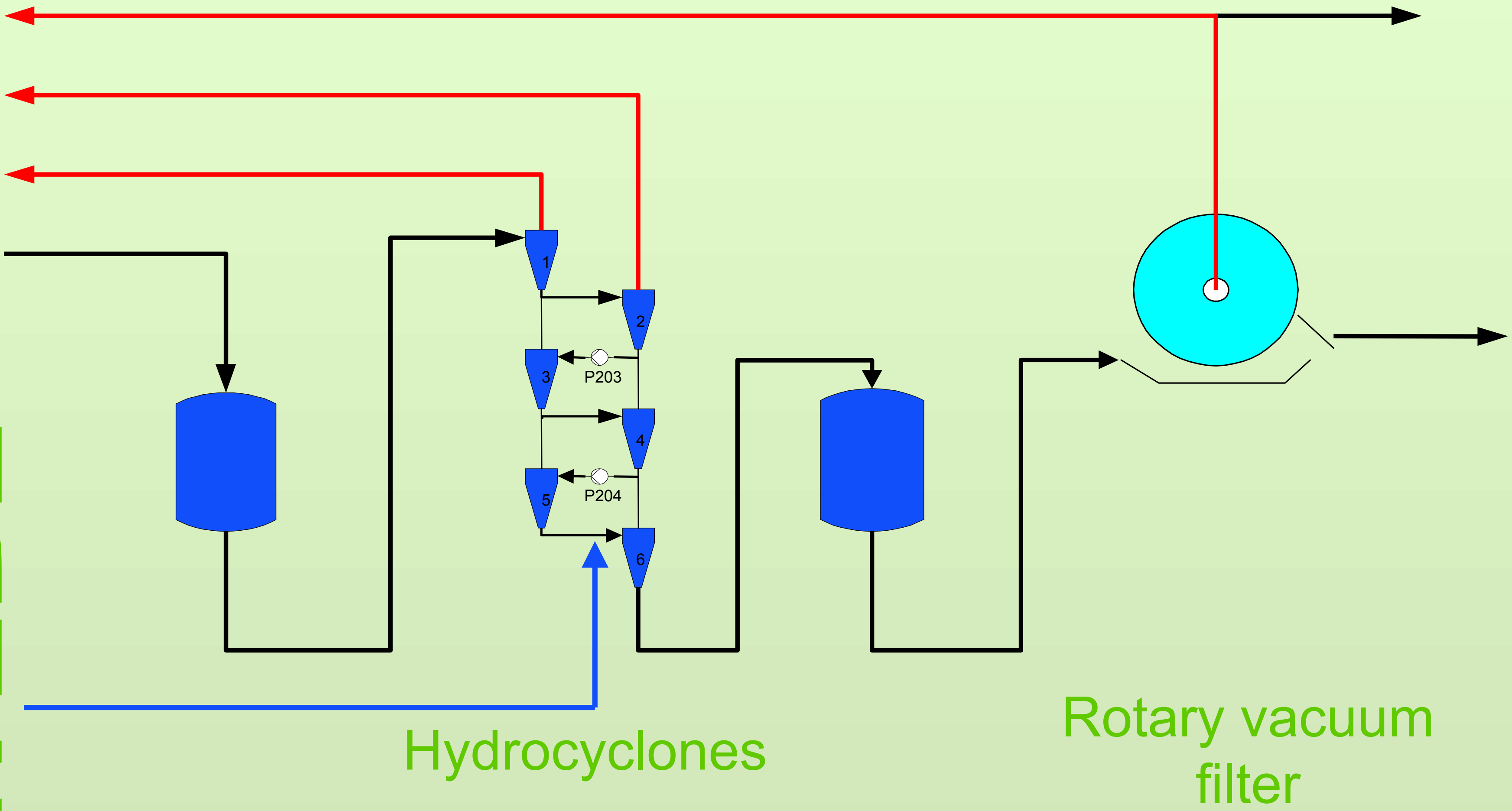
π Present Process



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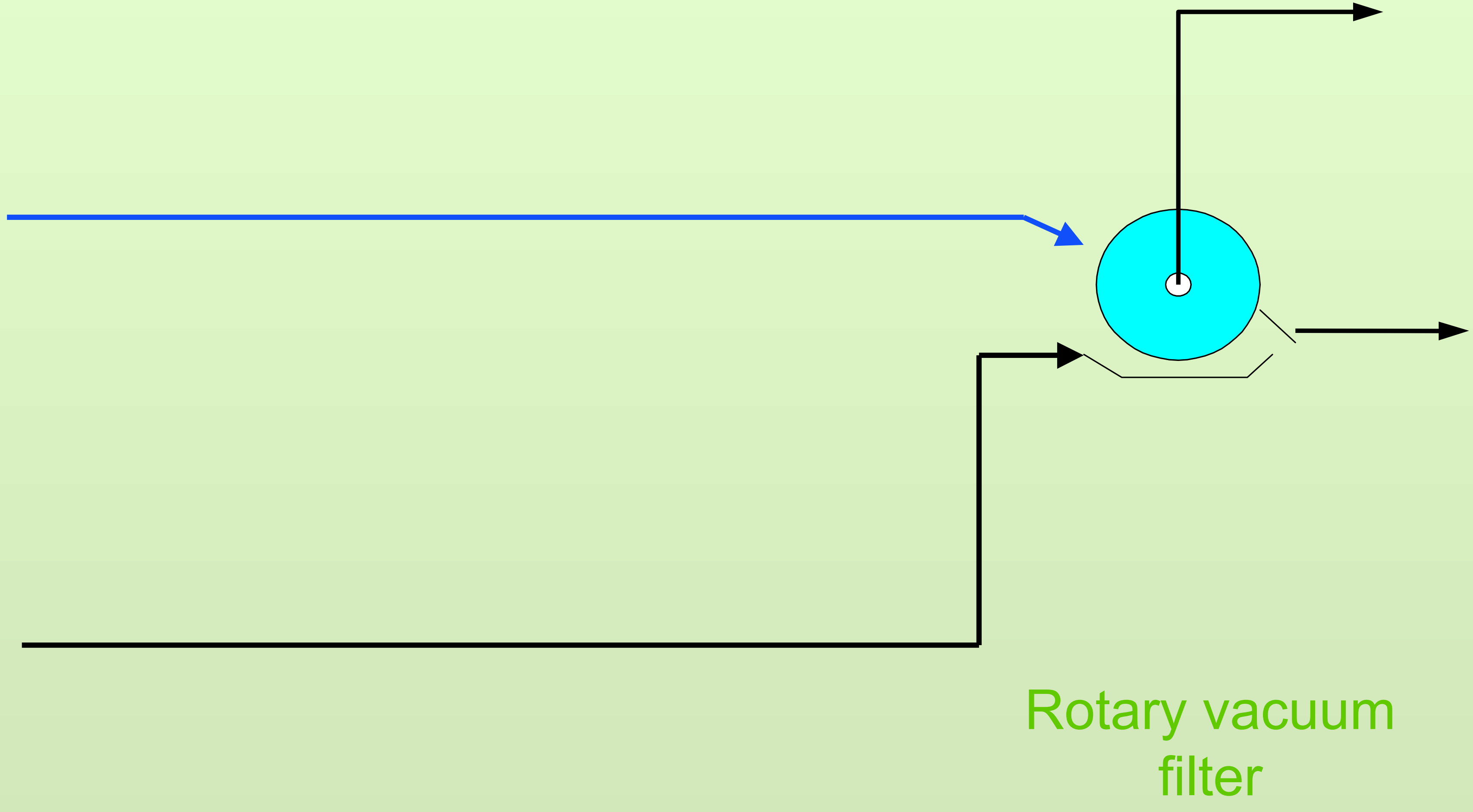
π Future Process



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π Practice: Initial trials at factories

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Starch derivative	Water ratio [$kgH_2O \cdot kg\ S^{-1}$]	Feed wt. %	Mode	Moisture [%]	Capacity [$kg \cdot m^2 \cdot h^{-1}$]
Oxidized & etherified	3 - 4	25	HC & VF	39 ± 1	320
	1	30	Top feed	40.6±0.2	290
Cross linked*	4	27	HC & VF	38.6± 0.3	470
	1	30	Top feed	38.0±0.2	225
Oxidized*	3 - 4	27	HC & VF	40.6±0.2	470
	1	30	Top feed	40.0±0.1	210

*Food application

- *stable, effective removal of salts*
- *initially lower capacities*
- *lower moisture content ➔ impact dryer capacity*
- *higher starch concentration in feed up to 39% vs 32% traditionally*

WO 02/28907

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π Conclusion

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- ***Water* reduction** **50 - 80 %**
- ***Energy* reduction** **> 60%**

- ***reduction starch losses***
- ***no recycles (GMP)***
- ***increased reliability***
- ***less investment***
- ***less maintenance***

- ***PI : be smarter, smaller, cleaner, cheaper,….***

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π Acknowledgements

- ***Process Research at R&D AVEBE***
  - *Drs Th. Franke (PL)*
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- ***Production co-workers Ter Apelkanaal***

- ***Conceptual***
  - *Ir B. Gras, Innovation Quotient*
  - *Prof H. van der Berg TU Twente*

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π Conference & Reading

- ***First international Symposium on Process Intensification and miniaturisation,***

  18 - 21 August 2003 Newcastle upon Tyne

- ***PIN news***

  http://www.ncl.ac.uk/pin/news/contents.htm

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