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COMPUTER AIDED DESIGN IN WHEY PROCESSING

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Abstract

Whey processing alternatives were investigated with the help of Computer Aided Design. Mass and energy balances were calculated, process units were sized, and an economic analysis was conducted. Using IRR and ACF methods for calculating profitability methods optimum economic strategies were suggested for whey processing.

Keywords: food waste processing, dairy, whey, Computer Aided Design, economic analysis.

Dairy processing comprises a large portion of the food processing industry. Cheese is a major dairy product, whey is a by-product of the cheese manufacturing process, with about 9 kilograms of whey being produced per kilogram cheese.

Whey is a potent waste in terms of its polluting strength with an average BOD of 45000 mg/l, which compares with 300 mg/l for human sewage sent to waste treatment facilities (JELEN, 1979). The high BOD makes disposal expensive.

Food waste streams are biodegradable and often have nutrient or biological value. Despite these characteristics, food processing wastes are generally grouped with municipal wastes or other industrial wastes. The characteristics of food processing wastes make them among the best waste products available for recycling, however the value of the by-products which can be produced has limited their utilisation. Increasing government restrictions on waste disposal and the rising cost of disposing of high BOD wastes is making the economics of by-production more attractive.

Fluid whey directly from cheese production generally contains 6.5% w/w solids. The usual composition of whey is 0.80% protein, 4.80% carbohydrate, 0.25% fat, 0.65% ash, 93.5% water.

Lactose makes up the bulk of the solids, comprising about 70% of the dry matter. On the other hand, the protein which only averages 11.5 – 18% of the dry matter, is nutritionally and functionally the most valuable component of whey. Minerals are the fourth largest component of whey and are the major factor hindering the development of new consumer products from whey (ALLUM, 1980).

Whey can be processed into a variety of products, e.g. Condensed Whey, Whey Protein Concentrate (WPC), Lactose, Demineralised Whey, Reduced Lactose Whey, Hydrolyzed Whey Syrup, Ethanol and other Fermentation Products.

Whey processing techniques are available for handling each of the components in whey as well as in other food substances.

Many alternatives for the disposal of whey exist, but determining the most profitable alternative for a particular situation from the myriad of existing options can be a difficult task. Computer Aided Design provides the engineer with capacity to model these alternative processes and to compare them economically.

An in-depth study of different process combinations was conducted using the CAD programme, Preliminary Process Design Package (PPDPACK), developed by HSU (1984), MOYER (1987), HAVLIK (1989), BÁLINT and OKOS (1989) to determine which whey process alternatives provide the best economic results.

1. Whey Protein Concentrate Processes with Permeate Disposal

Fig. 1 details the operation steps of WPC processes. The sizes of the boxes are proportional to the sizes of the units, the width of each arrow is proportional to the flow rate in the given stream.

Three different WPC products were investigated with differing final protein concentrations. Process *P*1 involved production of WPC containing 34%, process *P*7 50%, process *P*13 75% of protein. In these technologies the separation of protein is made by ultrafiltration. The protein content of WPC is set by the definition of the protein concentration in the output stream of the ultrafilter. During ultrafiltration the composition of the total solid content is determined. The ultrafiltration and the following evaporation and drying processes are closely connected, however, subsequently the composition of the solid content does not change. With increasing protein concentration the amount of the product gradually decreases, and the amount of water in the evaporator and in the drier also decreases. Changes in the proportion of the protein in the output stream therefore require changes in the sizes of the different process units. Thus the area of the ultrafilter membrane required significantly increases, whilst the heating area of the evaporator and the water evaporating capacity of the drier

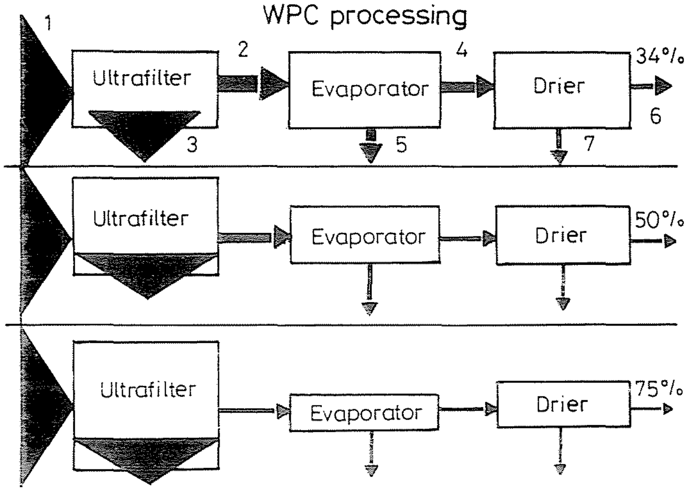

Fig. 1. Flow diagrams of WPC processes with permeate disposal

decrease. As the capital investment cost of the ultrafilter increases — it is interesting to note that the total capital investment does not change significantly — however, the energy savings in the process significantly increase. Also the electrical energy demand of the ultrafilter increases, the steam demand of the evaporator and the natural gas demand of the drier decrease. At a whey flow rate of 125 tons/day the product value increases as the protein concentration in WPC increases from 34% to 50%. No further increase occurs from 50% to 75% protein. The combination of these effects causes that the two most important economic indicators Internal Rate of Return on Investment (IRR) and Annualized Cash Flow (ACF) change with a maximum at a protein concentration of 50%. Values for IRR and ACF for 34, 50 and 75% protein are respectively: IRR 33,.5, 52.4, 40.858.2, 46.3 MFt at a whey flow rate of 125 tons/day.

Table 1 shows the material balances, *Table 2* shows the unit sizes and the energy demand, *Table 3* shows values obtained from the economic analysis of the processes.

From these values it is obvious that under these conditions WPC with 50% protein production yields the best economic results.

Table 1
WPC 34%, WPC 50%, WPC 75%, Processes material balances

Streamcode	Flow rate kg/h	Total solid	Protein	Carbohydrate m/m	Ash	Fat
WPC 34%						
1	4725.0	0.0630	0.0080	0.0480	0.0060	0.0010
2	1069.3	0.0998	0.0353	0.0528	0.0072	0.0044
3	3655.7	0.0522	0.0000	0.0466	0.0056	0.0000
4	266.7	0.4000	0.1417	0.2117	0.0289	0.0177
5	802.6	0.0000	0.0000	0.0000	0.0000	0.0000
6	111.1	0.9600	0.3401	0.5081	0.0693	0.0425
7	155.6	0.0000	0.0000	0.0000	0.0000	0.0000
WPC 50%						
1	4725.0	0.0630	0.0080	0.0480	0.0060	0.0010
2	497.4	0.1455	0.0760	0.0528	0.0072	0.0095
3	4227.6	0.0533	0.0000	0.0474	0.0059	0.0000
4	180.9	0.4000	0.2089	0.1452	0.0198	0.0261
5	316.5	0.0000	0.0000	0.0000	0.0000	0.0000
6	75.4	0.9600	0.5014	0.3484	0.0475	0.0627
7	105.5	0.0000	0.0000	0.0000	0.0000	0.0000
WPC 75%						
1	4725.0	0.0630	0.0080	0.4800	0.0060	0.0010
2	135.0	0.3750	0.2800	0.0528	0.0072	0.0350
3	4590.0	0.0538	0.0000	0.0479	0.0060	0.0000
4	126.6	0.4000	0.2987	0.0563	0.0077	0.0373
5	8.4	0.0000	0.0000	0.0000	0.0000	0.0000
6	51.6	0.9600	0.7468	0.1352	0.0084	0.0696
7	74.0	0.0000	0.0000	0.0000	0.0000	0.0000

2. Whey Protein Concentrate Processes with Permeate Utilization

Utilization of the permeate has been a major problem for WPC producers, as the permeate still has a high BOD (about 27 500 mg/l). The utilization of permeate was investigated. In some of the alternatives, products were made only by concentration and powdering without chemical modification of the solid content of the whey. In other processes physical and chemical modifications using fermentation, ion exchange and hydrolysis were made.

Process $P2$ produces, with the help of reverse osmosis and evaporation, a permeate product called condensed permeate syrup. This product can be used as a lactose source for a wide variety of fermentations or as a feedstock for crystalline lactose production. Process $P3$ uses a fermentation system to produce ethanol from the permeate. The product of process $P4$ is a dried version of that of process $P2$ and it is used as whey solids in

Table 2

WPC 34%, WPC 50%, WPC 75% Processes unit sizes and energy demand

	WPC 34%			WPC 50%			WPC 75%		
	El.	Gas	Steam	El.	Gas	Steam	El.	Gas	Steam
				kWh/year	m^3/year	kg/year			
Ultrafilter	2.0×10^6			2.7×10^6			6.0×10^6		
Evap.	1.0×10^3		4.8×10^6	6.7×10^2		2.0×10^6	3.9×10^2		1.9×10^6
Drier	4.5×10^4	1.4×10^5		3.0×10^4	9.5×10^4		2.2×10^4	6.6×10^4	
Sum	2.1×10^6	1.4×10^5	4.8×10^6	2.7×10^6	9.5×10^4	2.0×10^6	6.1×10^6	6.6×10^6	1.9×10^6
Ultrafilter m^2		3×68			3×92			3×204	
Evaporator m^2		2×3.5			2×1.5			1×0.06	
Drier kg·water/h		154.2			104.3			72.6	

Table 3
WPC Processes economic analysis values

	WPC 34%	WPC 50%	WPC 75%
Unit prices MFt			
Ultrafilter	11.5	13.5	20.9
Evaporator	8.0	5.6	0.7
Drier	15.9	14.0	12.6
Total	35.4	33.2	35.3
Energy prices MFt			
Electrical	10.0	13.0	28.8
Natural gas	1.6	1.1	0.8
Steam	4.8	2.0	0.2
Total	16.5	16.1	29.8
Total cap. inv. MFt.	192.3	179.9	186.0
Operating cost MFt/y	18.7	18.9	35.1
Product values MFt/y	83.2	113.3	110.9
Return on investment%	33.5	52.4	40.8
Annual cash flow MFt	30.4	58.2	46.3
Internal rate of return on inv. %	26.9	38.2	32.5

a variety of dairy and baked products. Obviously crystalline lactose can be produced from the lactose rich permeate, and the process for doing so constitutes process $P5$. Crystalline lactose is used for encapsulation of drugs in the pharmaceutical industry and for vitamins and other pill-type products. The last process utilizing permeate is $P6$, yielding hydrolyzed permeate syrup. In this process, lactose is hydrolysed using enzyme columns to produce glucose and galactose, increasing the sweetness of the product significantly. Hydrolysed permeate syrup has been used as a sweetener in some drinks, but more often it is used in dry form in the baking industry. Processes $P7 - P12$ and $P13 - P18$ repeat the processes just described, for 50% and 75% WPC final protein concentrations. The technologies were modelled at 5 different flow rates meaning that 90 alternatives were investigated.

Fig. 2 shows the total capital investment, *Fig. 3* the annual operating cost, *Fig. 4* the energy demand, *Fig. 5* and *6* show the IRR and the ACF values of the processes.

3. Results, Conclusions

According to the two most important economic measures, IRR Internal Rate of Return on Investment and ACF Annual Cash Flow, WPC 50%

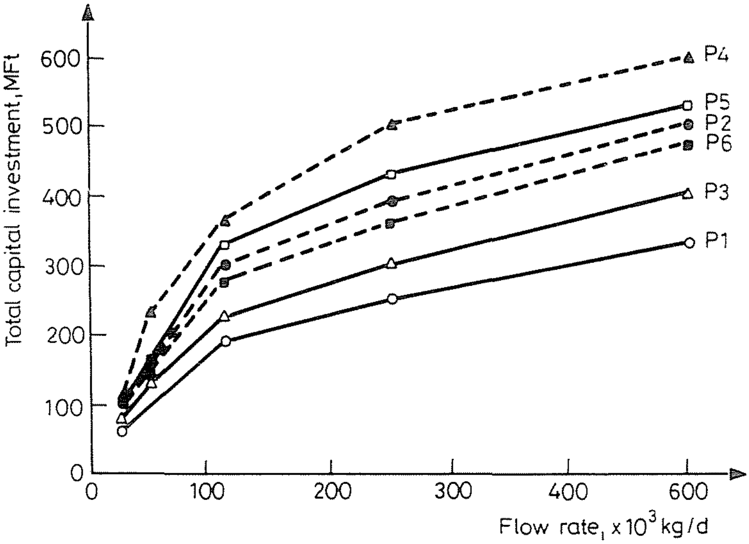

Fig. 2. *P*1 – *P*6 Processes total capital investment

P1=WPC 34%	P4=WPC 34% +Lactose spray
P2=WPC 34%+Condensed permeate	P5=WPC 34%+Edible lactose
P3=WPC 34%+Ethanol	P6=WPC 34%+Hydrolyzed Permeate

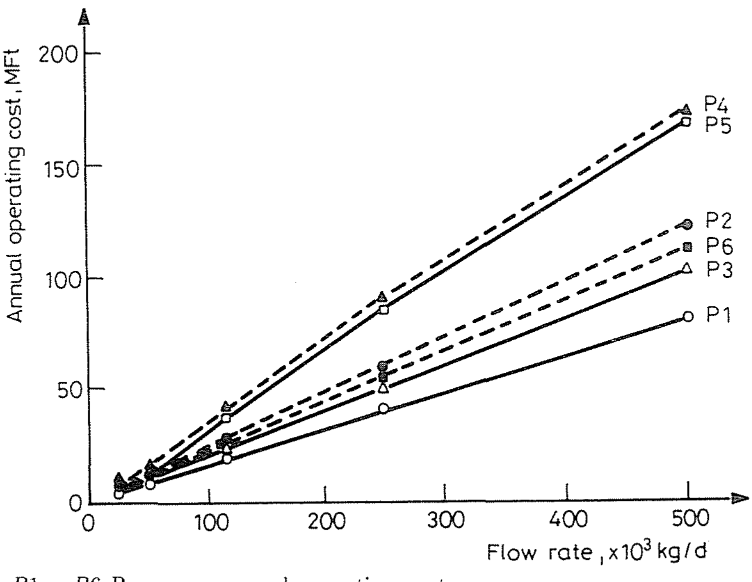

Fig. 3. *P*1 – *P*6 Processes annual operating cost

P1=WPC 34%	P4=WPC 34% +Lactose spray
P2=WPC 34%+Condensed permeate	P5=WPC 34%+Edible lactose
P3=WPC 34%+Ethanol	P6=WPC 34%+Hydrolyzed Permeate

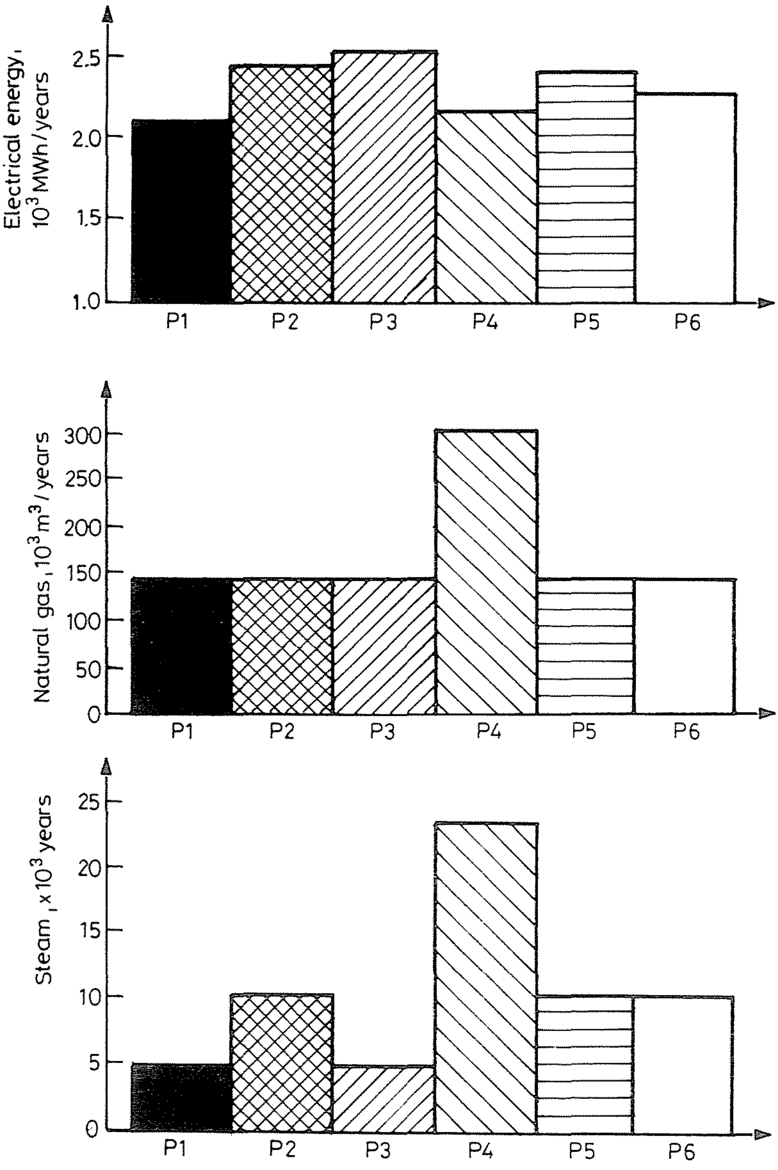

Fig. 4. *P*1 – *P*6 Processes energy demand

P1=WPC 34%
P2=WPC 34%+Condensed permeate
P3=WPC 34%+Ethanol
P4=WPC 34% +Lactose spray
P5=WPC 34%+Edible lactose
P6=WPC 34%+Hydrolyzed Permeate

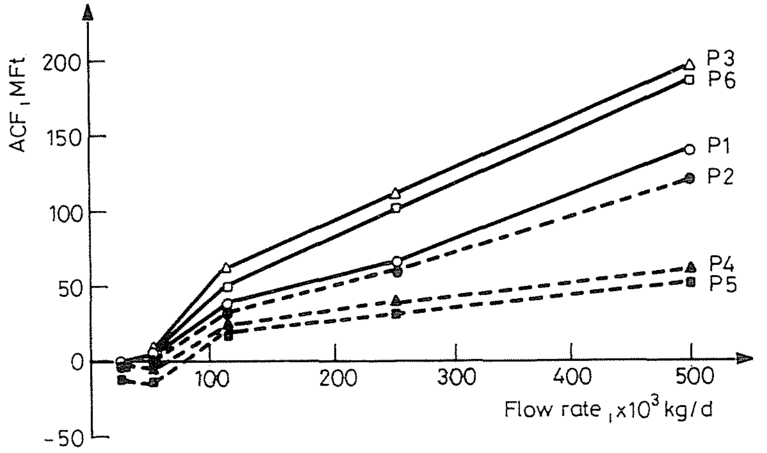

Fig. 5. *P*1 – *P*6 Processes annualized cash flow

P1=WPC 34% P4=WPC 34% +Lactose spray
P2=WPC 34%+Condensed permeate P5=WPC 34%+Edible lactose
P3=WPC 34%+Ethanol P6=WPC 34%+Hydrolyzed Permeate

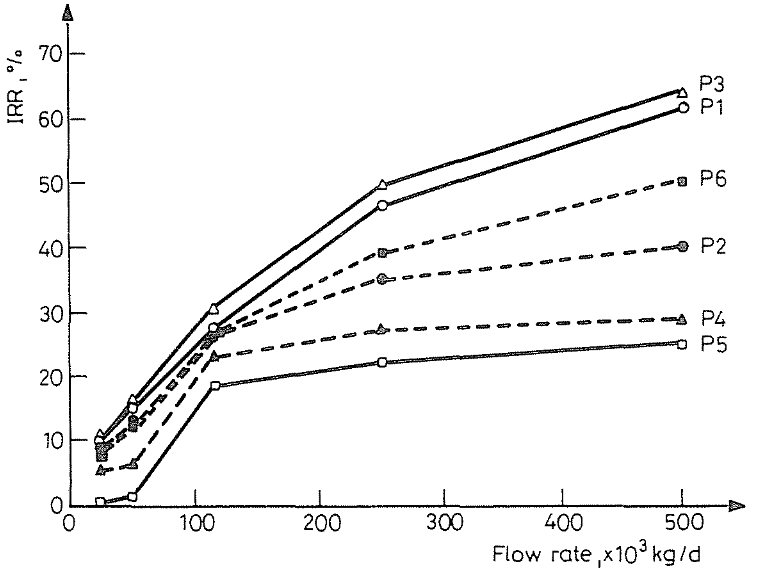

Fig. 6. *P*1 – *P*6 Processes internal rate of return on investment

P1=WPC 34% P4=WPC 34% +Lactose spray
P2=WPC 34%+Condensed permeate P5=WPC 34%+Edible lactose
P3=WPC 34%+Ethanol P6=WPC 34%+Hydrolyzed Permeate

production yields the best economic results compared to 34% and 75% WPC protein contents.

Among the WPC processes with permeate utilization, process *P*3 (ethanol fermentation) seems to be the best alternative at any flow rate. This process has the highest IRR and ACF values and the smallest capital investment and operating costs. Making lactose spray (*P*4) or edible lactose from permeate (*P*5) yields the worst IRR values and thus these processes are not economical alternatives.

The effect of the capacity was investigated, too. All technologies have a lower capacity limit and production under these limits is relatively uneconomical. This value was found to be about 50 000 kg/day. Since much of the disposed whey comes from smaller cheese factories which do not have financial resources to produce whey by-products, the data suggest that these cheese factories should combine production.

The effect of the WPC concentration of the different alternatives was also investigated. Analysis of the results showed that changes in concentration do not change the order of economic alternatives. For all the three alternative protein concentrations sets *P*3 (*P*9 and *P*15 respectively) were the best and processes *P*4 and *P*5 (*P*10, *P*11 and *P*16, *P*17 respectively) were the worst.

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