Dr.-Ing. F-W Hennecke, *former pump chief at BASF, is a member of the Pump Working Group of the VCI (Association of the Chemical Industry) and the Pump Standards Committee in Germany (DIN). Co-editor of the Guide to Pump Life Cycle Costs, published jointly (2001) by Europump and the Hydraulic Institute in the USA.*

A Comparative Study of Pump Life Cycle Costs

The author presents a survey of the comparative life cycle costs (LCC) of 5 pumps, four of which are well known in the paper industry and one which offers mills a cost effective alternative.

The survey covered 3 sizes of each type of pump - operating at i) flow rates from 1m³/hr to 8m³/hr; and ii) specific pressures from 5 to 100 bar. The results showed that in terms of LCC:

- *The Hydra-Cell, which has an 85% efficiency at high pressure, is the most economic pump overall and it can pump abrasive, viscous, corrosive liquids and liquids with particles.*
- *The side-channel pump is comparable, within its pressure range, but it can only handle clean fluids.*
- *Centrifugal pumps are for low pressures and high flow rates.*
- *The peristaltic pump - its LCC is increased by its high consumption of replacement tubes.*
- *Membrane piston pumps are very efficient, but their costs - investment, spare parts and labour when changing membranes - are extremely high. The LCC of this pump can be up to 3 times higher than that of the Hydra-Cell.*

Short term, money might be saved by buying a cheap pump - but how long will it

The theme of this article is an investigation undertaken in 2005 in which I examined the comparative lifetime costs of i) four types of pump well known in the process industries and ii) one which is less well known, but which in its field can be regarded as an interesting and viable alternative. The pump types considered are:

the centrifugal pump
the side-channel pump
the peristaltic pump
the membrane piston pump and
the 'Hydra-Cell' pump.

Each of these is generically different from other types of pump, and (with the exception of the Hydra-Cell, which is manufactured by Wanner) is produced by more than one company.

In looking at the costs of owning and operating an industrial pump, it is now widely accepted that we have to look at them from every aspect. The true cost evaluation should take account of all elements, from purchase to scrapping - what we now define as Life Cycle Costs (LCC).

Figure 1 is a definition of LCC using guidelines established by the VDMA (association of German engineering shops).

In calculating LCC through time, we have to take account of the service life of the pump in years and allow for interest rate and inflation to arrive at the real interest rate. The formula also gives the 'present value' of each cost element, *Figure 2*.

Factor examples and values for real interest - taking account of inflation - are worked out in *Figures 3 and 4*.

Elements of Life Cycle Costs (LCC)

$$LCC = C_{ic} + C_{in} + C_e + C_o + C_m + C_s + C_{env} + C_d$$

C_{ic}	=	initial cost
C_{in}	=	installation and commissioning cost
C_e	=	energy costs
C_o	=	operating cost
C_m	=	maintenance and repair costs
C_s	=	down time and loss of production cost
C_{env}	=	environmental cost
C_d	=	decommissioning and disposal cost

Figure 1

Calculation of LCC

$$\text{Discounting } C_p = \frac{C_n}{[1+(i-p)]^n}$$

where

n	=	number of years
i	=	interest rate
P	=	annual inflation
i – p	=	real discount rate
C_n	=	cost paid after "n" years
C_p	=	present value of a single cost element

$$\text{Present Value PV} = \sum C_{px}$$

Figure 2

be before repair costs, energy consumption and possible production losses cancel out the original saving? Life Cycle Costs are important.

Common elements and exclusions

LCC can be a valuable tool in purchase decisions and budget forecasting. The concept is also useful in comparing one type of pump with another. It is less useful for comparing pumps of the same type. For example, between two centrifugal pumps of similar capacity and material specification, differences in LCC will be relatively minor.

When comparing the LCC of different types of pump, we must assume common values for factors such as inflation and interest rates. And some elements of LCC can be excluded as being dependent on individual circumstances. For example, downtime causing loss of production may be very high but is very difficult to calculate in this context. Other elements, such as installation and com-

LCC calculation factor C_p/C_n													
	Real interest rate (nominal interest rate minus inflation rate)												
No. of years (n)	- 2	-1	0	1	2	3	4	5	6	7	8	9	10
1	1.02	1.01	1	0.99	0.98	0.97	0.96	0.95	0.94	0.93	0.92	0.91	0.91
2	1.04	1.02	1	0.98	0.96	0.94	0.92	0.91	0.89	0.87	0.85	0.84	0.82
3	1.06	1.03	1	0.97	0.94	0.92	0.89	0.86	0.84	0.81	0.79	0.77	0.74
4	1.08	1.04	1	0.96	0.93	0.89	0.86	0.82	0.79	0.76	0.73	0.70	0.68
5	1.10	1.05	1	0.95	0.91	0.86	0.82	0.78	0.75	0.71	0.68	0.65	0.61
6	1.12	1.06	1	0.94	0.89	0.84	0.79	0.75	0.71	0.67	0.63	0.59	0.56
7	1.15	1.07	1	0.94	0.87	0.82	0.76	0.71	0.67	0.62	0.58	0.54	0.51
8	1.17	1.08	1	0.93	0.86	0.79	0.74	0.68	0.63	0.58	0.54	0.50	0.46
9	1.19	1.09	1	0.92	0.84	0.77	0.71	0.65	0.60	0.55	0.50	0.46	0.42
10	1.21	1.10	1	0.91	0.83	0.75	0.68	0.62	0.56	0.51	0.47	0.42	0.39
15	1.32	1.15	1	0.87	0.76	0.66	0.57	0.50	0.43	0.38	0.33	0.28	0.25
20	1.44	1.20	1	0.83	0.69	0.58	0.48	0.40	0.34	0.28	0.23	0.19	0.16
25	1.56	1.25	1	0.80	0.64	0.51	0.41	0.33	0.26	0.21	0.17	0.13	0.11
30	1.69	1.30	1	0.77	0.59	0.46	0.35	0.27	0.21	0.16	0.12	0.09	0.07

Figure 3 Factor C_p/C_n for a single cost element after n years

LCC calculation discount factor													
	Real interest rate (nominal interest rate minus inflation rate)												
No. of years (n)	- 2	-1	0	1	2	3	4	5	6	7	8	9	10
1	1.02	1.01	1.00	0.99	0.98	0.97	0.96	0.95	0.94	0.93	0.93	0.92	0.91
2	2.06	2.03	2.00	1.97	1.94	1.91	1.89	1.86	1.83	1.81	1.78	1.76	1.74
3	3.12	3.06	3.00	2.94	2.88	2.83	2.78	2.72	2.67	2.62	2.58	2.53	2.49
4	4.21	4.10	4.00	3.90	3.81	3.72	3.63	3.55	3.47	3.39	3.31	3.24	3.17
5	5.31	5.15	5.00	4.85	4.71	4.58	4.45	4.33	4.21	4.10	3.99	3.89	3.79
6	6.44	6.22	6.00	5.80	5.60	5.42	5.24	5.08	4.92	4.77	4.62	4.49	4.36
7	7.60	7.29	7.00	6.73	6.47	6.23	6.00	5.79	5.58	5.39	5.21	5.03	4.87
8	8.77	8.37	8.00	7.65	7.33	7.02	6.73	6.46	6.21	5.97	5.75	5.53	5.33
9	9.97	9.47	9.00	8.57	8.16	7.79	7.44	7.11	6.80	6.52	6.25	6.00	5.76
10	11.19	10.57	10.00	9.47	8.98	8.53	8.11	7.72	7.36	7.02	6.71	6.42	6.14
15	17.20	16.27	15.00	13.87	12.85	11.94	11.12	10.3	9.71	9.11	8.56	8.06	7.61
20	24.89	22.26	20.00	18.05	16.35	14.88	13.59	12.4	11.4	10.59	9.82	9.13	8.51
25	32.85	28.56	25.00	22.02	19.52	17.41	15.62	14.0	12.7	11.65	10.6	9.82	9.08
30	41.66	35.19	30.00	25.81	22.40	19.60	17.29	15.3	13.7	12.41	11.2	10.2	9.43

Figure 4 Discount factor (df) for constant yearly expenditures

missioning, decommissioning and disposal and environmental costs, can be ignored for comparison purposes.

However, as this study confirmed, there can be significant differences between types of pump when comparing:

- Initial cost (which includes motor, base plate, couplings etc.)
- Energy cost.
- Routine maintenance cost.
- Repair cost.

The investigation: scope and methodology

The Scope of the investigation is shown in *Figure 5*. Five types of pump were investigated - 3 sizes of each type, to match specified flow rates from 1m^3/hr to 8m^3/hr. In each case LCC was calculated for operation at specific pressures from 5 to 100 bar.

In practice, not all the pump types are suited for operation in all circumstances. Limiting factors include pressure, temperature, solid content, hazardous fluids and pump pulsation.

Methodology: In each case, all data was provided by the pump manufacturer. For each type of pump a prominent reputable manufacturer was chosen as representative. Each company was requested to select and price its most appropriate model to best meet given operating criteria, including flow, pressure and liquid specifications. The same set of requirements was given to each pump company.

Data was also requested on manufacturer's recommendations for routine maintenance, costs of spare parts and labour for repairs, and the expected time between repairs. The required operational duty was 4000 hrs/year, based on 50% of the 8000 hours available in the year.

Figure 6 shows operating data and pump data relating to one type of pump, the HydraCell. Equivalent data was established for each type of pump over a hypothetical 10-year period. Zero values indicate that a particular element has been excluded for all pump types.

Scope of investigation

Flowrate	1.4		4.2		8.4	m^3/h
Pressure	5	10	50	75	100	bar

HydraCell Pump
Centrifugal Pump
Sidechannel Pump
Peristaltic Pump
Membrane Piston Pump

Figure 5

Operating data														
flowrate	1	m^3/h	1,4	1,4	1,4	1,4	4,2	4,2	4,2	4,2	8,2	8,2	8,2	8,2
head	2	m	50	100	500	750	50	100	500	750	50	100	500	750
density	3	kg/dm^3	1	1	1	1	1	1	1	1	1	1	1	1
kinem.Viscosity	4	mm^2/s	1	1	1	1	1	1	1	1	1	1	1	1
energy price per kWh	5	€	0,08	0,08	0,08	0,08	0,08	0,08	0,08	0,08	0,08	0,08	0,08	0,08
operating hours per Jahr	6	h	4.000	4.000	4.000	4.000	4.000	4.000	4.000	4.000	4.000	4.000	4.000	4.000
number of years	7	-	10	10	10	10	10	10	10	10	10	10	10	10
interest rate	8	%	9	9	9	9	9	9	9	9	9	9	9	9
inflation rate	9	%	0	0	0	0	0	0	0	0	0	0	0	0
Pump data														
Type			G10	G10	G10	G10	G25	G25	G25	G25	G35	G35	G35	G35
pump aggregate	10	€	3.300	3.400	3.600	3.700	3.590	8.198	8.198	8.198	13.900	14.150	14.800	15.200
add. Inverter etc	11	€	0	0	0	0	0	0	0	0	0	0	0	0
complete aggregate	12 10+11	€	3.300	3.400	3.600	3.700	6.800	6.900	7.500	8.000	13.900	14.150	14.800	15.200
installation a commissioning cost	13	€	0	0	0	0	0	0	0	0	0	0	0	0
power, hydraulic	14 1*2*3/367	kW	0,2	0,4	1,9	2,9	0,6	1,1	5,7	8,6	1,1	2,2	11,2	16,8
effiency	15	%	45	58	77	79	46	59	77	79	45	58	77	79
power, demanded	16	kW	0,4	0,7	2,5	3,6	1,3	1,9	7,4	10,9	2,5	3,9	14,5	21,2
energy cost per year	17 6*7*16	€	136	210	793	1.159	401	622	2.377	3.475	794	1.233	4.643	6.788
operating cost per year	18	€	0	0	0	0	0	0	0	0	0	0	0	0
routine maintenance cost per year	19	€	100	100	100	100	100	100	100	100	100	100	100	100
spare parts per repair	20	€	350	350	350	350	550	550	550	550	900	900	900	900
labour cost per repair	21	€	150	150	150	150	150	150	150	150	150	150	150	150
time between repairs	22	h	4.000	4.000	4.000	4.000	4.000	4.000	4.000	4.000	4.000	4.000	4.000	4.000
repair costs per 8000 operating hours	23 (20+21)/22*8000	€	1.000	1.000	1.000	1.000	1.400	1.400	1.400	1.400	2.100	2.100	2.100	2.100
repair costs per year	24 23/8000*6	€	500	500	500	500	700	700	700	700	1.050	1.050	1.050	1.050
maintenance costs per year	25	€	600	600	600	600	800	800	800	800	1.150	1.150	1.150	1.150
downtime costs per year	25	€	0	0	0	0	0	0	0	0	0	0	0	0
other costs per year	27	€	0	0	0	0	0	0	0	0	0	0	0	0
decommissioning costs	28	€	0	0	0	0	0	0	0	0	0	0	0	0

Figure 6 Input

In *Figure 7*, the data from *Figure 6* is used to calculate LCC for each of the 3 Hydra-Cell pumps working at 4 different pressure levels.

The chart in *Figure 8* (Results 1) presents the results from *Figure 7* as a bar chart, with data grouped by pressure level. In *Figure 9* (Results 2) the same data is grouped by flow rate and presented as a chart.

Data from each of the five manufacturers was now set down to provide a basis for comparison between pump types. The figures in the Pump Comparison tables (1), (2), (3) and (4) relate to pumps in the small size/flow category working at low pressure.

Figures 10 to 13 provide a detailed comparison of the pumps - starting with operational assumptions and covering cost, performance, maintenance requirements and LCC.

- The first comparison in *Figure 10* (Pump Comparison (1)) shows operational assumptions, which are the same for each pump.
- *Figure 11*, (Comparison (2)) shows pump-to-pump differences in initial cost, pump efficiency and energy costs.
- *Figure 12* (Comparison (3)) reveals differences in maintenance, repair costs and expected frequency of repair for the five types of pump.
- *Figure 13* (Comparison (4)) brings together these differences in the context of total LCC for each type of pump at a flow of 1.4m³/hr and 50m head (pressure of 5 bar).

Type			G10	G10	G10	G10	G25	G25	G25	G25	G35	G35	G35	G35
complete aggregate	1	€	3.300	3.400	3.600	3.700	6.800	6.900	7.500	8.000	13.900	14.150	14.800	15.200
installation and commissioning cost	2	€	0	0	0	0	0	0	0	0	0	0	0	0
Initial investment costs	3 1+2	€	3.300	3.400	3.600	3.700	6.800	6.900	7.500	8.000	13.900	14.150	14.800	15.200
energy costs per year	4	€	136	210	793	1.159	401	622	2.377	3.475	794	1.233	4.643	6.788
operating costs per year	5	€	0	0	0	0	0	0	0	0	0	0	0	0
maintenance costs per year	6	€	500	500	500	500	700	700	700	700	1.050	1.050	1.050	1.050
downtime costs per year	7	€	0	0	0	0	0	0	0	0	0	0	0	0
other costs per year	8	€	0	0	0	0	0	0	0	0	0	0	0	0
sum of yearly costs	9 3 to 8	€	636	710	1.293	1.659	1.101	1.322	3.077	4.175	1.844	2.283	5.693	7.838
discount factor df see table 2)=f(n,i-p)	10	-	6,42	6,42	6,42	6,42	6,42	6,42	6,42	6,42	6,42	6,42	6,42	6,42
present value of yearly costs	11 9*10	€	4.079	4.560	8.296	10.646	7.065	8.482	19.746	26.796	11.837	14.650	36.534	50.301
decommissioning costs	12	€	0	0	0	0	0	0	0	0	0	0	0	0
factor Cp / Cp (see table .1)=f(n,i-p)	13	-	0,42	0,42	0,42	0,42	0,42	0,42	0,42	0,42	0,42	0,42	0,42	0,42
present value of decommissioning costs	14 12*13	€	0	0	0	0	0	0	0	0	0	0	0	0
Result														
Life Cycle Costs	15 3+11+14	€	7.379	7.960	11.896	14.346	13.865	15.382	27.246	34.796	25.737	28.800	51.334	65.501
- present value energy costs	16 4*11	€	870	1.351	5.087	7.437	2.573	3.990	15.253	22.304	5.098	7.911	29.796	43.562
- pesent value maintenance costs	17 6*11	€	3.209	3.209	3.209	3.209	4.492	4.492	4.492	4.492	6.739	6.739	6.739	6.739

Figure 7 LCC calculation

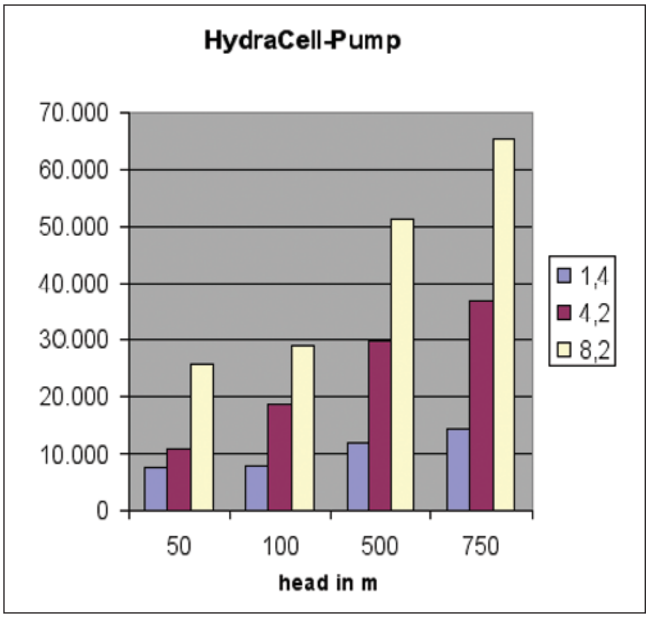

Figure 8 Results (1)

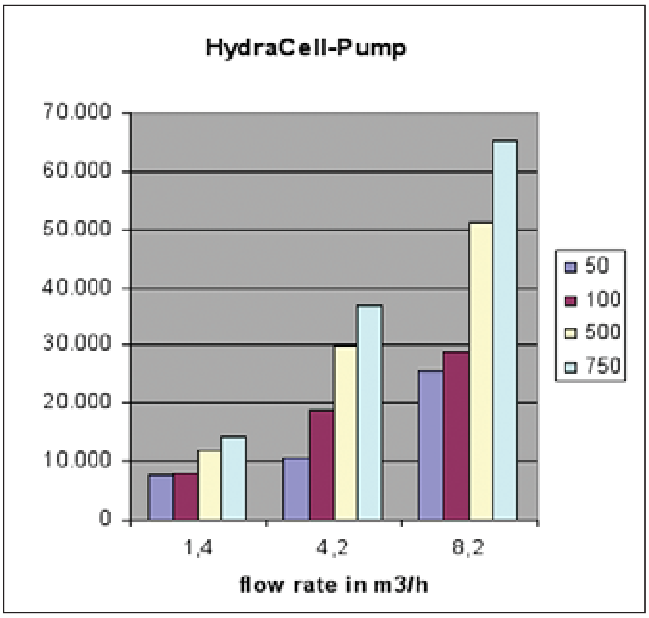

Figure 9 Results (2)

Type			Hydra Cell	Centrifugal	Side channel	Peristaltic	Membrane Piston
			G10	32-200	1204	VF25	LDB/3
flowrate	1	m^3/h	1.4	1.4	1.4	1.4	1.4
head	2	m	50	50	50	50	50
density	3	kg/dm^3	1	1	1	1	1
kinen. viscosity	4	mm^2/s	1	1	1	1	1
energy price per kWh	5	€	0.08	0.08	0.08	0.08	0.08
operating hours per year	6	h	4,000	4,000	4,000	4,000	4,000
number of years	7	-	10	10	10	10	10
interest rate	8	%	9	9	9	9	9
inflation rate	9	%	0	0	0	0	0

Figure 10 Pump comparison (1) 1.4 m^3/h 50 m

Type			Hydra Cell	Centrifugal	Side channel	Peristaltic P.	Membrane Piston P
			G10	32-200	1204	VF25	LDB/3
pump aggregate	10	€	3,300	3,550	3,400	1,968	8,700
add.Inverter etc	11	€					500
complete aggregate	12 10+11	€	3,300	3,550	3,400	1,968	9,200
installation and commissioning cost	13	€					
power, hydraulic	14 1*2*3/367	kW	0.19	0.19	0.19	0.19	0.19
efficiency	15	%	45	19	19	27	55
power, demanded	16	kW	0.4	1.0	1.0	0.7	0.3
energy cost per year	17 6*7*16	€	136	321	321	226	111

Figure 11 Pump comparison (2) 1.4 m^3/h 50 m

Type			Hydra Cell	Centrifugal	Side channel	Peristaltic	Membrane Piston
			G10	32-200	1204	VF25	LDB/3
operating cost per year	18	€	0	0	0	0	0
routine maintenance cost per year	19	€	100	100	100	100	250
spare parts per repair	20	€	350	400	450	170	1,550
labour cost per repair	21	€	150	1,000	1,000	150	2,000
time between repairs	22	h	4,000	16,000	16,000	1,000	8,000
repair costs per 8000 operating hours	23 (20+21)/22*8000	€	1,000	700	725	2,560	3,550
repair costs per year	24 23/8000*6	€	500	350	363	1,280	1,775
maintenance costs per year	25	€	600	450	463	1,380	2,025
downtime costs per year	26	€	0	0	0	0	0
other costs per year	27	€	0	0	0	0	0
decommissioning costs	28	€	0	0	0	0	0

Figure 12 Pump comparison (3) 1.4 m^3/h 50 m

Type				Hydra Cell	Centrifugal	Side channel	Peristaltic	Membrane Piston
complete aggregate	1		€	3300	3550	3400	1968	9200
installation and commissioning cost	2		€	0	0	0	0	0
initial investment costs	3	1+2	€	3,300	3,550	3,400	1,968	9,200
energy costs per year	4		€	136	321	321	226	111
operating costs per year	5		€	0	0	0	0	0
maintenance costs per year	6		€	600	450	463	1,380	2,025
downtime costs per year	7		€	0	0	0	0	0
other costs per year	8		€	0	0	0	0	0
sum of yearly costs	9	3 to 8	€	736	771	784	1,606	2,136
discount factor df see table 2)=f(n,i-p)	10		-	6.42	6.42	6.42	6.42	6.42
present value of yearly costs	11	9*10	€	4,721	4,950	5,030	10,307	13,708
decommissioning costs	12		€	0	0	0	0	0
factor Cp / Cp (see table 1)=f(n,i-p)	13		-	0.42	0.42	0.42	0.42	0.42
present value of decommissioning costs	14	12*13	€	0	0	0	0	0
Result								
Life Cycle Costs	15	3+11+14	€	8,021	8,500	8,430	12,275	22,908
of which are energy costs	16	4*10	€	870	2,062	2,062	1,451	712
of which are maintenance costs	17	6*10	€	3,851	2,888	2,968	8,856	12,996

Figure 13 Pump comparison (4) 1.4 m³/h 50 m

All of these differences are expressed graphically in the bar chart in *Figure 14* (Comparison (5)). It shows that at low flows and low pressures the LCC for Hydra-Cell, centrifugal and side-channel pumps are similar. The peristaltic pump has the lowest initial cost and high repair costs. The membrane-piston pump, though energy efficient, has easily the highest initial cost and is expensive to repair.

Parallel analysis was applied to values for larger sized pumps, representing the 5 types at higher flow rates. The bar chart in *Figure 15* (Comparison (6)) shows the LCC for the pumps delivering 8.2m³/hr, again operating at low pressure (5 bar). In these circumstances, Centrifugal pumps showed the lowest LCC.

For higher pressure applications (above 10 bar), only the Hydra-Cell and membrane piston pumps are taken into account, as the other types in our survey cannot usefully be considered for working at these pressures. The bar chart in *Figure 16* (Comparison (7)) shows that the LCC for the Hydra-Cell pump is much lower than for the membrane-piston pump - its only real alternative at the higher pressure.

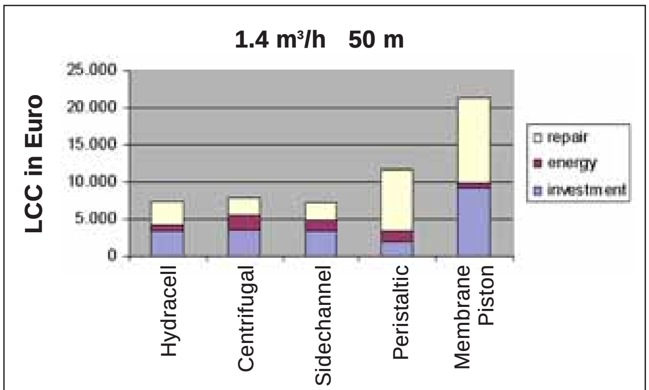

Figure 14 Pump comparison (5)

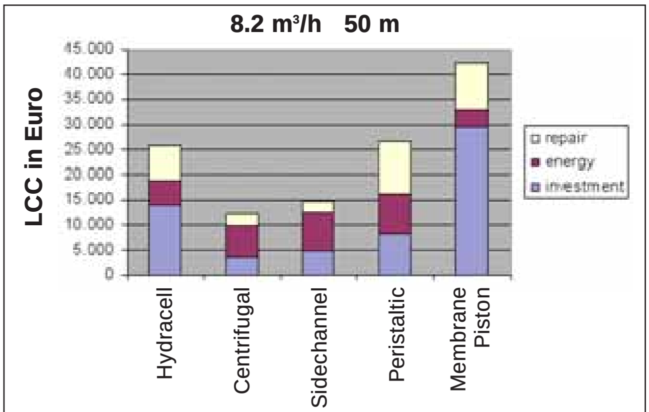

Figure 15 Pump comparison (6)

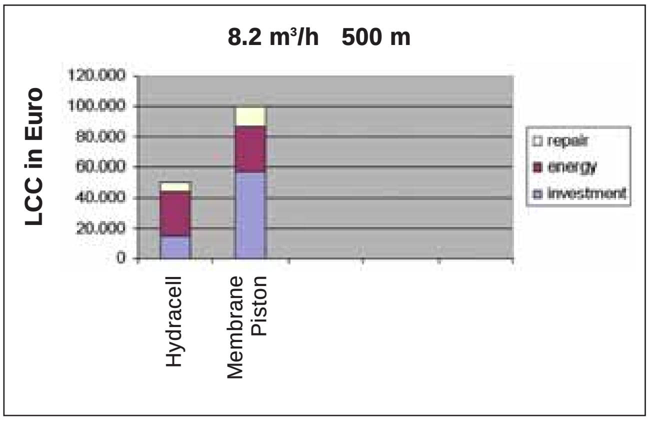

Figure 16 Pump comparison (7)

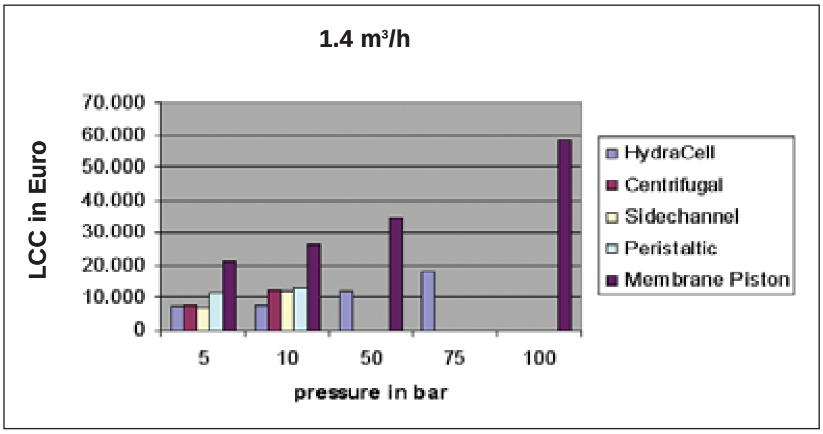

Figure 17 LCC comparison survey (1)

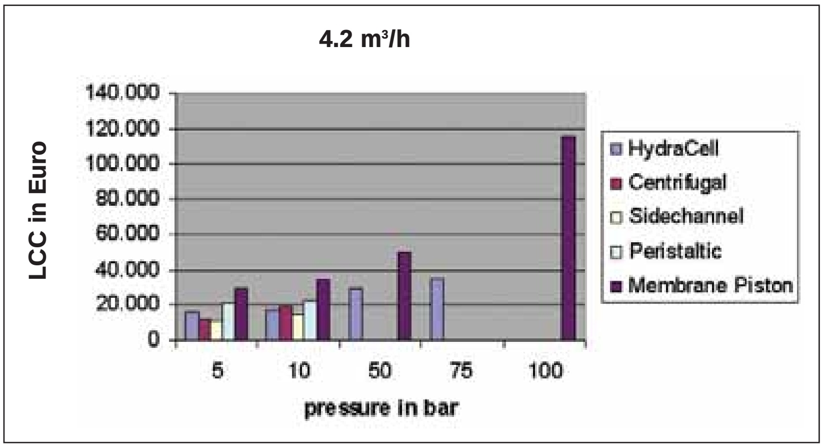

Figure 18 LCC comparison survey (2)

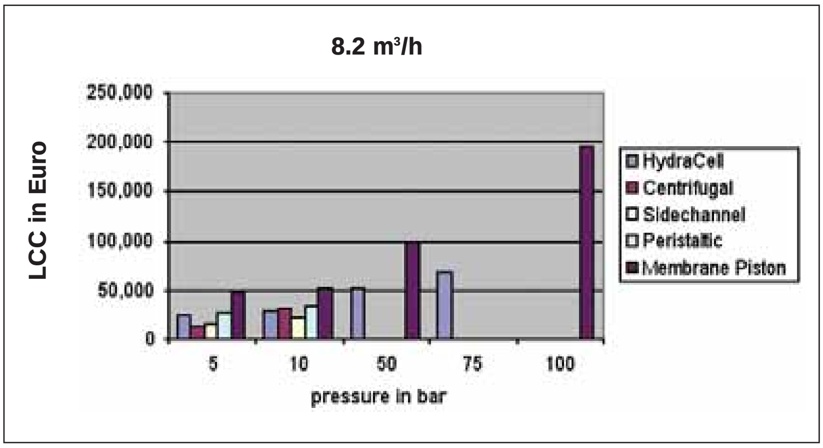

Figure 19 LCC comparison survey (3)

The bar charts in *Figures 17, 18 and 19* LCC comparison survey (1), (2) and (3) provide the results of a comparison surveys and present a graphical summary of the results of the investigation into Life Cycle Costs. The results are arranged by size of pump.

- *Figure 17* shows the results of Survey (1) which covers pumps capable of a flow rate of 1.4m^3/hr.
- *Figure 18* shows the results of Survey (2) which covers pumps capable of 4.2 m^3/hr. *Figure 19* shows the results of Survey (3) which gives results for larger pumps, able to deliver 8.2 m^3/hr.

Each survey chart relates the LCC of the pump to the five pressure levels at which it is operating. That is 5 bar, 10 bar, 50 bar, 75 bar and 100 bar. As previously noted, centrifugal, side-channel and peristaltic types have not been taken into account for operating at pressures above 10 bar (100m head).

From our survey, whose overall results are summarized in these three charts, we can draw certain conclusions.

In terms of LCC, the Hydra-Cell, whose efficiency at high pressure is around 85%, is the most economic pump overall in the considered range, and it can pump abrasive, viscous, corrosive liquids and liquids with particles.

The LCC of the side-channel pump is comparable, within its pressure range, but the pump can only handle clean fluids.

Centrifugal pumps are for low pressures and high flow rates. The LCC of the peristaltic pump is increased by its high consumption of replacement tubes.

Membrane piston pumps are very efficient, but their investment cost and the costs of spare parts and labour when changing membranes are extremely high. The Life Cycle Cost of this type of pump can be up to 3 times higher than that of the Hydra-Cell.

LCC is of course not the only factor in a pump purchase decision. First there is the task the pump has to perform. The pump has to pump a fluid, which may have special characteristics. For example, it could be corrosive, viscous or non-lubricating - and the pump will have to operate under specific conditions of flow rate, pressure and temperature. There may be other requirements, such as low pulsation and the ability to perform to standards of strict accuracy. And the pump must be reliable.

If more than one type of pump can handle the task, LCCs have to be compared. Short term, money might be saved by buying a cheap pump - but how long will it be before repair costs, energy consumption and possible production losses cancel out the original saving? Life Cycle Costs are important.