Centrifugal pumps

Pump selection: a real example

Choosing the most appropriate and cost-effective centrifugal pump for a given duty requires strict adherence to a thorough selection process, as Eduardo Larralde and Rafael Ocampo discussed in the first article of this two-part series. Here they demonstrate the application of the selection procedure in practice with a real-life example.

The recommended procedure for the selection of centrifugal pumps was presented in the previous article[1]. The information required in order to prepare the quotation request for the pump and electric motor was examined in detail as well as the recommended approach for studying the corresponding offers. In this second, concluding part, a case study is presented in order to exemplify how to apply the aforementioned procedure.

The studied system

In a tyre manufacturing plant a pumping system is required to circulate hot water through a set of 24 tyre vulcanization presses. In order to carry out the complete curing cycle of the tyres, the following sequence of fluids should be supplied to the inner part of the mould (bladder):

1. Shaping steam.
2. Pre-curing steam.
3. Hot water for curing. This step requires the pumping of hot water to push out the steam and fill the bladder (1.6 minutes) and then maintain the hot water circulation until the end of the curing step.
4. Cooling water.
5. Drain.
6. Vacuum.

The implementation times for these steps may vary according to the design and dimension of the tyres to be manufactured. Usually the curing step (3) takes up about 80% or even more of the complete curing cycle duration. The curing cycle in each press is controlled by a programmable regulator and the operating sequence of all the presses is governed by a PLC in order to ensure the fulfilment of the operating order, which was used as the basis for calculating the consumption of every fluid in the process.

Operating conditions

The chosen circulation pump will have to satisfy the following operating conditions:

a) Maximum circulation flow, which occurs when all the 24 presses are simultaneously operating in the hot water circulation step.

b) Peak maximum flow, which occurs when six presses simultaneously begin filling the bladders with hot water (maximum consumption) plus the flow to the rest of the presses already filled and circulating. This is the flow value used to select the pump.

c) Minimum operating flow, given by the minimum hot water process demand, which occurs when all the presses are operating but only six are running in the curing step.

d) Safe minimum flow for pump protection, specified by the pump manufacturer.

Selected operating parameters for the hot water circulation pump

- Normal pumping temperature: 185°C; maximum: 195°C
- Normal capacity at pumping temperature: 105 m^3/h
- Rated capacity at pumping temperature: 120 m^3/h
- Minimum operating flow: 45 m^3/h
- Rated differential head: 126.3 m
- Discharge pressure: 2.46 MPa
- Maximum discharge pressure allowed by the process: 2.58 MPa

Table 1. Load duty cycle for hot water circulation pump

Flow rate (m^3/h)	45	65	80	85	100	105	120
Time (h/year)	1216	1116	520	372	149	3198	149
%	18.09	16.61	7.74	5.53	2.22	47.59	2.22

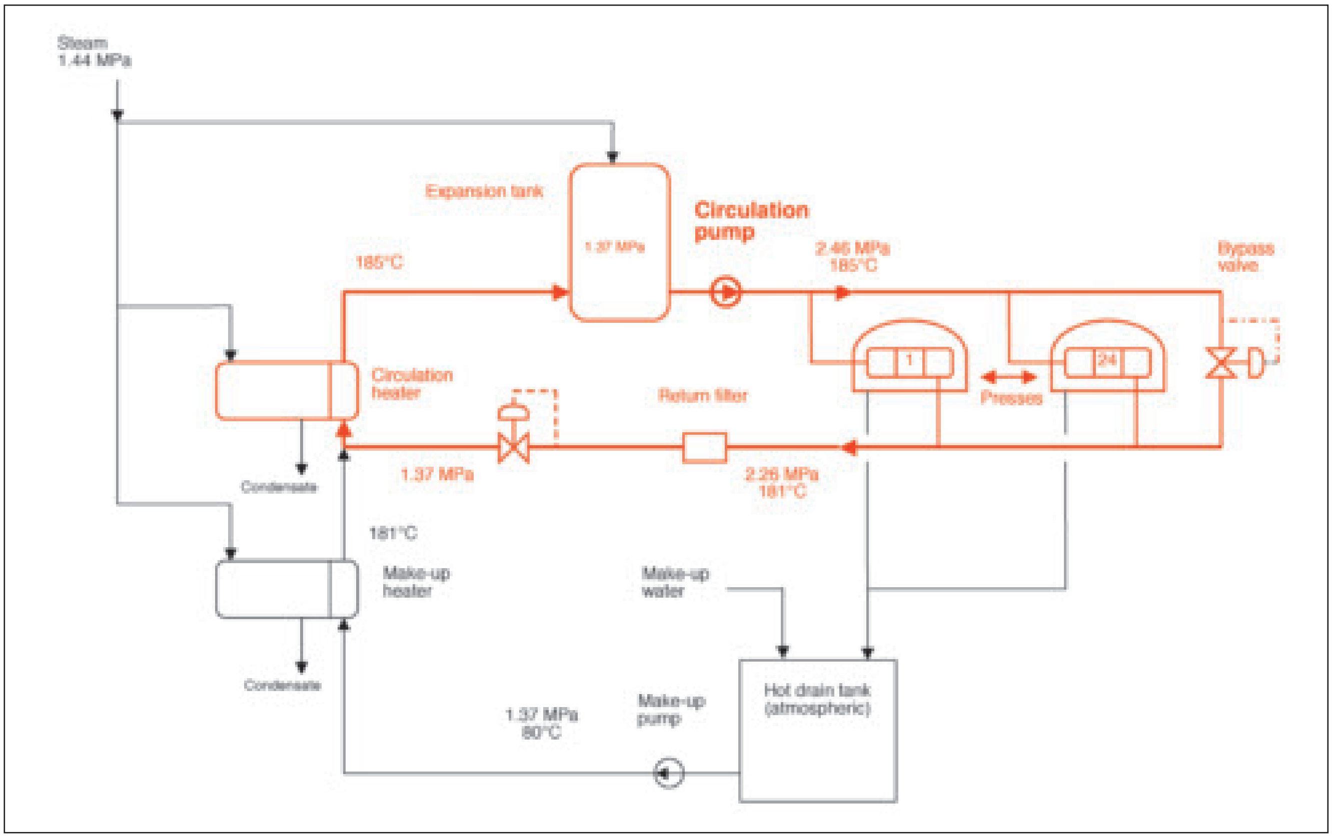

Figure 1. Hot water system for the vulcanization presses.

Moreover, due to the operating sequence of the set of 24 presses, the circulation pump will have to run with variable capacity according to the quantity of presses in each step of the curing process and the type of tyre being manufactured. Table 1 shows the values of the flow pumped during the different operational combinations of the presses, the number of hours in a year the pump runs at each capacity and the percentage of time represented by each operating condition against the total running time. It is obvious that the process imposes very variable operating conditions on this pump, making it more difficult to achieve a satisfactory pump selection.

In order to ensure the quality of the vulcanization and the correct operation of the presses, the discharge pressure of the pump must not be greater than 2.58 MPa. This requirement must be carefully taken into account; otherwise the pump will not satisfy the operation of the system as expected.

A sketch of the hot water system for the presses is shown in Figure 1, where two loops are clearly identifiable, one for hot water circulation, the other for water make-up and heating. This article deals with the pump selection for the circulation loop only because of its greater interest and operational complexity. The sketch shows the inlet and outlet headers, the bypass line between them and its automatic pressure-regulating valve. This bypass is used during the start-up of the system when none of the presses demands hot water and also to guarantee the safe minimum flow for the protection of the pump during periods of low demand.

Table 2. Summary of LCC for best options from different suppliers (in US$)

Cost element	**Supplier 1**	**Supplier 2**	**Supplier 3**
Initial investment (purchase, installation and commissioning)	*43002.72*	*55248.51*	*41934.35*
Current energy price ($/kWh)	0.09	0.09	0.09
Adjusted medium power (kW)	35.6	36.0	35.9
Operating hours per year	6720	6720	6720
Calculated energy cost per year	21531.35	21772.80	21736.51
Calculated energy cost in life cycle	*229765.83*	*232342.39*	*231955.16*
Maintenance cost per year	769.00	706.46	817.90
Repairs cost (every 2 years)	1889.98	806.39	1999.18
Maintenance cost in life cycle	*18100.09*	*11760.21*	*19193.56*
Pump life span	14	14	14
Interest rate (%)	8	8	8
Inflation rate (%)	4	4	4
Current value of LCC	**290868.63**	**299351.11**	**293083.07**

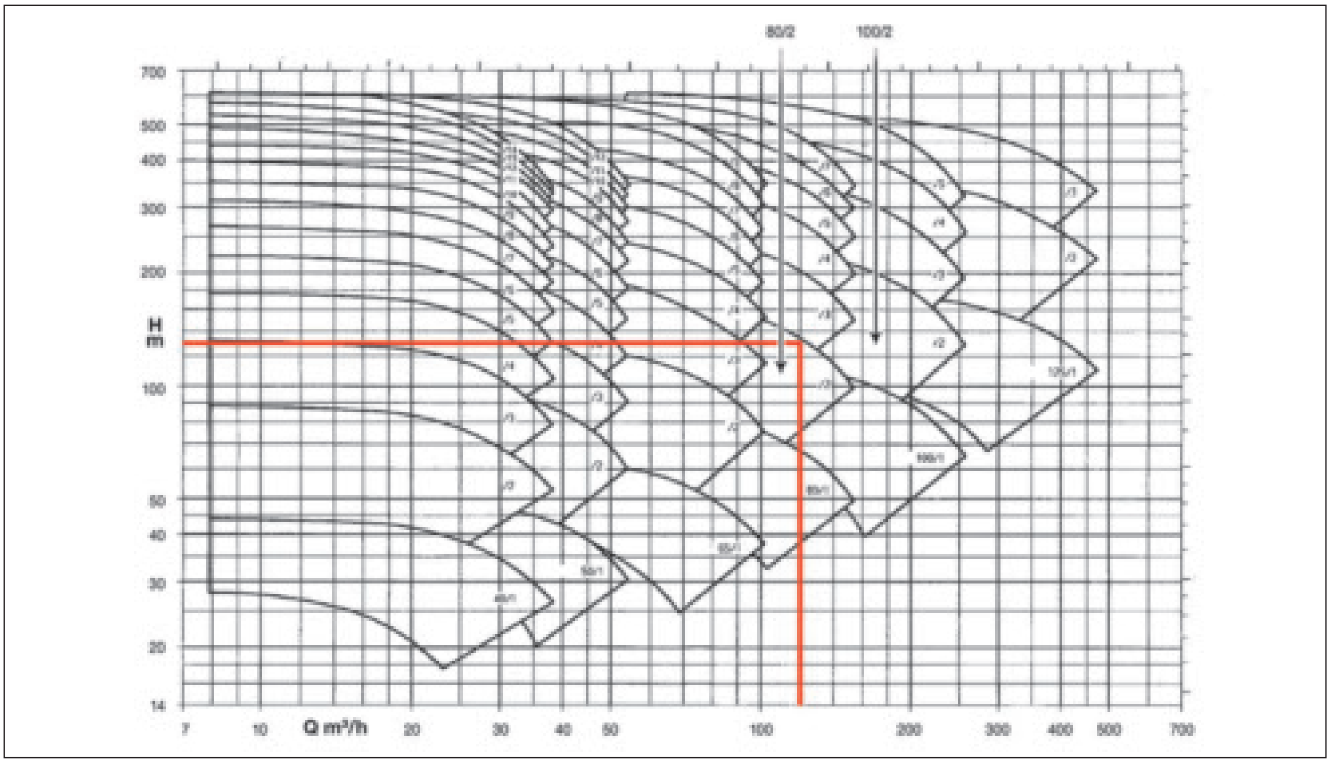

Figure 2. Pump selection chart for 3500 rpm.

The most important operating parameters for determining the selection of the pump are shown in the box. A full listing of the minimum specifications required for the pump quotation request was given in the previous article (*World Pumps*, February 2010, p. 27)[1].

Choosing the supplier

The procedure described in the first article was applied to analyse several pumps offered by three different suppliers. Life cycle cost (LCC) calculations were carried out for the best of the proposed pumps and a summary of the results is shown in Table 2. This indicates that the lowest cost of ownership belongs to supplier number one, who also satisfied the rest of the commercial requirements. The efficiency for this manufacturer was the highest of all, reaching 73.9% at BEP. Supplier number two was eliminated because of the high investment cost resulting from the use of materials of excessive quality, a slightly lower efficiency (73.2% at BEP) and high energy consumption. In spite of lower maintenance costs the LCC of this supplier is substantially higher than the rest. Although the initial investment for supplier number three is the lowest of all, a lower efficiency (72.5% at BEP) and higher maintenance cost lead to a higher LCC and therefore also take this manufacturer out of contention.

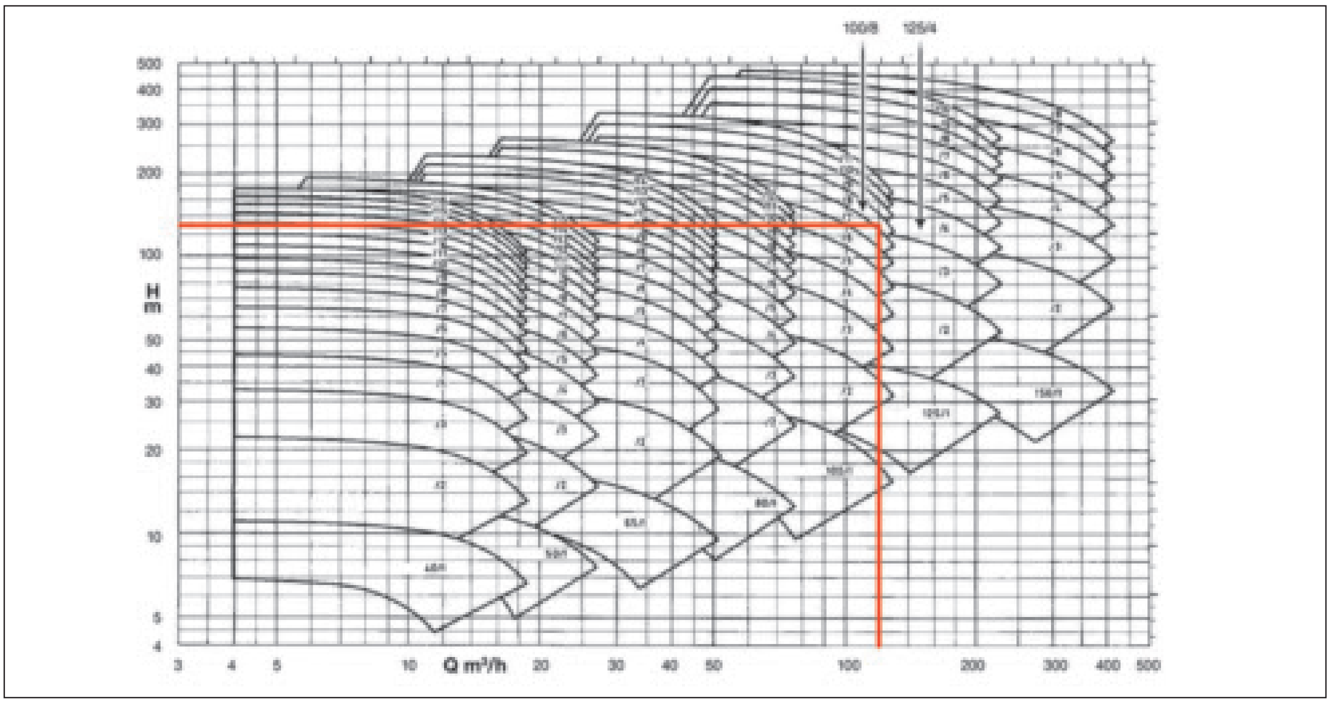

Figure 3. Pump selection chart for 1750 rpm.

Pump selection

Once the supplier was selected, the following decision-taking process was undertaken to determine the optimum pump for the tyre manufacturing task.

Preliminary selection

The pump is selected from those designed to be used for industrial hot water and boiler feed service, featuring one or more stages, with a radially split design casing. The required head and capacity are 126.3 m and 120 m^3/h, respectively. According to the selection charts shown in Figures 2 and 3, models 80/2 and 100/2 running at 3500 rpm and models 100/8 and 125/4 running at 1750 rpm satisfy these requirements. The installation of two or three pumps in parallel might have been a better option from the point of view of efficiency but was ruled out because of the very high instantaneous flow demand occurring when six presses simultaneously reach the bladder-filling step, creating a sudden pressure drop even if the pumps are automatically governed, and this is undesirable if good vulcanization quality is to be achieved.

Characteristic curves analysis

The information obtained from the selection chart is not sufficient to choose the appropriate pump. A careful and detailed checking and comparison of the characteristic curves for those pumps that are able to satisfy the intended service is also required.

The standard impeller diameter best fitting the load requirement was chosen for each of the pre-selected pumps. The characteristic Q-H and Q-η curves and standard impeller diameters of the four pumps are shown in Figure 4. The Q-H curve profile for pump model 100/8 makes it inadequate for the intended service because of the high head obtained at flow rates below the rated value. Pump model 125/4 is also inadequate because the head obtained at flow rates above 100 m^3/h is substantially smaller than the head required. Since 250 mm is the maximum standard impeller diameter for that pump model it is impossible to increase that head figure.

Fine-tuning the options

The other two pre-selected pump models do not exactly fulfil the requisite head at the rated capacity and it is therefore necessary to find, through calculation, impeller diameters yielding a discharge pressure of 2.46 MPa or slightly higher at 120 m^3/h. For model 100/2 the diameter remains the same due to the fact that 205 mm is the minimum available. Calculation results are shown in Table 3.

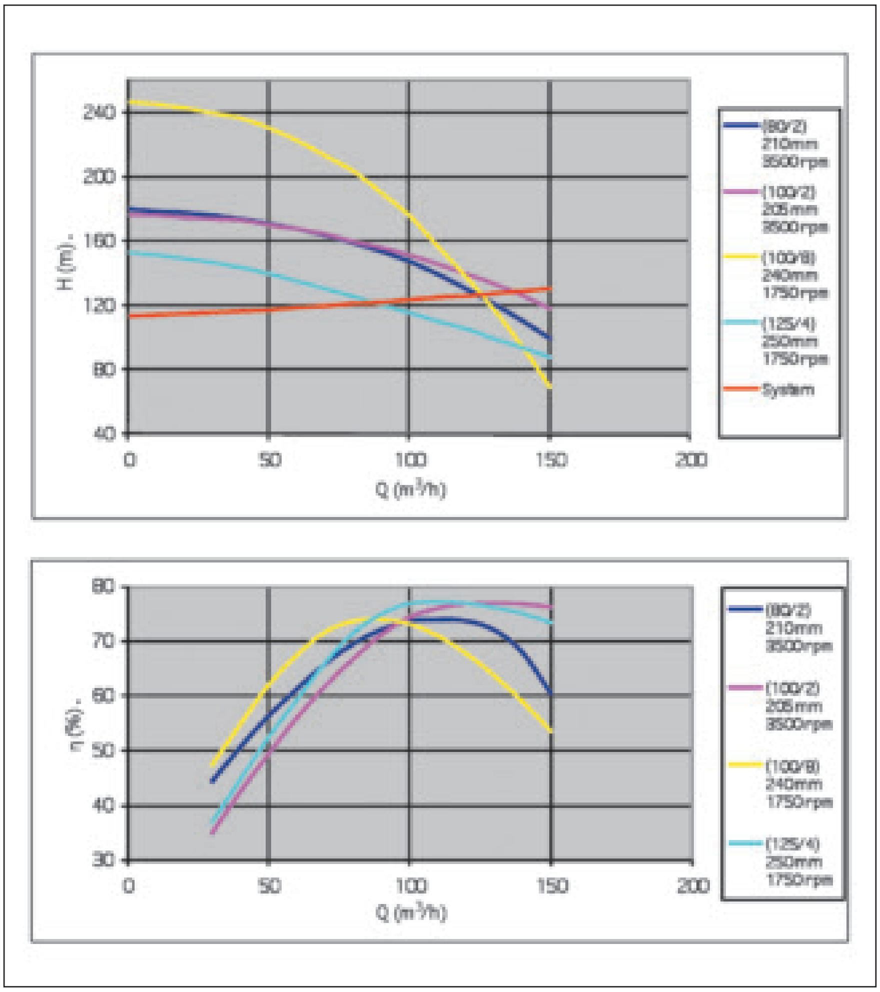

Figure 4. Characteristic Q-H and Q-η curves for standard impeller diameters.

For the minimum flow rate of 45 m^3/h both pump models exceed the maximum figure of 2.58 MPa imposed by the process and therefore alternative solutions have to be found and assessed. The simplest solution is to install a control system governing the bypass valve and ensuring the pressure limit in the inlet header is not exceeded. A second option is the use of a pressure control system combining a variable speed drive (VSD) and the bypass valve. Whenever the flow rate varies (above 45 m^3/h) this control system would modify the pump speed to adjust the head to the required 126.3 m. Figure 5 shows the behaviour of pump model 80/2 under this condition. The graph is also useful to define the frequency range applicable to the control of this pump, which in this case is from 60 Hz to 52 Hz.

Knowing that the initial investment for the option using a VSD is higher and also that the static head of the system is high, it is imperative to carry out a deeper analysis to reach a final selection. Technical calculations show that the VSD option yields lower energy consumption figures in spite of its lower efficiency compared with the control option using the bypass valve alone. In addition, reliability is lower for the VSD option because operating

Table 3. Significant data from characteristic curves for calculated diameters

Pump model (Impeller diameter, Ø)	rpm	Q = 120 m^3/h		Q = 45 m^3/h	
		H (m)	Discharge pressure (MPa)	H (m)	Discharge pressure (MPa)
80/2 (Ø = 207.4 mm)	3500	126.3	2.46	*167.9*	*2.82*
100/2 (Ø = 205.0 mm)	3500	140.0	2.58	*170.6*	*2.84*

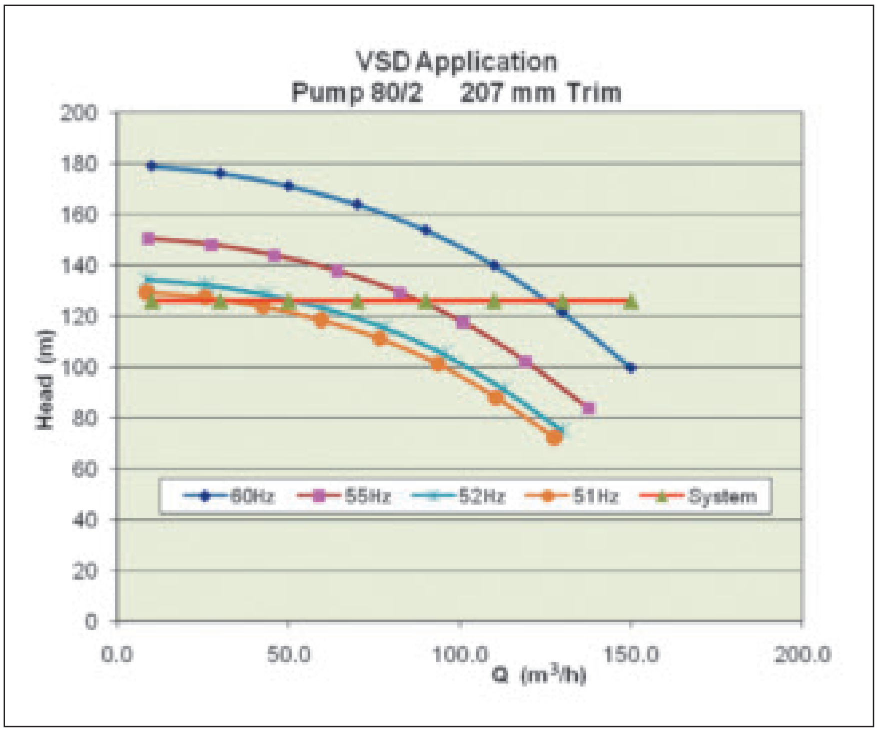

Figure 5. Behaviour of pump 80/2 with a variable speed drive.

flow rates are farther from the BEP. The relevant figures are shown in Table 4. VSD options show lower energy consumption because they are better suited to the flow variations imposed by the process. It is necessary to use LCC analysis as a key tool for the final selection.

LCC analysis

When several presses are out of service the hot water demand can be drastically reduced, even below the minimum safe flow specified for the pump. During start-ups it is zero.

In order to confront these conditions and also attain adequate pressure regulation throughout the operating range it will be necessary to apply a combined control system using a VSD and bypass valve; therefore both should be included in the LCC assessment for the VSD option.

Calculation results for the two pre-selected pump models are presented in Table 5. This shows that the best selection is the two-stage pump model 80/2, running at 3500 rpm, with an impeller diameter of 207.4 mm using pressure control via a VSD/bypass valve combination.

It is important to point out that in this case, because of the wide capacity range, the narrow margin for discharge pressure and the intolerance to pressure fluctuations (only ±5%), it is impossible to choose a pumping system with the ideal performance.

Finally, the average adjusted flow rate for the selected pump will be 85% of flow at BEP, meaning that the average efficiency will be 71% compared to 74.8% at BEP. Reliability is estimated at 86% to 89% of the maximum obtained at BEP.

Other important data for the selected pump are as follows:

- Absorbed power at rated capacity: 49.5 kW.
- NPSH(A): 20 m.
- NPSH(R) at rated capacity: 7.7 m. The Hydraulic Institute recommends that the NPSH(A) be at least 25% greater than the NPSH(R). Therefore the recommendation is fulfilled with a wide margin.
- Safe minimum flow (as indicated by the manufacturer): 35 m^3/h. The combined pressure control guarantees that under any condition the pump flow will be equal to or greater than 45 m^3/h so a reasonable safety margin will always exist.

This pump model also satisfies all the other technical requirements stated by the buyer. Moreover, the offer satisfies the desires of the buyer from the commercial standpoint.

Installation

Taking into consideration the characteristics of the pumping service intended two pumps are installed, one operating and one on stand-by.

It has been demonstrated elsewhere that a pumping service should be studied in an integral manner, considering not only the pump but also the driver and the system; otherwise it will be insufficient and the results could be incorrect. Therefore the whole system including pipes, fittings, valves (manual and automatic), presses, filter, heaters and tank was assessed.

The pipes were rationally plotted and correctly dimensioned, applying the recommended velocities for the type of fluid and type of piping. Valves and fittings were carefully selected with regard to the type and material of construction. The instrumentation, alarm devices and interlocks required for correct, safe operation were also selected. In this case it was compulsory to install an alarm for high discharge pressure, a trip for extra-high discharge pressure and a safety valve.

Conclusions

Engineers in charge of pump specification and procurement are responsible for precisely defining the performance requirements for the pumping service and

Table 4. Results for different control system options

Pump model (Impeller diameter)	Parameters	Options	
		Bypass	VSD + bypass
80/2 (207.4 mm)	Avg. efficiency (%)	74.2	71.0
	Avg. power (kW)	46.8	35.6
	Annual energy (kWh)	314241.8	239237.2
	Avg. flow/BEP flow	0.99	0.85
100/2 (205.0 mm)	Avg. efficiency (%)	76.8	69.0
	Avg. power (kW)	52.5	36.4
	Annual energy (kWh)	352880.1	244687.3
	Avg. flow/BEP flow	1.00	0.60

Table 5. Life cycle cost results

Option 1. Pressure control via bypass valve			Option 2. Pressure control via VSD + bypass valve		
Cost element	Pump model		Cost element	Pump model	
	80/2	100/2		80/2	100/2
Initial investment cost	*33821.24*	*37694.82*	Initial investment cost	*43002.72*	*46876.30*
Current price of energy per kWh	0.090	0.090	Current price of energy per kWh	0.090	0.090
Average adjusted power (kW)	46.76	52.51	Average adjusted power (kW)	35.60	36.41
Annual operating hours	6720	6720	Annual operating hours	6720	6720
Annual energy calculated cost	28281.76	31759.21	Annual energy calculated cost	21531.35	22021.86
Life cycle energy cost	*301800.99*	*338909.59*	Life cycle energy cost	*229765.83*	*235000.15*
Annual maintenance cost	664.00	702.00	Annual maintenance cost	769.00	807.00
Repair cost (every 2 years)	1800.00	1912.00	Repair cost (every 2 years)	1889.98	3331.20
Life cycle maintenance cost	*16508.58*	*17500.40*	Life cycle maintenance cost	*18100.09*	*26050.31*
Life span (years)	14	14	Life span (years)	14	14
Interest rate (%)	8	8	Interest rate (%)	8	8
Inflation rate (%)	4	4	Inflation rate (%)	4	4
Current LCC value	**352130.81**	**394104.82**	**Current LCC value**	**290868.63**	**307926.76**

for choosing equipment offering a suitable and efficient behaviour during a reasonably long life span. In order to do a thorough job, they must know and use technical procedures that have been previously tested and ensure reliable results, such as those established in international standards. Overlooking important aspects of those procedures may lead to an inappropriate selection of the pump causing difficulties and damage during its operation. Although internationally recognized standards do not cover every detail they set some space aside to consider these matters. The buyer should use that tool in order to ensure that their requirements reach the supplier appropriately and to ensure they receive from the supplier all the information stated in the standards at each stage of the negotiation or contract. Good communication and exchange between buyer and manufacturer will help to achieve a successful pump selection.

The analysis of pump performance must include not only the design operating point but also any other operating conditions that can be foreseen, even temporary, as well as the drawing up of tables or charts with foreseeable flow rates and operating times corresponding to each. In addition, necessary measures must be taken to avoid flow rates below the minimum safe value. Operating efficiency must be carefully studied and compared with the efficiency at BEP, not allowing unreasonable differences. Operating a pump far from its BEP, besides wasting energy, can lead to adverse effects, such as cavitation, shortening of seal, impeller and bearing life, internal recirculation and temperature increases, all of which decrease pump reliability and increase maintenance costs.

The correct selection of pump, drive and system should ensure such a performance that the energy consumption per unit volume of pumped fluid is as low as possible. This is not always achieved via higher efficiency. In the case presented, the greater portion of the reduction in energy consumption was obtained by adapting the pump operating regime to that required by the process through the use of the combined VSD + bypass control system.

It has been widely demonstrated that initial investment is not the most important factor in the cost of ownership. Therefore the LCC calculation should be applied in each case. In the example presented, the initial investment represents only 14.8% of LCC. As usually occurs with pumps operating for more than 2000 hours in a year, the cost of energy in this case is a high percentage of the LCC, at 79%.

In spite of the general validity of all the previous statements, sometimes a pump must confront certain harsh requirements and to fulfil them the buyer will be compelled to reject some predilections. The case study presented is a clear example: to satisfy the very stiff conditions imposed by the process both the efficiency and the reliability had to be sacrificed. ■

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