

CASE STUDIES – CS2

Segment – Pumping System \ Forces in centrifugal pumps \ Materials of construction

Topic/ case – Circulating water pumps in an oil refinery- Part flow operation and frequent shaft failure

Description of the case – A petroleum refinery installed a series of axially split case pumps for cooling tower application. Due to increase in the demand for cooling water, the number of pumps installed was increased from five to eight. While the total flow from the system has increased, flow per pump has reduced after additional pumps were installed. Additionally, pump shafts fail very frequently. The refinery is looking for solutions to both:

- a. Short shaft life
- b. Rapid erosion of impeller

The initial investigation suggests inadequate sump design and an increase in the system head to be the major reasons for early failure.

Question for discussion-

1. What are the guidelines for a good sump design that will prevent flow starvation?
2. Why is double volute casing mandatory for large pumps subject to variation in flow rate?
3. How does shaft material affect the life of the shaft when unusual radial loads are present?
4. How does selection of impeller material affect the life of pumps subject to cavitation?

IOCL HALDIA – 24/24 CME CIRCULATING WATER PUMPS

PROBLEMS	Under capacity Performance	Pump delivers only 50-60%of the rated flow.
	Shaft Breakage	Shafts fail adjacent to the impeller after 2/3 months of operation.

PUMP DETAILS	Following details have been provided by IOCL	
	Pump Model	24/24 CME
	Rated Capacity	4500m ³ /hr
	Discharge Pressure	5.5 kg/cm ²
	Total Head	52.7 M
	Speed	991 rpm
	BHP	1027.51 (766.8Kw)
	Pump Efficiency	84% (calculated from the power figure)
	Casing Material	CI Gr 14 BS 1452
	Shaft	AISI 410
	Other Components	Bronze (Presume, LG2 Bronze for impeller)

PUMP DESIGN DATA	The following design data for this pump is available with us:		
	Impeller OD, D2	670 mm	
	Width at Outlet, b2	164 mm	
	No. of Vanes	5	
	Outlet Vane Angle, β_2	19 ⁰	
	Eye Diameter, D ₁	464 mm	
	Hub Diameter, D _o	147.5mm	
	Shaft Diameter at impeller, D	111mm	
	Eye Area	236 in ²	
	Volute Throat Area	352in ²	
	Best Efficiency Point as per test curve at 670 mm	Q= 5177 M ³ /hr	
		H= 41.2 m	
		Efficiency = 87% (Rated duty is 13% to the left of BEP)	
NPSHr based on 3% head drop test	19 ft (5.8m)		

OPTIMUM EFFICIENCY FOR THE DUTY Ref: Hydraulic Institute Standards	Capacity	4500 M ³ /hr=19813 USgpm
	Head	52.7 m
	Speed	991 rpm
	Specific Speed N _s	2926 US Units
	According to HIS	Attainable Efficiency – 91.2%
		Specific Speed – Efficiency Correction - NIL
		Deviation from Attainable Efficiency ± 1.8%
Therefore, optimum pump efficiency for this installation is 89.6% to 92.8%		

Our observations at site – During our last visit, we saw two pumps in operation. We also looked at a damaged impeller and a broken pump shaft. Our observations are as follows:

1. Distinct gravel sound from pumps indicative of cavitation
2. Delivery pressure of 4.5kg/cm ² and suction pressure of 0.7 kg/cm ² g
3. Damaged impeller was belzona coated. The coating has peeled off at several locations due to cavitation pitting
4. Cavitation damage on the visible side of the impeller vanes close to impeller eye. Location of the damage strongly suggests cavitation due to part flow operation.
5. Shaft shear near impeller suggests failure due to excessive radial load and cavitation

NPSH available and the right speed for this pump –

Available data suggests that for this installation

NPSHA = 12 M minimum (perhaps more)

Using, N_{ss} = 8500 as per HIS, maximum operating speed of the pump works out to:

$$8500 = \frac{N\sqrt{19813 \times 0.5}}{(12 \times 3.28)^{0.75}} \text{ OR } N = 1341 \text{ rpm max}$$

Therefore, speed of 991rpm is quite acceptable.

NPSH required and available margin – the required margin between NPSHA and NPSHr for cavitation for free operation depends on the suction energy of the pump. Suction Energy, SE, is defined as

$$SE = D_e \times N \times N_{ss} \times sp.gr$$

Here, D_e = Eye diameter = 18.3", N = 991 rpm, N_{ss} = 10840 (Based on NPSHr = 19 ft, tested value), $sp.gr$ = 1.0

SE = 196x10⁶

This suction energy is considered to be very high and Hydraulic Institute recommended a margin of NPSHA / NPSHr between 2 and 2.5 for cavitation free operation. Since NPSH required by the pump is 19 ft, the available NPSH should be 38 to 47.5ft or 12m to 14.5m. Suction gauge reading and other site data suggest that this level of NPSH is available at site.

Radial Thrust

This is a single volute pump. The evidence suggests that the pump capacity during operation is around 2250 to 2500 m³/hr. This means that pump operates at 50% of its BEP capacity.

Radial thrust is given by

$$RT(\text{Metric}) = K \times H \times \rho \times g \times D_2 \times b_2 \text{ (including shrouds)}$$

Here, K = 0.28 (from HIS)

H = 60 m (approx)

ρ = 1000 kg/m³

g = 9.81 m/sec²

D_2 = 670 mm = 0.670 m

b_2 = 184mm = 0.184m (including shrouds)

Therefore, RT = 20,317 Newtons

At the best efficiency point, the radial thrust is only 5700 Newtons. This means that the shaft is constantly subjected to 3.5 times its normal design load due to part capacity operation.

Influence of Sump

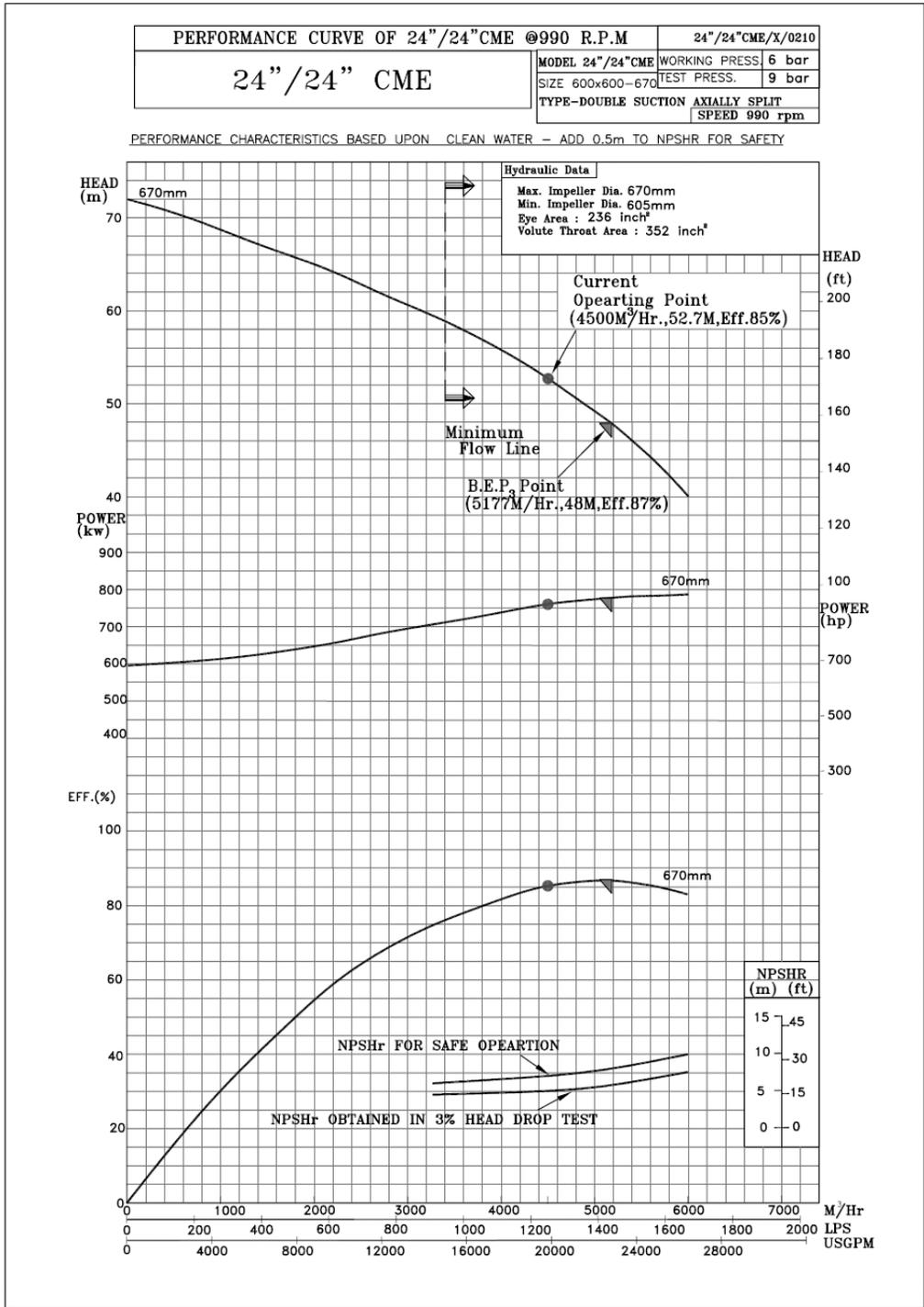
The above analysis suggests that pump operating speed, available NPSH, required NPSH by the pump are all adequate for this duty. We do not have data pertaining to sump, but the following figures may be checked to ensure that recommendations of HIS have been followed for sump geometry.

Suction pipe velocity (8ft/sec max)	This suggest a minimum suction pipe diameter of 750mm
Velocity at suction bell	1.7 m/sec. This suggests a minimum suction bell diameter of 950 mm to 1000 mm
Suction sump width for each suction bell	1.9 m to 2.0 m
Velocity of approach	0.5 m/sec max
Minimum submergence	2.25 m based on Froude Number

Conclusions

1. **Pump design as a possible reason for frequent failure.** Available evidence does not suggest anything wrong with the basic design of the pump. We have looked at test results of this pump both at M+P's UK and Indian plants. We have also checked the performance record of the pump in other installations. There seems to be adequate NPSH margin at site and at the point of rated operation is not too far to the left of BEP. We would only point out that based on the technical evidence now available this pump should have been of double volute construction to begin with. However, the pump was supplied in the seventies and very little empirical data was available on radial loading and recirculation flow at that time.
2. **Sump could be a source of problem.** Adequacy of sump can be studied based on ANSI / HIS 9.8 - 1998.
3. It will be necessary to **establish the system resistance curve** properly. This will provide very clear indication of the system head and lead to a more optimum impeller design.
4. In the interim, better impeller and shaft life can be obtained by:
 - a. Changing shaft material from AISI 410 to AISI 431. Later has a higher strength.
 - b. Changing Impeller material from Bronze LG2 to Nickel Aluminum Bronze AB2. This material has much higher cavitation resistance.

- c. Design new impeller such that suction energy level is reduced and the point of operation is brought closer to BEP. This last step will reduce both radial load and part flow cavitation.



IOCL HALDIA – 24”/24” CME CIRCULATING WATER PUMPS

Ideal Sump Dimensions

HIS Recommendation for Rectangular Sump Structure

Following Sump dimensions are established according to the recommendation of HIS for sump geometry based on the flow-rate at the operating point of the pump.

At the operating point

Rated flow has been assumed to the design flow for dimensioning the sump.

Capacity = 4500 m³/hr.

Suction Pipe Diameter(ds)

Suction pipe can be assumed by keeping the suction pipe velocity(Vs) to 8 ft/sec.(recommended).

Suction pipe dia.(ds) = $(Q/\pi V_s)^{1/2} = 807 \text{ mm} = 32''$

Inlet Dia. of Suction Bell(D)

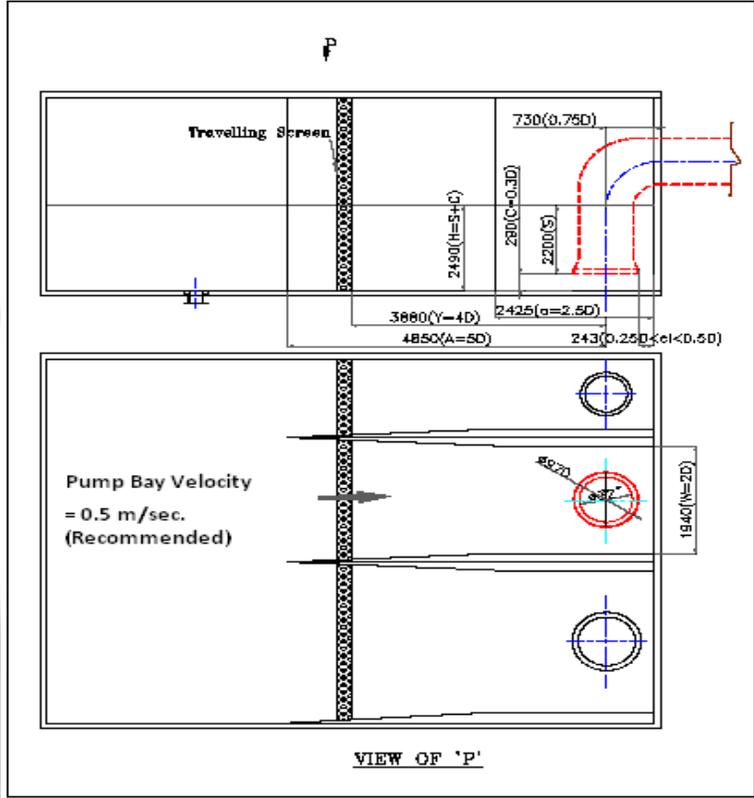
Inlet bell velocity – Recommended 1.7 m/sec.

Acceptable 1.2 m/sec.

So, the inlet dia. of suction bell mouth should be somewhere in between 870mm to 970mm.

Assuming, D = 970mm

Other dimensions can be derived from the value of D.



(All dimensions are in mm.)

Sump Geometry for Rectangular Intake Structure

Above sketch can be used as for the reference of the following dimensional guidance. It has been assumed no significant cross flow at the entrance to the intake structure generated.

Recommended Dimensions

Dimensional Index	Description	HIS recommended Value
D	Inlet bell design outlet dia.	Determined as discussed above
A	Distance from the pump inlet bell center-line to intake structure entrance	$A = 5D$ (Assuming no significant cross-flow at the entrance to the intake)
a	Length of the constricted bay section at the pump inlet	$a = 2.5D(\text{min.})$
B	Distance from the back wall to the pump inlet bell center-line	$B = 0.75D$
C	Floor clearance (distance between inlet bell & floor)	$C = 0.3D \text{ to } 0.4D$
H	Minimum liquid depth	$H = S + C$
S	Minimum pump inlet bell submergence	$S = D(1+2.3FD)$ FD = Froude number (will be discussed below)
W	Pump inlet bay entrance width	$W = 2D \text{ min.}$
X	Pump inlet bay length	$X = 5D \text{ min.}$
Y	Distance from inlet bell center-line to the through flow travelling screen	$Y = 4D$

Froude Number (FD) & Its Relation with Min. Submergence

Froude number is a dimensionless number that accounts for the min. submergence, S that is required to prevent strong air core vortices.

$$FD = V/(gD)^{0.5}$$

(V = Velocity at suction bell, g = Gravitational Acceleration)

$$= (1.7 \text{ m/sec.})/(9.81 \text{ m/sec}^2 \times 0.970 \text{ m})^{0.5}$$

$$= 0.55$$

$$\text{Therefore, } S = D(1 + 2.3FD) = 0.970(1 + 2.3 \times 0.55) = 2.2 \text{ m}$$

$$\text{Min. Liquid Depth(H)} = S + C = 2200 + 290 = 2490 \text{ mm}$$

Pump Bay Velocity

Recommended value of pump bay velocity = 1.5 ft/sec.

Or 0.5 m/sec.

$$H = 2490 \text{ mm} \ \& \ W = 1940 \text{ mm}$$

$$\text{Area} = 4.83 \text{ m}^2, \ \text{Flow} = 4500 \text{ m}^3/\text{hr.}$$

Here, the pump bay velocity = 0.26 m/sec.

It does not exceed the recommended value, this can be acceptable.