CASE STUDIES – CS3

Segment – Affinity Laws \ Pumping System

Topic/ case – Cooling water pumps in a petrochemical plant –

Part flow operation and impeller damage due to increase in the system head drop

Description of the case – The petro-chemical plant has a series of circulating water pumps for heat exchanger cooling. A larger pressure drop across the heat exchanger forces the pumps to operate at part flow. To obtain the required flow rate the plant operator has to run a larger number of pumps than originally planned. Total power consumption is significantly higher compared to the original estimates. Additionally, the impellers suffer damage due to recirculation cavitation at part flow. The user wants to investigate whether it is possible to use a larger impeller to achieve the present head at the best efficiency point of the pump. This will improve life and save power.

Question for discussion-

2. Why are there no shaft shearing episodes in this installation when this case is compared with the refinery case 2?
3. What is the method to be followed for establishing a new system characteristic for this installation?
4. How do we determine the diameter of the impeller needed to meet the revised system characteristics at the best efficiency?
5. How do we ensure that the existing drive motor is adequate for the new and larger diameter impeller?

20/24 DV Medivane Pumps at HPCL, Haldia

Cavitation Damage and Part Flow Operation

The following report is based on the discussions the writer and Mr. Niloy Deb had with M/S A.K. Ghosh, Nirmallya Sen, Goutam Chattopadhyay and other engineers at HPCL Haldia on 28th July 2010. The report also uses the observations of pumps at Cooling Tower I (CTI), inspection of one partially damaged impeller at HPCL workshop, data sheet collected at HPCL and information available with us about the performance of 20/24 DV Medivane.

1. Problems of Cooling Tower I

   This cooling tower has nine 20/24 DV Medivane pumps, each rated for 4500 $m^{3/}$hr at 55m head. Estimated total flow requirement is 31,500 m^3/hr. Consequently, HPCL planned to run seven pumps while two were meant to be standby units. The pressure drop across heat exchangers is significantly more than originally expected. Pumps, therefore, run at approx 65 m total head instead of 55 m. This alteration in the system curve pushes the operating point on each pump back on its H-Q curve – pump delivers much less than the rated flow and all nine pumps must be run to come close to 31,500 m^3/hr flow rate required for the system. Part flow operation of the pump causes cavitational damage to the impeller and the life of the impeller is significantly reduced.

2. Point of Operation of the Pump

   Pressure gauge readings of nine pumps at CTI indicate an average pump head of 65 m. We have tried to estimate the original system curve and the present system curve. We have superimposed our estimate of the pump H-Q curve to establish the present flow from each pump. This is shown in the enclosed system curve – **annexure 1**.
   We estimate that each pump delivers no more than 3000 m^3/hr. This means that pump operates about 35%to the left of its best efficiency point leading to:
   a) Part flow cavitation
   b) Recirculation damage

3. Observations on the Damaged Impeller

We looked at one impeller at the workshop. We have attached a representative sketch to indicate the nature of damage on the non-pressure (seen) side of the inlet vanes. An area measuring 40mm x 70mm on the non-pressure side of most vanes have been subject to heavy cavitational pitting. Mechanical impact has resulted in cracks which have propagated to the end of suction vanes.

Similarly, the pressure side of the inlet vanes near the shrouds could be felt and appears to be very spongy due, most probably, to recirculation cavitation as a result of part flow operation. Attached documents as **annexure 2** explain the nature of cavitational damage mentioned above.

4. Pump Data Sheet

Pump data sheet collected at HPCL and the hydraulic data derived from it are enclosed as **annexure 3**. It will be observed that the suction specific speed of the pump is 11,143 US units. This is considered to be high and limits the operating window to a narrow region around the best efficiency point of the pump. Additionally, suction energy calculated as 196×10^6 is considered to be "very high" by Hydraulic Institute Standards(HIS). Pumps of "very high" suction energy are prone to severe recirculation and cavitation damages when operated at part flow.

5. Possible Solutions

We were advised that HPCL have initiated a system study to see if the pressure drop across heat exchangers and system components can be brought down so that the pump total head at 4500 m^3/hr is restored to the design value of 55 m. If this is done the pump will operate at its best efficiency point and cavitation / recirculation problems due to part flow operation will be eliminated.

There are, however, a few other steps that can be suggested if a reduction in system head is not possible:

a) Using a Larger Impeller Diameter (Eight Pump Solution)

It should possible to re-rate the pump for the following duty:
Q = 4000 $m^{3/}$hr
H = 68 m
(Assuming that current system head is about 68 m at flow of 32,000 m^3/hr.)

The above duty can be achieved by using an impeller diameter of 755 mm and we understand that the pump manufacturer has an impeller for 20/24 DV Medivane with full diameter of 780 mm. This impeller can be trimmed to the duty suggested above and the performance of the pump shall be as follows:

Q = 4000 m^3/hr
H = 68 m
Impeller diameter = 755 mm
Efficiency = 90.5%
Point of operation – Best Efficiency Point of the pump
BKW = 819 kW

Available motor rating = 810 kW

We believe that BHEL will be able to confirm continuous output of 819 KW or more once they are provided with the actual ambient conditions and actual variations in voltage/frequency.

This solution requires running eight pumps to get the required flow of 31,800 m^3/hr. One pump will be stand-by. We also need to check the volute tongue diameter and other internal dimensions of the volute to ensure that this impeller of larger diameter can be fitted without difficulty.
Pump curve for this solution is attached as **annexure 4**.

b) <u>Using a Custom Designed Impeller (Nine Pump Solution)</u>

If above solution is not practical (only restriction could be volute dimensions), it should be possible to design a special impeller for the existing volute.

This customised impeller will be designed for the following duty:
Q = 3500 m^3/hr
H = 68 m
Efficiency = 90.0%
BKW = 720 kW
Available motor = 810 kW
This impeller will work at the best efficiency point. Although HPCL will need to run all the nine pumps to get rated throughput of 31,500 m^3/hr, the problems of recirculation and cavitation erosion will be eliminated and the reliability of the pumps will be significantly increased.
Pump curve and system curve for this solution is attached as **annexure 5**.

c) Changing the Impeller Material

We would suggest that the impeller material is changed from current BS 1400 PB1 (Phosphor Bronze) to Nickel Aluminum Bronze, BS1400 AB2. This material offers significantly more resistance against cavitation erosion compared to other classes of bronze.

This can be seen from the cavitation erosion rating chart attached as **annexure 6**. However, change of impeller material should be done in conjunction with step a or b mentioned above.

We strongly feel that the existing cooling Tower pumps at HPCL can be brought back to health. Quite apart from an increase in life and reliability, changes suggested above offer a great opportunity for energy optimisation.

We will be very happy to be a part of the solution and can easily design, manufacture, supply and install the impellers suggested in steps a, b and c above.

We would like to thank the management of HPCL for giving us an opportunity to visit the site and discuss this important operational problem.

Enclosures:

Annexure 1 - Estimated Performance Curve of 20/24 DV MEDIVANE with existing impeller & its superimposition on the system curve.

(Pump curve has been drawn based on the figures given in the datasheet and test data available with us for 20/24 DV MEDIVANE & its variant 20/24 DV CME).

1) **Annexure 2 –** Representative sketch showing the nature of damage to impeller inlet vanes. Schematic for explaining nature of various types of cavitation erosion in impellers.

2) **Annexure 3 –** Extracts from pump data sheet. Calculation of suction specific speed and suction energy as per guidelines of Hydraulic Institute.

3) **Annexure 4 –** Eight pump solution. Performance Curve of pump with new 755 mm diameter impeller – duty 4000 m3/hr at 68 m.

4) **Annexure 5 –** Nine pump solution. Estimated Performance Curve of new custom designed impeller – duty 3500 M3/hr at 68 m.

5) **Annexure 6 -** Comparative chart of cavitation resistance of various metals.

Annexure – 1

ESTIMATED PERFORMANCE CURVE OF 20/24 DV MEDIVANE @980 R.P.M		20/24 MEDIVANE/X/0810	
20/24 DV MEDIVANE WITH EXISTING IMPELLER	MODEL–20/24 DV MEDIVANE	WORKING PRESS.	16 bar
	SIZE 600x500–680	TEST PRESS.	24 bar
	TYPE–AXIALLY SPLIT CASE SINGLE STAGE		
		SPEED 980 rpm	

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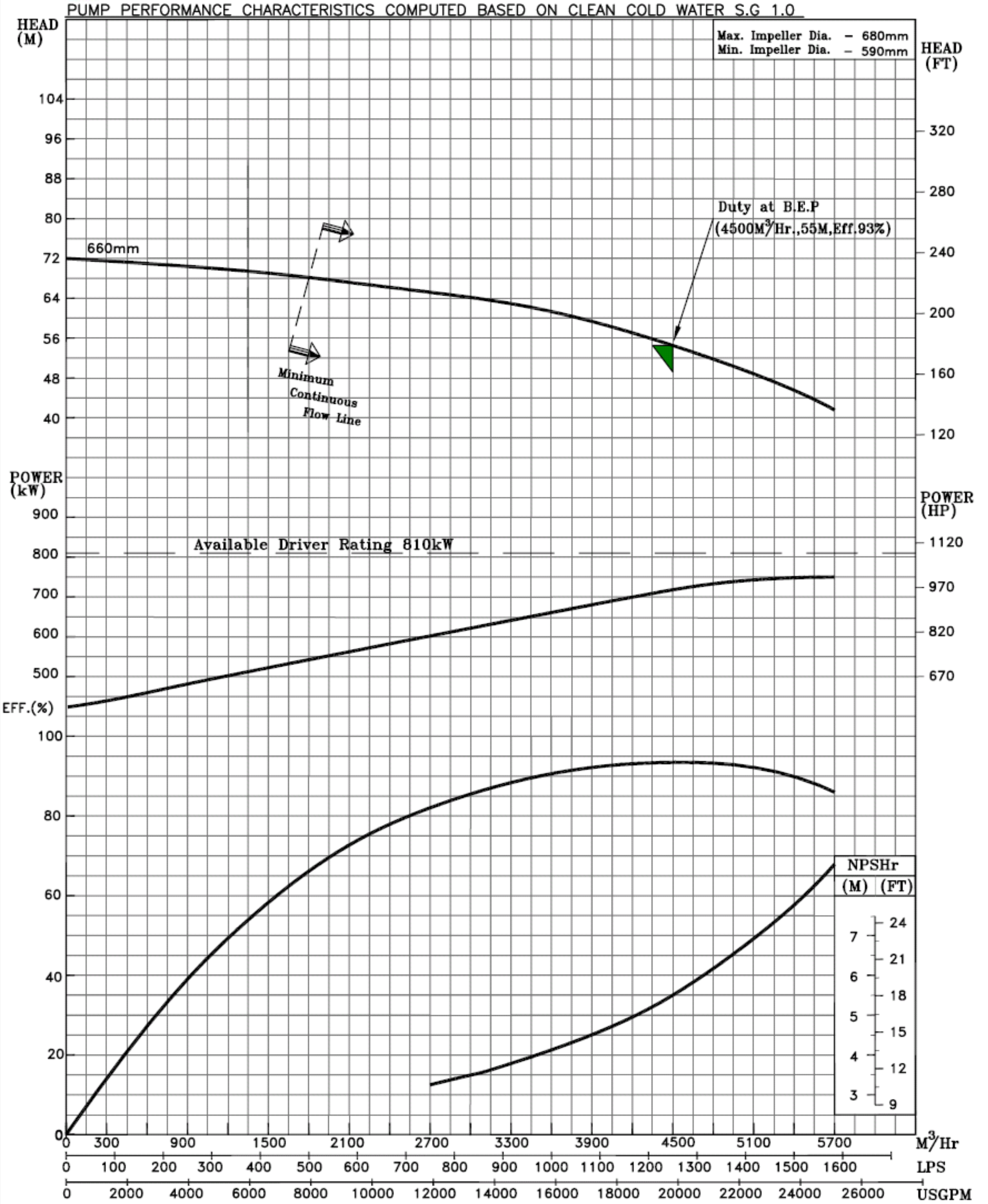
PUMP PERFORMANCE CHARACTERISTICS COMPUTED BASED ON CLEAN COLD WATER S.G 1.0



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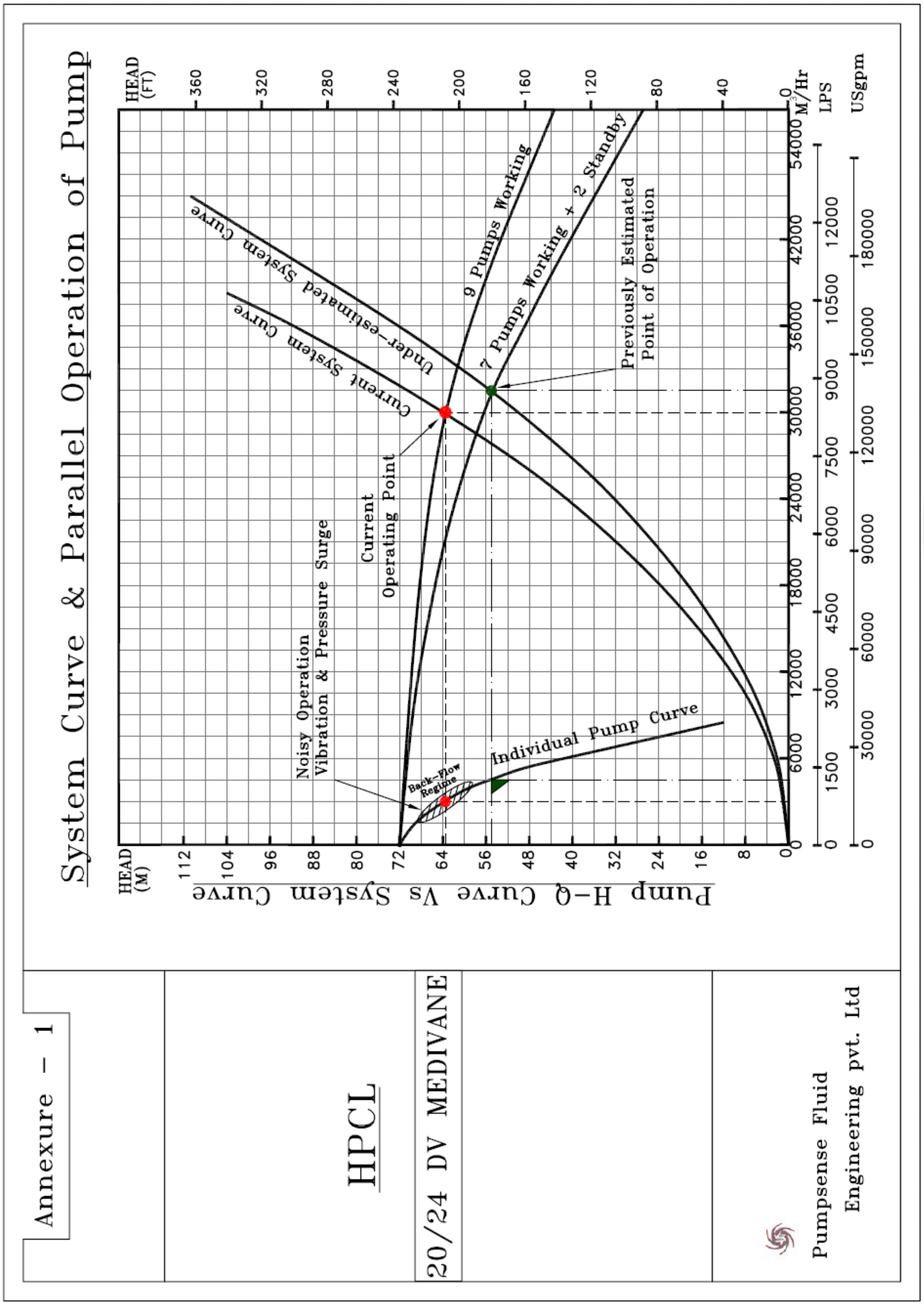
System Curve & Parallel Operation of Pump
Pump H-Q Curve Vs System Curve
HEAD (M)
HEAD (FT)
M³/Hr
LPS
USgpm
9 Pumps Working
7 Pumps Working + 2 Standby
Under-estimated System Curve
Current System Curve
Previously Estimated Point of Operation
Current Operating Point
Noisy Operation Vibration & Pressure Surge
Back-Flow Regime
Individual Pump Curve
Annexure - 1
HPCL
20/24 DV MEDIVANE
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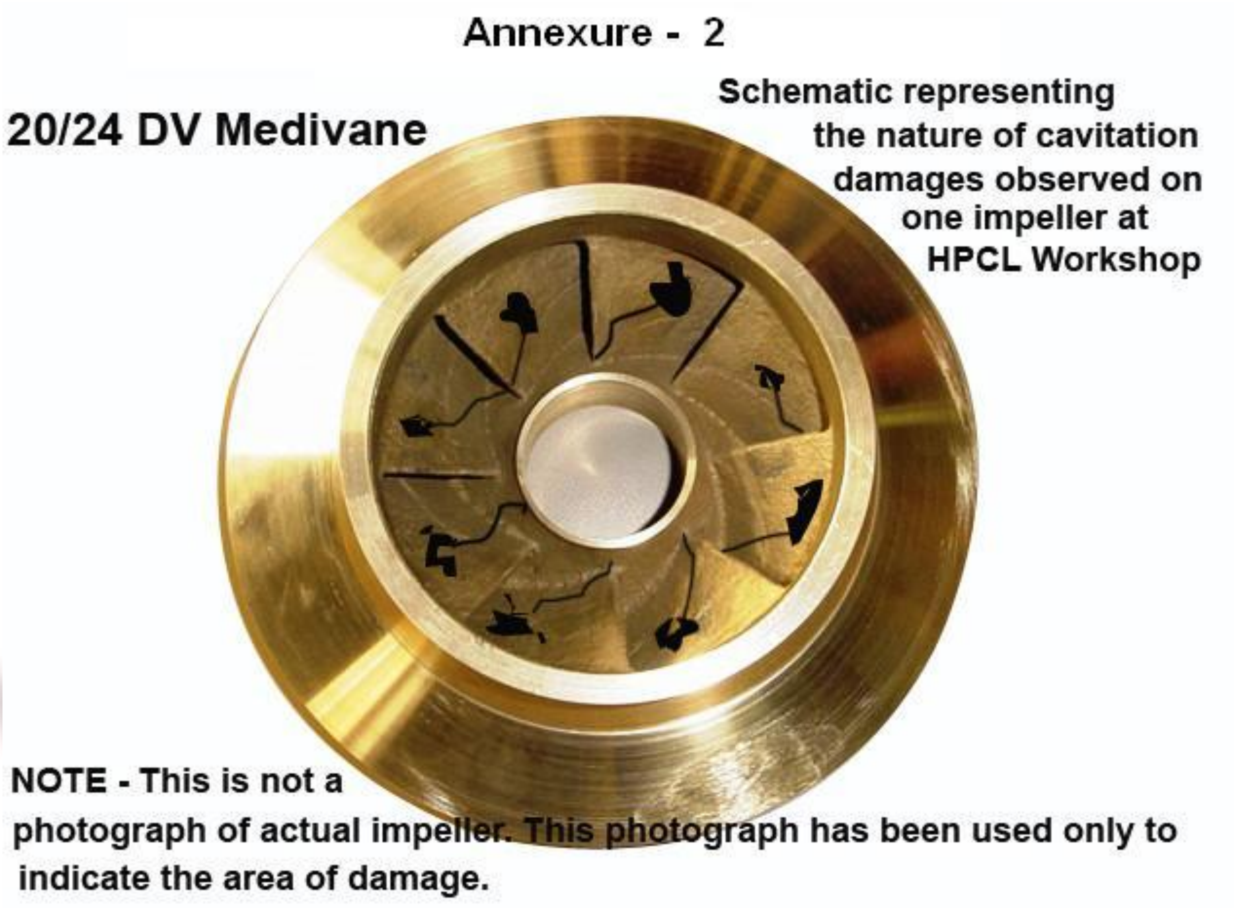
Annexure - 2
20/24 DV Medivane
Schematic representing the nature of cavitation damages observed on one impeller at HPCL Workshop
NOTE - This is not a photograph of actual impeller. This photograph has been used only to indicate the area of damage.

Annexure - 3

HPCL - 20/24 DV MEDIVANE - PERFORMANCE DATA
GENERAL REPORT

Data Obtained from Pump Datasheet

Pump Model – 20/24 DV Medivane

Rated Capacity – 4,500 m^3/hr.

B.E.P capacity – 4,500

Differential Head – 55 m

Rated Speed – 980 rpm

NPSHr – 5.5 m

Efficiency – 93%

BkW – 724.7 kW

Max. BkW Rated Impeller – 766.3 kW

Driver rating – 810 kW

Max. Head Rated Impeller – 72 m

Min. Continuous Flow – 1800 m^3/hr.

Impeller Dia . Rated – 660 mm

Impeller Dia. Max. – 680 mm

Impeller Dia. Min. – 590 mm

Data Derived from Pump Datasheet

Pump Specific Speed – 2800 Us Units

Suction Specific Speed – 11,143 Us Units

Suction Energy (S.E) = 196 x 10^6

Level of Suction Energy – " Very High " as per HIS.

Calculation of Suction Energy

Suction Energy is an important parameter defining the safe operating range of a pump.

S.E = De x N x Nss x Sp. Gravity of fluid medium

Here,

De = Impeller Eye Diameter(Inches), 18”

(Assumed, applying the general norm, De = 0.75x24” = 18”)

N = Operating Speed (Rpm), 980 rpm

Nss = Suction Specific Speed of the pump (Us Units)

Nss is calculated as follows:

Nss = N x (Q/Eye)0.5 / NPSHr0.75

Here,

Q (Usgpm) = Rated Flow, 4,500 m3/hr. or 19813.5 Usgpm,

Flow per Eye = 9906.75 Usgpm

Npshr (ft) = Net Positive Head Required for the pump, 5.5m or 18.04 ft

We get, Nss = 11,143 Us Units,

Putting the values all together the S.E obtained is 196 x 106

For a split-case pump,

Values of Suction Energy	Level of Suction Energy As per HIS
S.E < 120 x 106	Low
120 x 106 < S.E < 180 x 106	High
180 x 106 < S.E	**Very High**

Remark:

As per HIS suction energy value of this pump is very high. Higher the value of S.E & Nss higher will be the percent of B.E.P capacity at which the suction recirculation starts & safe operating zone for the pump will be constricted. The pump will be subjected to vibration & noisy operation due to suction recirculation & part flow cavitation if the pump is operated beyond its safe operating window. The probability of flow separation will also be high.

Annexure – 4

PERFORMANCE CURVE OF 20/24 DV MEDIVANE – 8 PUMP SOLUTION		20/24 MEDIVANE/X/0810	
20/24 DV MEDIVANE WITH 755mm IMPELLER DIAMETER	MODEL–20/24 DV MEDIVANE	WORKING PRESS.	16 bar
	SIZE 600x500–780	TEST PRESS.	24 bar
	TYPE–AXIALLY SPLIT CASE SINGLE STAGE		
		SPEED 980 rpm	

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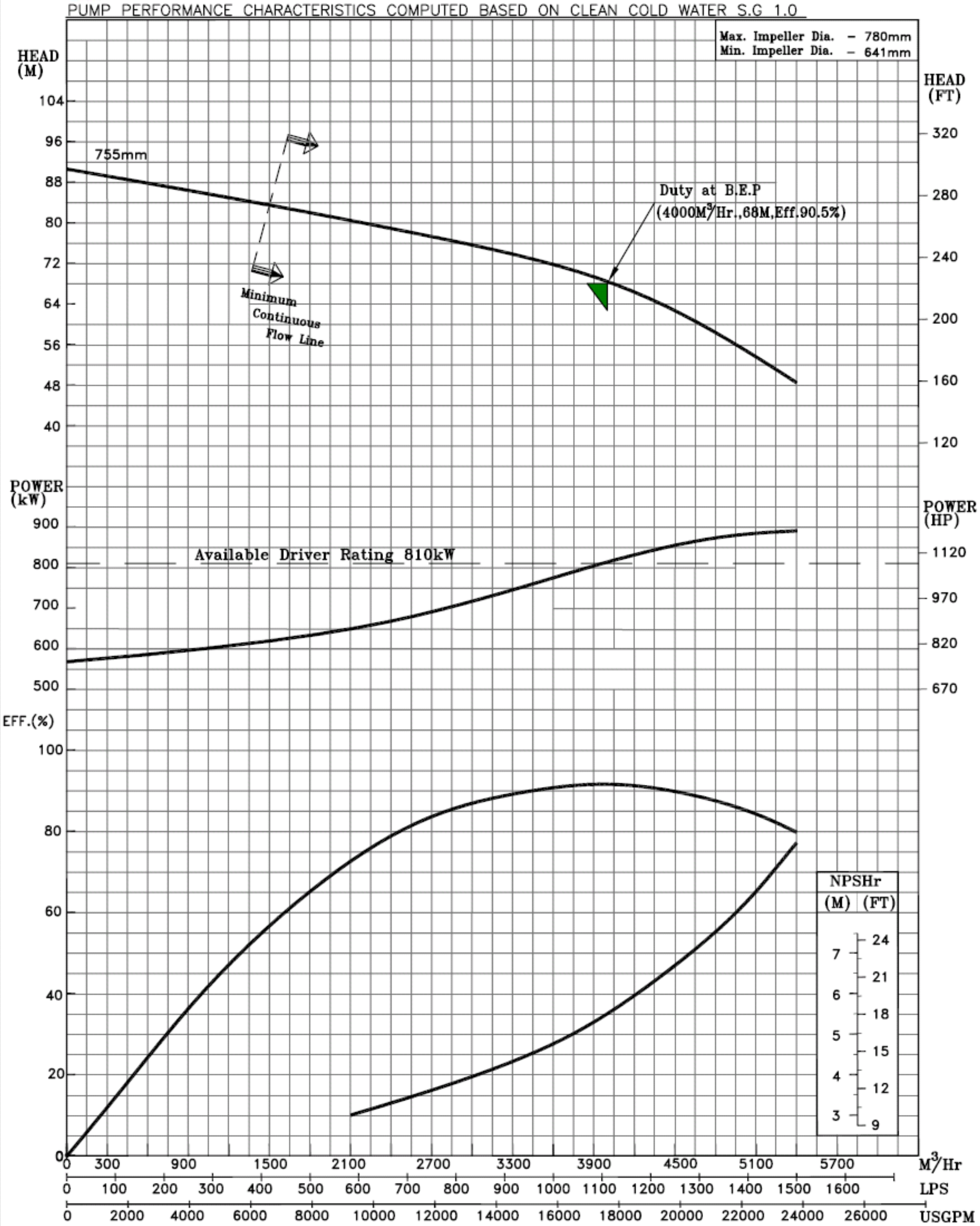
PUMP PERFORMANCE CHARACTERISTICS COMPUTED BASED ON CLEAN COLD WATER S.G 1.0



Annexure – 5

PERFORMANCE CURVE OF 20/24 DV MEDIVANE – 9 PUMP SOLUTION		20/24 MEDIVANE/X/0810	
20/24 DV MEDIVANE WITH CUSTOM DESIGNED IMPELLER	MODEL–20/24 DV MEDIVANE	WORKING PRESS.	16 bar
	SIZE 600x500–730	TEST PRESS.	24 bar
	TYPE–AXIALLY SPLIT CASE SINGLE STAGE		
		SPEED 980 rpm	

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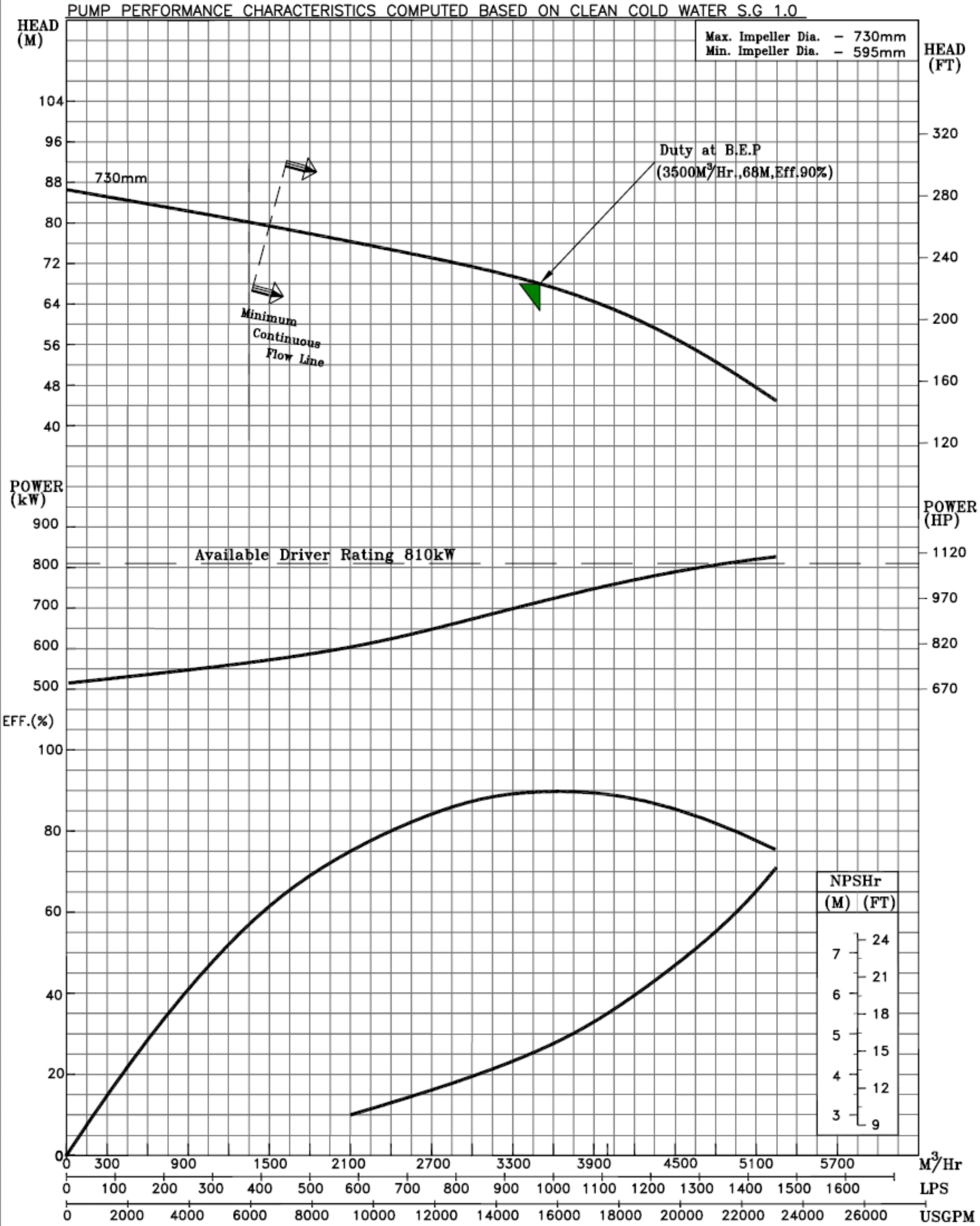

Annexure - 6

Cavitation Resistance of Materials

General Ranking of Cavitation Erosion resistance of Common Cast Metals When Pumping Clear Water at Ambient Temparature