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Design of a Pelton Turbine Installed on Centrifugal Pump in Reverse Osmosis System for Energy Recovery

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ABSTRACT: In this work, injector regulating valve and Pelton turbine impeller has been numerically and analytically designed and simulated. The impeller of the Pelton turbine added on the shaft of a high pressure multistage pump which is used in sea water reverse osmosis package to recover a part of input power from rejected flow return back after filter unit. Using ANSYS CFX, flow through the regulating valve for many outlet injector diameters has been numerically simulated to obtain head loss. For the point of operation, dimension of turbine impeller calculated using turbomachinery relations and some experimental data in order to synchronize as much as possible with the pump. The exact point of operation for the pump, turbine and injector obtained by intersecting performance curves of pump and turbine. In order to investigate the results, the full-scale Pelton turbine and regulating valve manufactured with the material of duplex and installed on the pump. Performance test on the site shown about 26% decrease in input power. Because of the affinity relation for turbomachinery, the results can be validated for other point of operation due to change in pump speed.

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1- Introduction

According to United Nations estimation, due to sharp rise in freshwater demand in recent decades, Iran is facing a water crisis, with demand expected to outstrip supply [1]. One of the most used method to make fresh water is reverse osmosis (RO) technique. To economize use of RO package, the application of Energy Recovery Devices (ERDs), including Pelton turbine unit which is installed in the same shaft of centrifugal pump of RO package has been increased. This unit recovers a part of input power from rejected flow return back after filter unit. In hydraulic design of a Pelton turbine, some related practical experiences and theoretical researches have thus always played a major role to improve efficiency [2 -8] but for synchronizing performance of turbine with the pump in the ERD unit, there are not any significant academic publications. In this paper the major requirements of the design of the Pelton turbine unit added to a RO package has been investigated.

2- Site Condition and Scope of Work

Before adding ERD, the input power of the high pressure pump was 753 kW with the capacity of capacity of 325 m3/h. Head of the pump was 340 m which is decreased to 320 m after passing through the filter. Angular velocity is 2700 rpm. About 60% of the flow is wasted water that was aimed to be used in the recovery unit which is including Pelton wheel and regulating valve as schematically shown in Fig. 1.

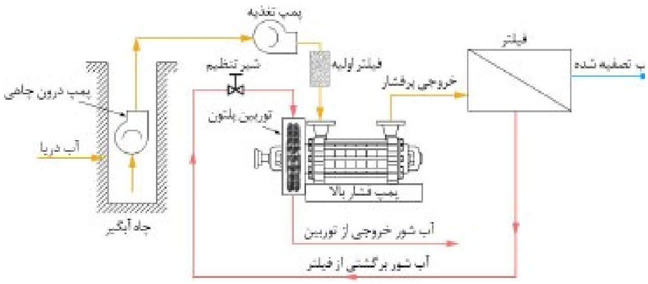

Fig. 1. Schematic view of the proposed plan for the cycle performance packag

3-Pelton Turbine and Nozzle Design

Based on hydraulic condition of the wasted water returned back from the filter, which was head of 320 m and flowrate of 195 m3/h, outlet diameter of the valve nozzle determined and flow through the valve has been numerically simulated to obtain exact condition of the flow before incidence to the bucket of the turbine. The best operation of the pump and valve has been determined using intersecting of operating performance curves which is synchronizing point of operation as shown in the Fig. 2. Operating performance of the turbine has been obtained using Eq. (1) for the flow entering the regulating valve:

$$H_i(m) = \omega(rpm)^{\frac{4}{3}} \times [\eta \times \gamma \times Q_T(m^3/s)]^{\frac{2}{3}}/(100 \times N_s^{\frac{4}{3}}) \qquad (1)$$

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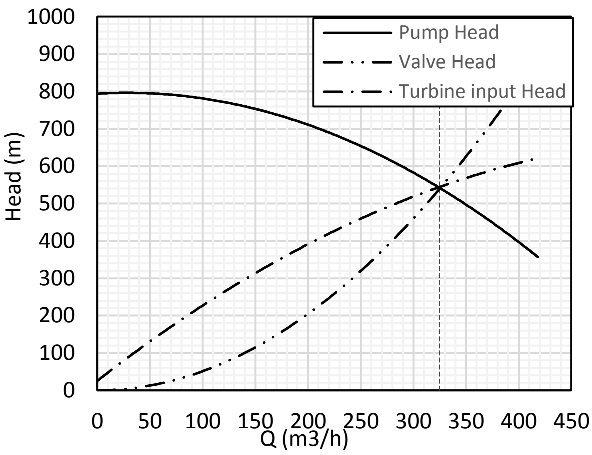

Fig. 2. Intersection of pump, valve and turbine performance curve that determined operation point

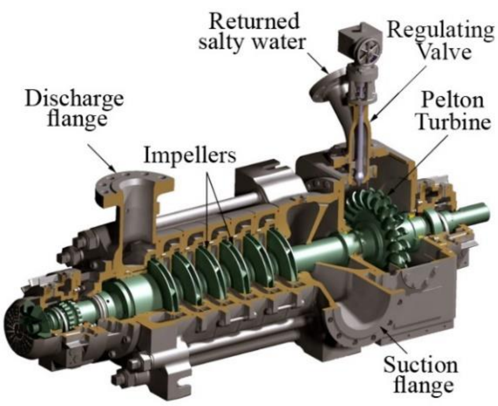

Fig. 3. Adding ERD to high pressure pump

where H_i is input head of the valve, ω stands for rotation speed of the turbine, η is the efficiency and γ denotes specific weight of the flow.

It is noted that resistance curve of the valve has been extracted from Computational Fluid Dynamics (CFD) simulation for various flowrates.

Using turbomachinery relation and some experimental data [9-13], Pelton wheel has been modeled and manufactured with the material of duplex to resist erosion from sea water. Also manufacturing of regulating valve with design condition resulting from synchronize point of operating has been done Fig. 3 and added to high pressure pump.

3- Results and Discussion

Hydraulic and geometrical parameter of the ERD unit based on operation point of package has been listed in the table 1

To verify design operation of the package, site test has been done and the results performance of the total package (pump and ERD) including head, efficiency and power shown in Fig. 4

As said, before adding ERD, input power of the high pressure was 753 kW, but after installation ERD at the rated point

Table. 1. Hydraulic and geometrical of parameter of the ERD unit

Parameter	Value
Coeff. of loss	$C_v = 0.95$
Jet velocity	$V_j = 95.9$ m/s
Turbine Flowrate	$Q_T = 195$ m^3/h
Jet diameter	$d_j = 26.8$ mm
Turbine linear speed	$U_{opt} = 44.1$ m
Turbine diameter	$D_{m\_opt} = 303$ mm
Bucket width	$B = 84.7$ mm
Bucket depth	$h = 23.3$ mm

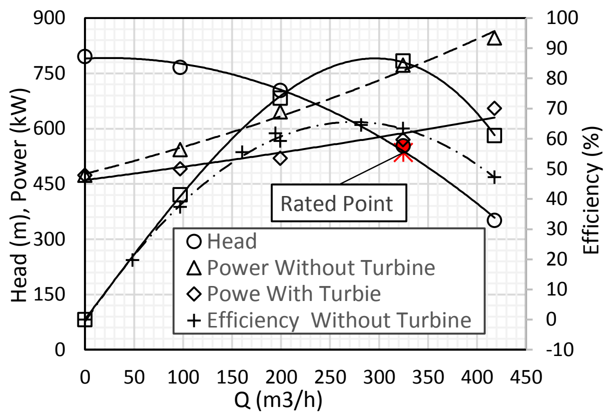

Fig. 4. Test result of the performance of RO package

input power has been decreased to 557 kW which shows 26% reduction in energy consumption. Also the power required per one cubic meter of fresh water scaled down from 5.8 to 4.28 kWh/m3.

4- Conclusion

In this paper it is generally shown that using Pelton type ERD unit if properly designed and synchronized with high pressure pump in the RO package can save a significant part of the input power. Certainly, in addition to optimum design of the turbine, matching its operation point with the pump shall be inevitably considered. It is noted due to affinity law in turbomachinery, approximately the same results may be expected in the other speed of the pump if it is required for changing capacity of the RO package.

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