INFLUENCE OF PUMP IMPELLER TYPE ON THE PERFORMANCE OF A RECOVERY PUMPING SYSTEM HANDLING NILE WATER HYACINTH

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ABSTRACT

In the present study the effect of a centrifugal pump impeller type on a recovery pumping system performance characteristics is experimentally investigated. Experiments were performed using water hyacinth. The types of impellers used in the present study are semi-open, vortex, and double channel impeller. Experiments results are presented for Nile water hyacinth recovery rate and the effectiveness of the recovery pumping system.

The obtained results show that, the effect of impeller type on the performance of Nile water hyacinth recovery system depends on the other operating condition. In general, the results show that using double channel impeller instead of vortex or semi-open is more effective and economic. However, within the operating range of the present study and in certain cases the vortex and semi-open impellers are more effective and economic than the double channel impeller.

Keywords: Water hyacinth, Mechanical removal, Harvesters, Submersible pump

1- INTRODUCTION

The importance of fresh water bodies as an environmental resource that can be used for the benefit of mankind cannot be overemphasized. Water bodies are important for fisheries, domestic and industrial water supplies, recreation, transportation, irrigation, communication, tourism as well as for receiving waste water effluents, Uka and Chukwuka (2007).

The water hyacinth is considered the worst weed plant which grows on water. It grows well in the shallow water where it is able to extract nutrients from soil but it does very poorly in the deep water. In general, the plant was found to consist of 17.7% leaves, 43.8% petioles and 38.5% roots on a green base with average moisture contents of 90.9, 95.5 and 86.5% respectively, Bader and Nofel (2007). In addition, Water hyacinth affects the water quality by reducing water temperature, pH, bicarbonate content, dissolved oxygen and increasing biological oxygen demand, free carbon dioxide and nutrient level that ultimately makes water unfit for livestock and human use, Rai and Munshi (1979). Water hyacinth is capable of multiplying faster than any other known fresh water plant. It produced as many as 90 million seeds per hectare which remain viable and able to germinate up to 20 years, Zerrudo et al. (1983). In USA, water loss in irrigation channels due to existence water hyacinth has been estimated to be 2425 billion m^3, valued at US $39.3 million every year, Verma et al. (2003).

On the other hand, water hyacinth has a huge potential for removal of the vast range of pollutants from wastewater and that a great number of aquatic systems with water hyacinth as basic component were construct, Aoi and Hayashi (1996). Moreover, water hyacinth is well studied as an aquatic plant that can improve effluent quality from oxidation ponds and as a main component of one integrated advanced system for treatment of municipal, agricultural and industrial wastewaters, Maine et al. (2001).

In Egypt, people are dependent on river Nile and lakes for transportation, fishing, tourism, and drinking. The presents of water hyacinth in the river Nile and lakes have caused severe socio-economic losses and problems as well as interfere with irrigation and hydroelectric-power schemes. El-Sawaf (1998a, b) reported that water losses due to the presence of water hyacinth in the river Nile, branching channels and drainage system are about 47523000 m^3/year from river Nile.

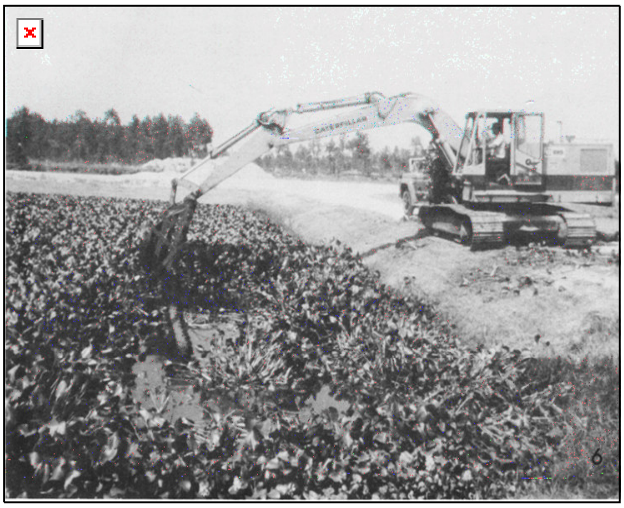
On the other hand, Egyptian Channel Maintenance Research Institute (2009) proved that water hyacinth can be used successfully for improving the water quality of drains. Results showed that the presence of the floating mats of water hyacinth on water surface removed a considerable amount of pollutants. Badawy (2009) stated that, water hyacinth could be used for treatment of sewage waste water such as those in Abu Rawash and Zenein where 64.7% and 89.0% of Phosphorus, and 37.9% and 36.6% of Potassium can be removed from the effluent of the two plants respectively. Other elements like Calcium, Magnesium, and Sodium can be removed with 7.3%, 6.2% and 3.44%, 3.75%, and 5.8%, and 5.5% from the effluent of the two plants respectively. For Nitrogen, about 1686.0 and 963.0 ton can be removed annually. It could be used also as a source of energy.

The previous review raised an important question, Water hyacinth, a crisis or an opportunity? The "world’s worst water weed", or a "golden plant"? Water hyacinth has caused many problems, and ruined the livelihoods of many people. However, we have a moral imperative to think about how this abundantly available source of biomass could be utilized for the benefit of those same people for whom it has created such havoc. There are already many examples in many countries of the world of how individuals and communities have used water hyacinth to great advantage. There are two dangers associated with water hyacinth utilization that must be taken seriously. For these reasons, some people even say that water hyacinth should never be used. The danger of seeds being transported to new locations, perhaps quite innocently in the form of silage or mushroom substrates, and a new infestation of water hyacinth appearing. Therefore, never transport water hyacinth that may contain seeds and if people find water hyacinth to be really very useful, they may well deliberately plant it in a new location, and thus start off a new infestation which gets out of control. Therefore, never plant water hyacinth except in very strictly controlled conditions.

Biological control requires a minimum of several years, usually 3 to 5 years, for insect population to increase to a density that could bring down the weed stand to a substantial decline, Gnanavel and Kathiresan (2007). Chemical use restrictions imposed countries laws resulted in the almost exclusive use of mechanical means for invasive aquatic plant management, including the use of crusher boats, saw-boats, and harvesters, Figure 1.

For short-term control measures there are physical removal and chemical control. All have serious constraints for implementation in water bodies of developing countries of the tropical and sub-tropical regions, Labrada et al. (1995). Physical control involves manual removal of the weed using simple tools and equipment. This is aimed at keeping landing beaches, water sources, pumps, and recreational areas free from water hyacinth, Labrada (1995). Public perception is often favorable to nonchemical control methods. Mechanical plant harvesting is a frequently used alternative to herbicide application, but harvesting is relatively costly and time consuming, Greenfield et al. (2006). Manual removal demands a high labor force but, if systematically implemented it may be of great value to reduce a moderate stand of the weed. Manual removal may also be of help in temperate areas where the weed stand is low. In this case removal of the weed becomes an important preventive measure. However, in highly infested areas, manual removal does not seem to be a technically effective or economically feasible method. Barriers may be used to control the floating water hyacinth and prevent it reaching to important areas, Hosam (2006). Mechanical removal is more effective in highly infested areas, but here some harvesters would be needed plus fuel and maintenance costs of the machinery. Without effective financial support to permit the purchase of the machinery and supply of fuel it is doubtful whether mechanical removal will be widely implemented in many developing countries. The use of mechanical controls for invasive aquatic plants began in response to the growing threat of water hyacinth throughout many parts in the world, for example many countries, they used "crusher boats" to remove water hyacinth from navigable waterways.

Under certain circumstances, mechanical controls can be more beneficial than other methods for managing invasive aquatic plants. Types of mechanical controls (machines) used for removal of water hyacinth; dragline and trackhoes, mechanical weed cutters, harvesters, hi-ballers and saw boats. Also, shredding of water hyacinth is one of the mechanical controls. This method leaving them in the water column to die and senesce has lower control costs than harvesting, Stewart and Mcfarland (2000). Large-scale shredding operations (without vegetation removal) have recently been undertaken in Lake Victoria, Africa, and Lake Champlain, Vermont, and are presented in some statewide aquatic plant management plans.



a) Modified bucket attached to a back hoe

b) Chopper-conveyor harvester

c) Harvesting Process

Figure 1 Mechanical equipment used in the water hyacinth recovery

Transfer of nutrients to the water column, oxygen depletion, and associated water quality effects may result from either mechanical shredding or chemical herbicide application, Tucker et al. (1983). If shredding were undertaken at a regional scale, releases of nitrogen, carbon, phosphorus, and trace metals could be substantial, possibly resulting in fundamental shifts in the trophic state of the water body, Greenfield et al. (2007). Physical removal poses a serious problem with the mass of water hyacinth removed. It is true that the mass may be used either for mulching in perennial plantations or a small part (only very small) for handicraft production, but in the first case transportation would be a problem. Not all developing countries have the means available to transport the mass of water hyacinth to the plantations. In these applications, one of the major problems is the high cost of transportation of freshly harvested water hyacinth from water bodies to the factories. A major contributory factor to the failure of water hyacinth harvesting machinery is the large volume and moisture content which greatly reduces harvesting efficiency by increasing requirements for handling and transport. Capacities of mechanical management systems for aquatic plants are usually limited by the volume of the plant material that must be handled, transported and stored. Water hyacinth plants are usually harvested and transferred in their natural state to the hauling unit which, in turn, delivers the plants to a disposal site which may be at a considerable distance from the harvesting site. As fresh water hyacinth has around 92% moisture content with the bulk density of approximately 96 kg m^{-3}. Chopping and compressing or compacting has been proposed as a means of reducing volume and weight or increasing density to increase the efficiency of water hyacinth removal operations, Mathur and Singh (2000).

The design of a particular program of water hyacinth control in developing countries is not an easy task. There are socio-economic constraints which may prevent the practice of any particular control method: public opinion led by the journalists of the country who will rightly question all matters regarding the introduction of any bio-agent, chemical compounds, practice of any control measure, the lack of equipment, funding and sufficient personnel trained on control methods to be developed. In addition, there might also be the lack of suitable link between the national institutions involved.

There are few works related to the usage of pumping system for control water hyacinth and studied the improvement of its performance. For example, El-Sawaf (1998a, b) used theory of operation jet pump for water hyacinth control. El-Sawaf (1998a) designed an annular-type jet pump model for floating weed and water hyacinth removal from the water channels and investigated the ability to use an annular-type jet pump model with conical inlet device successfully in weed control with weed concentration up to 30%. Moreover, El-Sawaf (1998b) developed the jet pump model by using two peripheral nozzles jet pump with conical inlet device.

The fundamental difference between a centrifugal submersible pump (pumping weeds) impeller and those of its clear water cousins is its ability to pass weeds material that would normally clog the latter. The scientific work concerning with the different types of mechanical control is limited in the literature. This reflects the need for additional efforts both experimental and theoretical related to the pumping system characteristics and performance.

Khalil et al. (2009a and b) studied experimentally the effect of varying the operating parameters on the performance of a recovery pumping system handling Nile water hyacinth. The operating parameters considered in Khalil et al. (2009a) were pump suction inclination angle, water height above pump inlet, inlet suction cone diameter, and pump flow rate. Meanwhile, Number of cutter blades, with/without scrapper, plant parts (complete plant, plant without roots and separate leaves) and water hyacinth concentration are the operating parameters considered in Khalil et al. (2009b). They studied the variation of all these parameters on the Nile water hyacinth recovery rate, NRR.

Meanwhile, Khalil et al. (2009c) introduced a parameter called the effectiveness of the pumping system, E, as the ratio between the rate of water hyacinth quantity collected by the pumping system and the mixture flowrate of the pumping system multiplied by the water hyacinth density. The effectiveness of the pumping system, E, is defined as:

$$E = [0.06 \times M_c] / [\rho_{wh} \times Q] \quad (1)$$

where: M_c: The rate of water hyacinth quantity collected, (gm/min)
ρ_{wh}: Water hyacinth density [= 96 kg/m^3, Mathur and Singh (2004)]
Q: The mixture flowrate through the pumping system (m^3/hr).

The present investigation is a continuation of the research program started sometimes age by the authors dealing with the influence of the operating parameters, on the performance of mechanical device that used to recover the water hyacinth from water, Khalil et al. (2009a, b, and c). The present study is a step further of this program. The objective of this stage is to study the influence of the centrifugal pump impeller type on the performance of the recovery pumping system.

2- EXPERIMENTAL SET UP

A schematic diagram of the recovery pumping system used in the present study is shown in Fig. 2. The details of experimental setup as well as details of the centrifugal pump unit used in the experimental study, its specifications and operating procedure are given by Khalil et al. (2009a). The processes of the collection and separation of the recovered Nile water hyacinth are illustrated in Fig. 3.

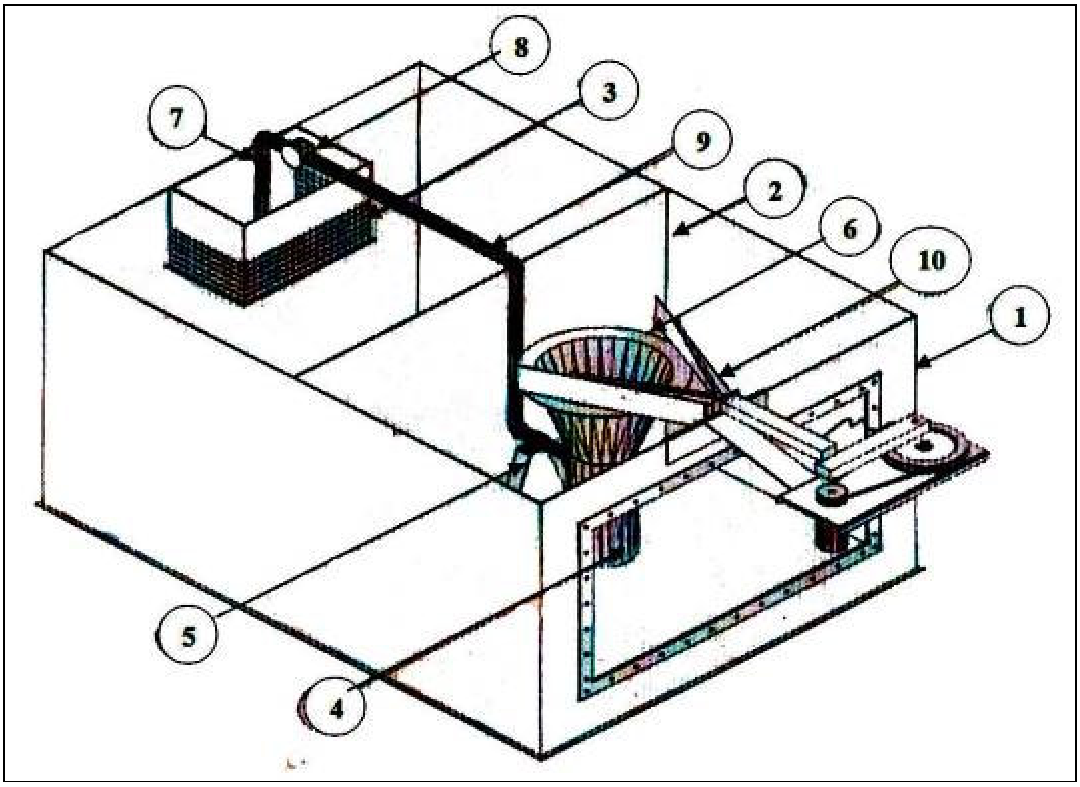
The experiment was conducted to know the effect of impeller type on the performance of Nile water hyacinth recovery system. Three impeller types are used in the present study. These types are: semi-open, vortex, and double channel impeller. They are shown in Fig. 4.

The Nile water hyacinth recovery rate, NRR is calculated as follows:

$$NRR = M / T \quad (2)$$

where: M = Nile water hyacinth recovery mass
T = Time of collecting Nile water hyacinth recovery mass.

All experiments are carried at ambient temperature. The uncertainty of the Nile water hyacinth recovery rate, NRR is ± 2 %. The details of the operating procedure are given by Khalil et al. (2009a).



1. A steel tank	2. Buffer plate	3.An auxiliary tank	4. Transfer pump
5. Steel frame	6. Pump inlet	7. Perspex pipe	8. Turbine flowmeter
9. Pipe	10. scraper system		

Figure 2 Schematic diagram of experimental setup

a) The water hyacinth before recover

b) Water hyacinth during recover **c) Water hyacinth after recover**

Figure 3 The processes of the collection and separation of the recovered Nile water hyacinth

a) Semi-open impeller **b) Double channel impeller** **c) Vortex impeller**

Figure 4 Impeller types used in the present study

3- RESULTS AND DISCUSSIONS

Figure 5 presents Nile water hyacinth recovery rate, NRR, for various types of impeller (double channel impeller, vortex impeller, and semi-open impeller) with pump flow rate ratio, Q/Q_{max}, at different values of the submergence ratio, H/D_s. These results are for constant inclination angle of the centerline of the pump suction cone with respect to the vertical plane, $\theta = 0°$, constant diameter ratio, $D_i/D_s = 4.5$, and constant water hyacinth concentration ratio, $M/M_{max} = 0.5$. Figure 5 shows that, for certain impeller type, as Q/Q_{max} increases NRR increases. In addition, for certain Q/Q_{max}, double channel impeller gives the highest NRR values while the semi-open impeller gives the lowest NRR values. An exception of this trend is the case of the highest submergence ratio, $H/D_s = 1.25$ where the vortex impeller takes the place of the double channel impeller. Moreover, it is important to note that double channel impeller covers the widest range of discharge and the semi-open covers the lowest range. These results are due to the difference of construction between the impeller types, see Fig. 4, which results in different aerodynamic effects and consequently different ability to suck water hyacinth from the water surface into the pump suction.

Figure 6 presents the variation of the effectiveness of recovery pumping system, E, with the variation of mixture volume flow rate ratio, Q/Q_{max}, at various values of the submergence ratio, H/D_S, and for different impeller types. These results are for constant inclination angle, $\theta = 0°$, constant diameter ratio, $D_i/D_s = 4.5$, and constant water hyacinth concentration ratio, $M/M_{max} = 0.5$. For certain value of H/D_s, Fig. 6 indicates clearly that the effectiveness of recovery pumping system, E, is strongly impeller type dependent, and consider an important factor in the chain of pumping system.

It is important to point out that, the observations during the experiments work revealed that as the flowrate ratio, Q/Q_{max}, increases the flow of water hyacinth deviated from its direction towards the pump suction funnel to both sides of the tank. The reason of this behavior can be explained as follows: as the flowrate ratio, Q/Q_{max}, increases, the unsteadiness of the flow formation from the funnel increases. Consequently, the amount of water hyacinth reaches to the funnel reduced as well as the effectiveness decreases. This phenomenon indicates that the use of scrapper system surrounding the water hyacinth area can add a benefit to the pumping system that is decreasing the effect of the unsteadiness formation and consequently improve the effectiveness.

Figure 7 presents the variation of water hyacinth recovery rate, NRR with submergence ratio, H/D_s, at various values of pump inlet inclination angle, θ, and different impeller types. These results are for constant mixture volume flowrate ratio, $Q/Q_{max} = 0.55$, constant cone diameter ratio, $D_i/D_s = 4.5$, and constant water hyacinth concentration ratio, $M/M_{max} = 0.5$. Figure 7 shows that there is a maximum value for NRR at $H/D_s \approx 0.50$ for all presented cases. This is in agreement with Khalil et al. (2009a). In addition, for certain value of H/D_s, double channel impeller gives the highest NRR values while the semi-open impeller gives the lowest in agreement with the results presented in Fig. 5.

Figure 8 presents the variation of the effectiveness of pumping system for three different impellers. The trend of the results in Fig. 8 is the same as in Fig. 7 regarding the position of maximum effectiveness and the relative E values for different impeller types.

Figures 9, 10 present the variation of water hyacinth recovery rate, NRR, and the effectiveness of recovery pumping system, E, with pump inlet inclination angle, θ, at various value of submergence ratio, H/D_s, and different impeller types. These results are for constant mixture volume flowrate ratio, $Q/Q_{max} = 0.55$, constant cone diameter ratio, $D_i/D_s = 4.5$, and constant water hyacinth concentration ratio, $M/M_{max} = 0.5$. Figures 9 and 10 show that, for all impeller types, as θ increases NRR and E decreases.

These results confirm and extent the results of Khalil et al (2009a, b) for various types of centrifugal pump impellers. In addition, these two figures show that, for certain angle θ, double channel impeller gives the highest NRR and E values.

Figure 11 presents the variation of water hyacinth recovery rate, NRR, with cone diameter ratio, D_i/D_s, at various values of mixture volume flowrate ratio, Q/Q_{max}, and different impeller types. These results are for constant submergence ratio, $H/D_s = 0.5$, constant pump inclination angle, $\theta = 0°$, and constant water hyacinth concentration ratio, $M/M_{max} = 0.5$. Figure 11 shows that, for all types of impeller, as D_i/D_s increases NRR increases. In addition, for certain D_i/D_s, the double channel impeller gives the highest NRR values.

Figure 12 presents the variation of the effectiveness of recovery pumping system, E, with the variation of pump inlet diameter ratio, D_i/D_o at various impeller types, and submergence ratios, H/D_s. These results are for mixture volume flowrate ratio, $Q/Q_{max} = 0.55$, constant pump inclination angle, $\theta = 0$, and constant water hyacinth concentration ratio, $M/M_{max} = 0.5$. Figure 12 shows that the effectiveness of recovery pumping system, E, is a strongly impeller type dependent and, for a certain D_i/D_o value, the double channel impeller gives the highest E values.

4- CONCLUSIONS

Experimental system was designed and constructed to analyze the factors which indicate the influence of impeller type on the performance of pumping system handling water hyacinth.

Within the operating range of the present experimental study and from the presented results and related discussions the following concluding remarks can be obtained:

- The present results confirm the previous results of the authors using the same set up.
- For the whole operating range cover in the present study, there is no straight forward clear results favor one type of impeller over the other types.
- The semi-open impeller produces less maximum flow rate than the other two types.
- The double channel impeller is the most efficient and allows the collection of the largest possible quantity of the water hyacinth.
- In case of high submergence ratio, using vortex impeller is more efficient.

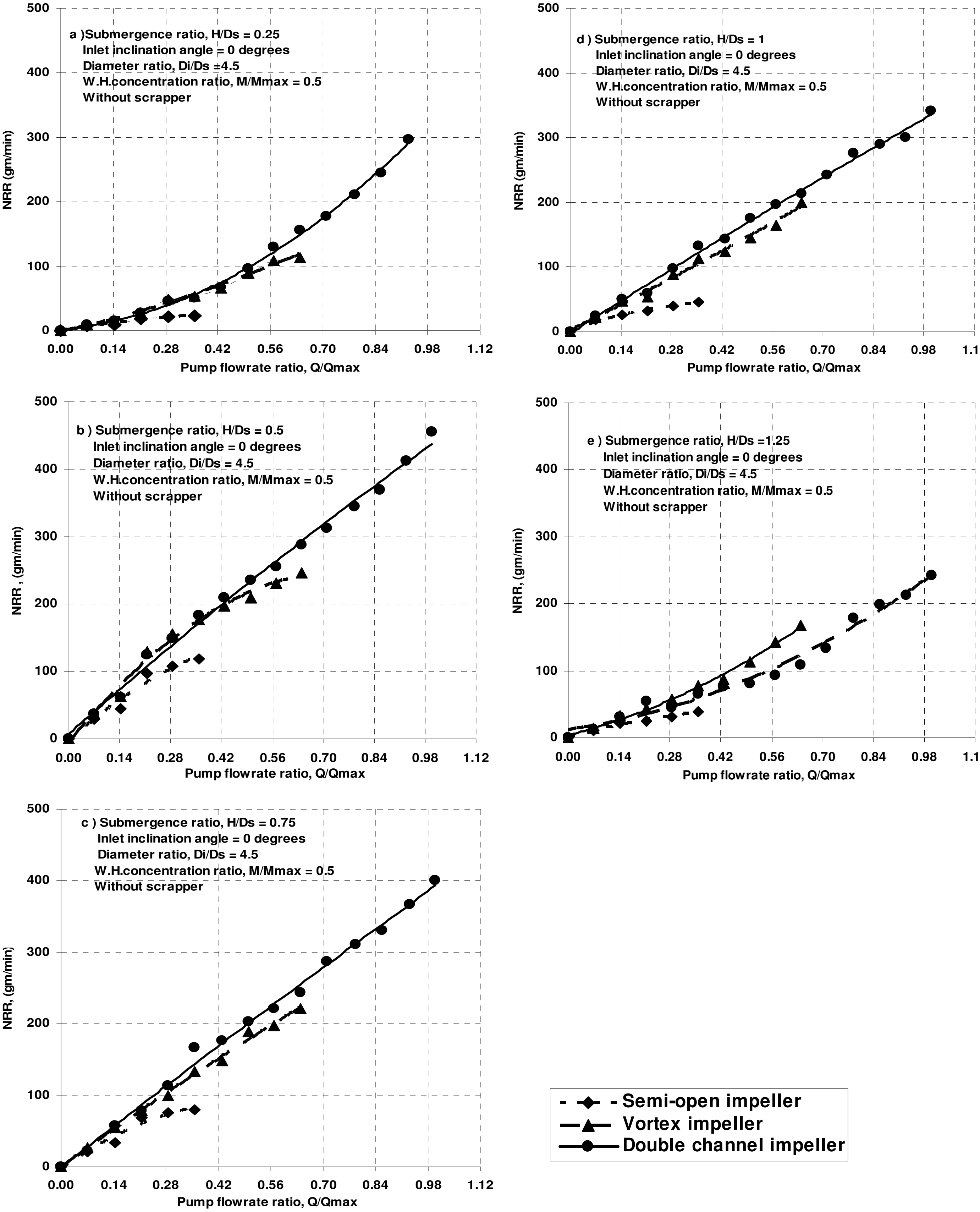


Figure 5 Variation of Nile water hyacinth recovery rate, NRR with pump flow rate ratio, Q/Q_{max}, at various impeller type, and submergence ratio, H/D_s,
a) $H/D_s = 0.25$ b) $H/D_s = 0.5$ c) $H/D_s = 0.75$ d) $H/D_s = 1$ e) $H/D_s = 1.2$

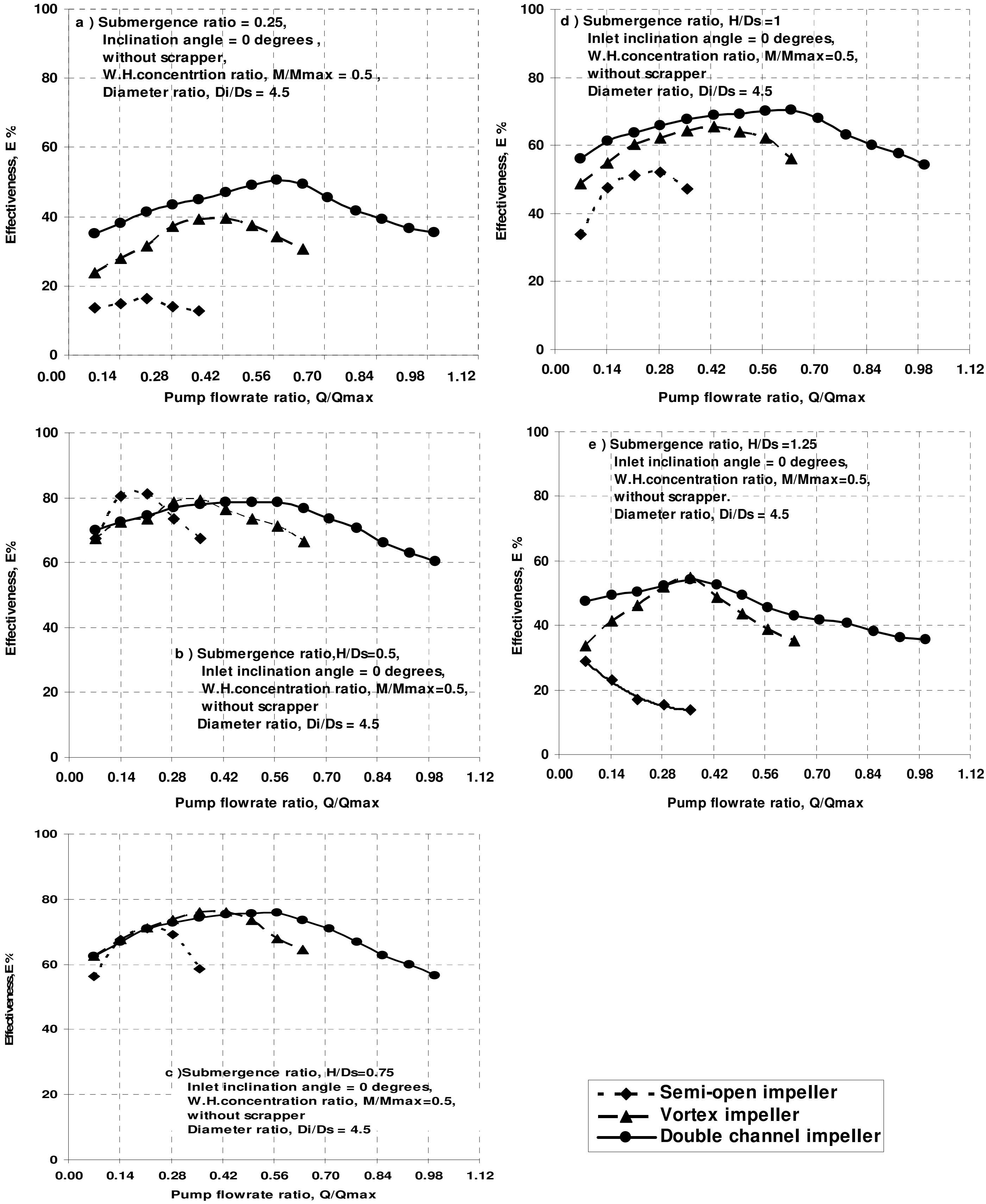


Figure 6 Variation of recovery pumping system effectiveness, E, with pump flow rate ratio, Q/Q_{max}, at various impeller type, and submergence ratio, H/D_s,
a) $H/D_s = 0.25$ b) $H/D_s = 0.5$ c) $H/D_s = 0.75$ d) $H/D_s = 1$ e) $H/D_s = 1.25$

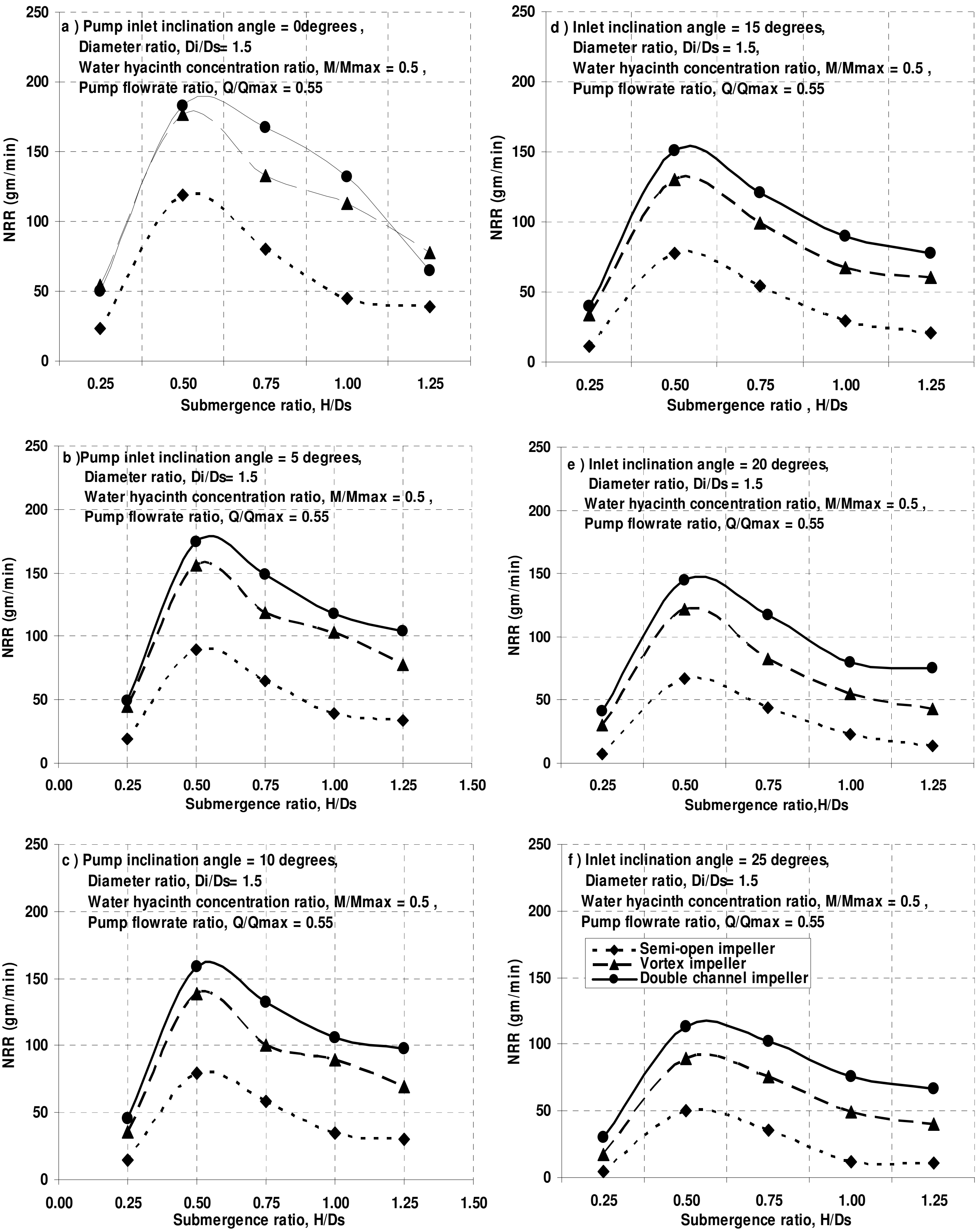


Figure 7 Variation of Nile water hyacinth recovery rate, NRR, with submergence ratio, H/D_s, at various impeller type, and pump inlet inclination angle, θ

a) θ = 0°　b) θ = 5°　c) θ = 10°　d) θ = 15°　e) θ = 20°　f) θ = 25°

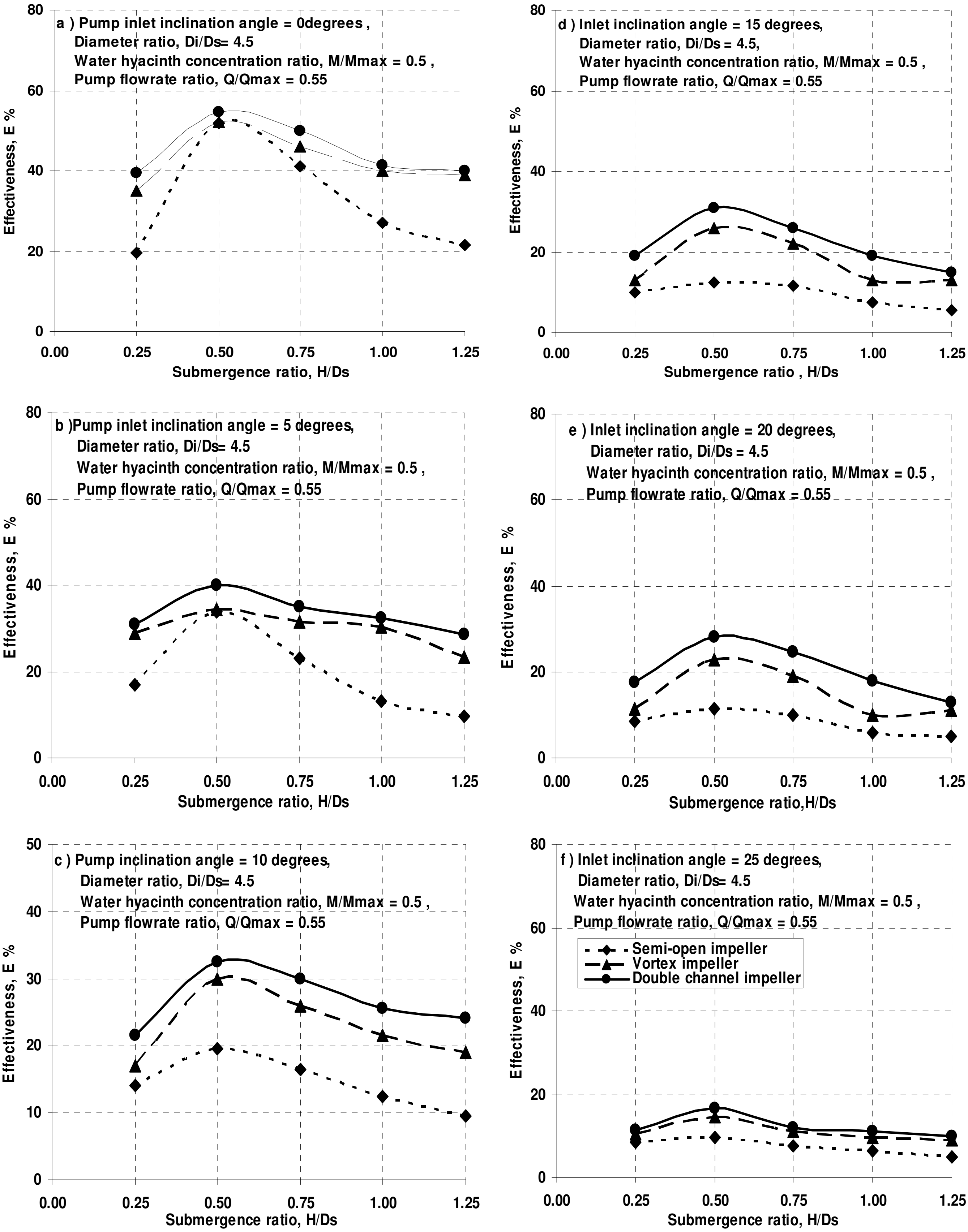


Figure 8 Variation of recovery pumping system effectiveness, E, with submergence ratio, H/D_s, at various impeller type, and pump inlet inclination angle, θ

a) θ = 0° b) θ = 5° c) θ = 10° d) θ = 15° e) θ = 20° f) θ = 25°

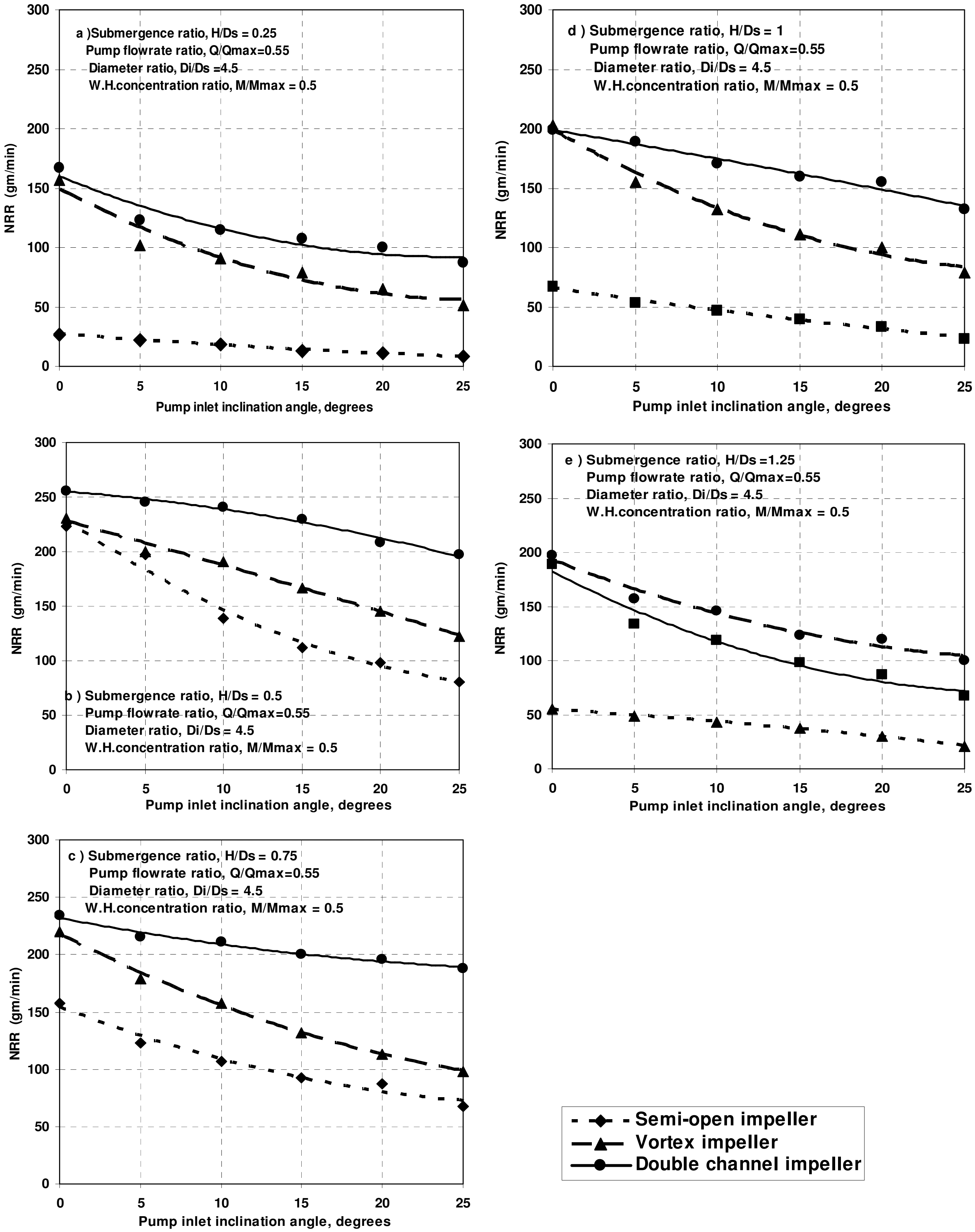


Figure 9 Variation of Nile water hyacinth recovery rate, NRR, with pump inlet inclination angle, θ at various impeller type, and submergence ratio, H/D_s,
a) $H/D_s = 0.25$ b) $H/D_s = 0.5$ c) $H/D_s = 0.75$ d) $H/D_s = 1$ e) $H/D_s = 1.25$

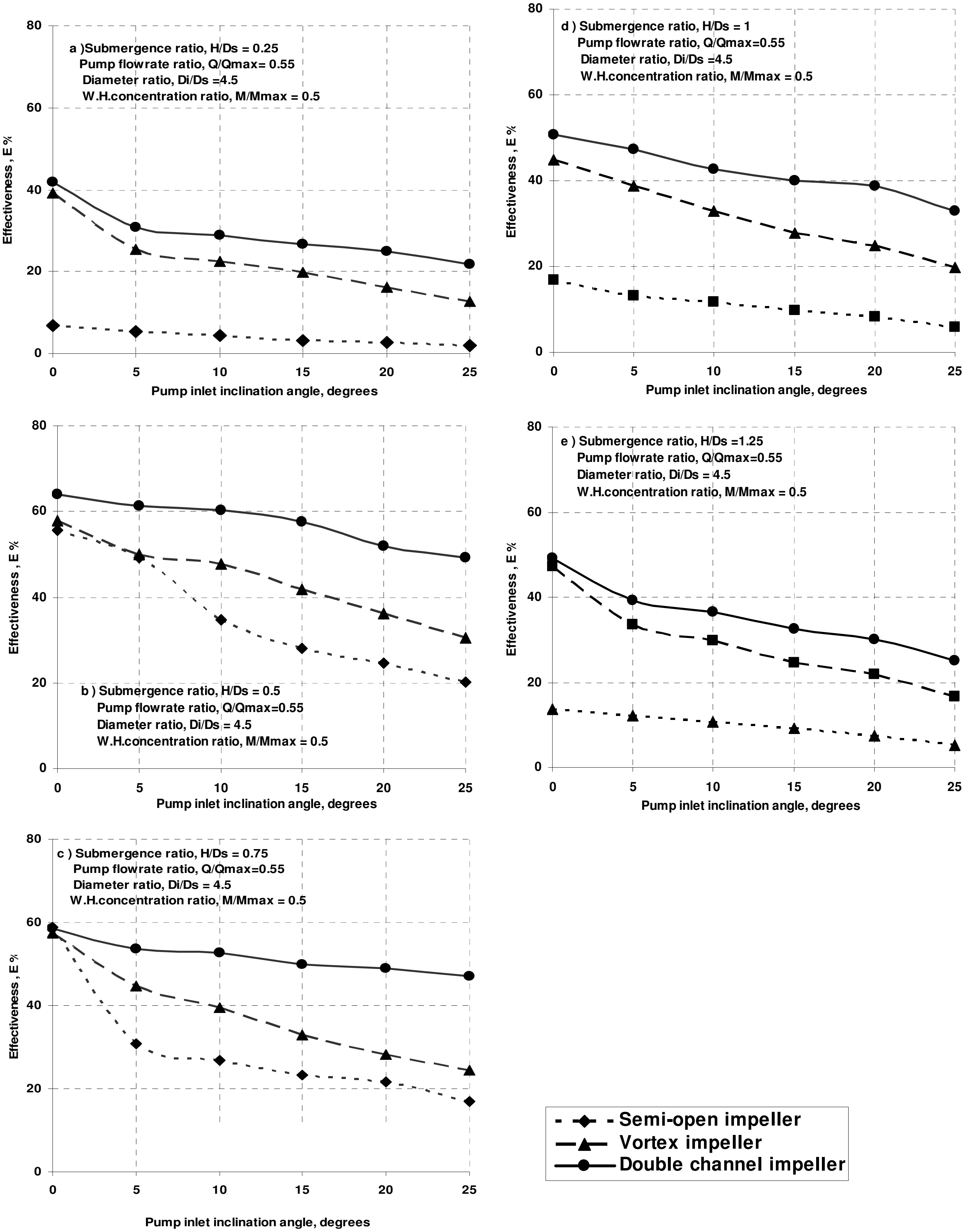


Figure 10 Variation of recovery pumping system effectiveness, E, with pump inlet inclination angle, θ at various impeller type, and submergence ratio, H/D_s,
a) $H/D_s = 0.25$ b) $H/D_s = 0.5$ c) $H/D_s = 0.75$ d) $H/D_s = 1$ e) $H/D_s = 1.25$

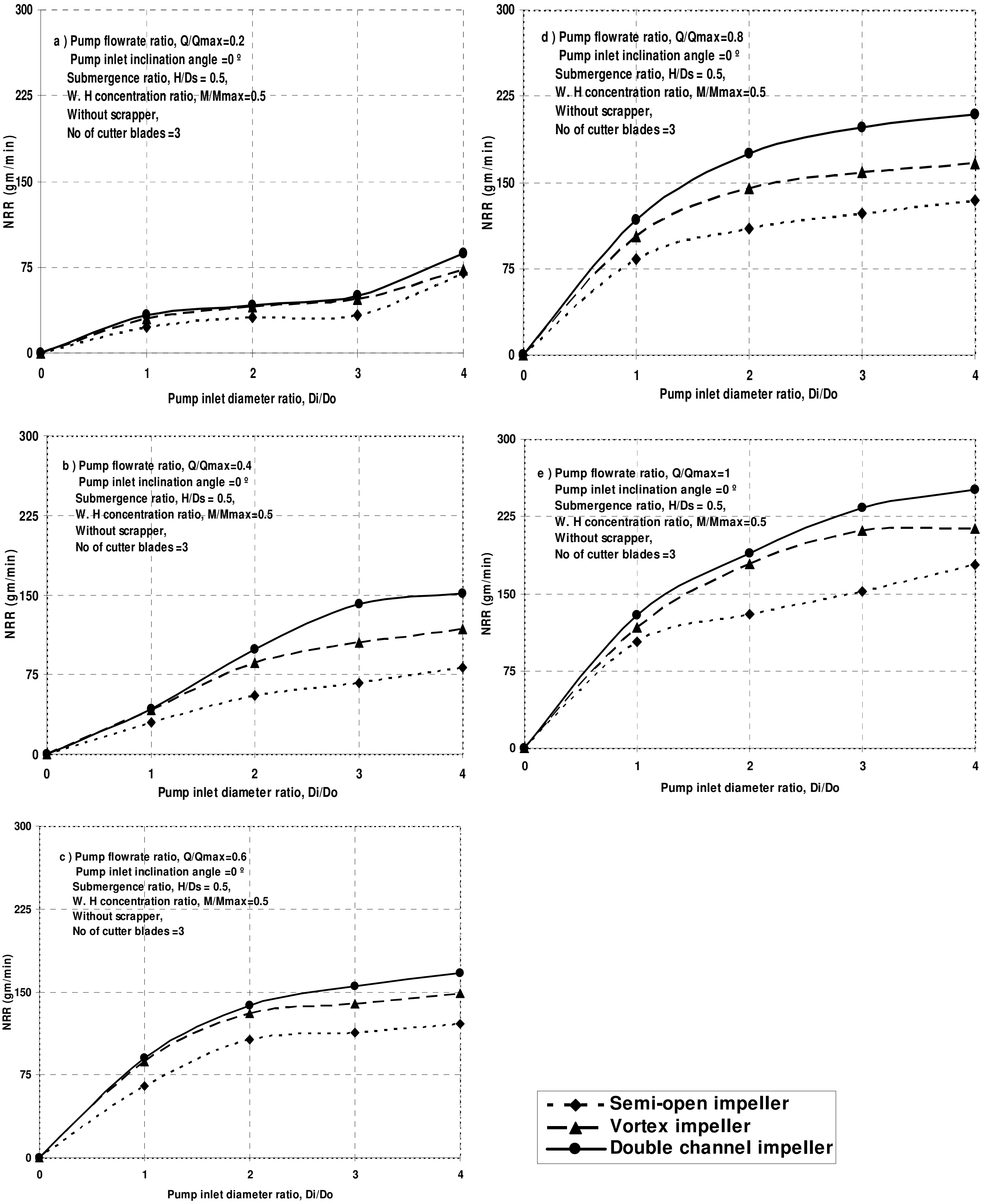


Figure 11 Variation of Nile water hyacinth recovery rate, NRR, with pump inlet diameter ratio, D_i/D_o at various impeller type, and pump inlet flowrate, Q/Q_{max}
a) $Q/Q_{max} = 0.2$ b) $Q/Q_{max} = 0.4$ c) $Q/Q_{max} = 0.6$ d) $Q/Q_{max} = 0.8$ e) $Q/Q_{max} = 1$

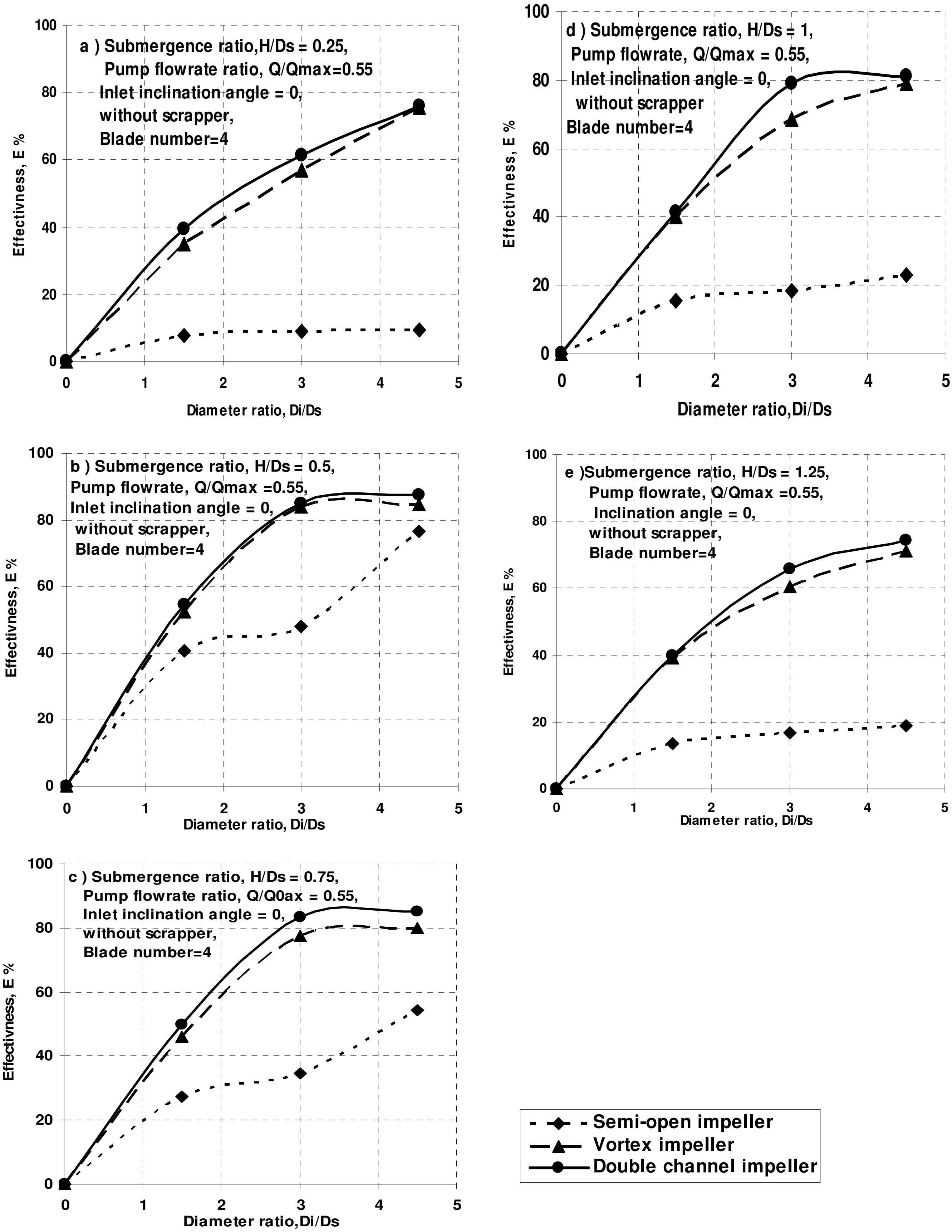


Figure 12 Variation of recovery pumping system effectiveness, E, with pump inlet diameter ratio, D_i/D_o at various impeller type, and submergence ratio, H/D_s,
a) $H/D_s = 0.25$ b) $H/D_s = 0.5$ c) $H/D_s = 0.75$ d) $H/D_s = 1$ e) $H/D_s = 1.25$

NOMENCLATURES

D_s	Pump suction diameter
D_i	Cone inlet diameter
L	Cone height
H	Submergence height
M	Recovered mass of the Nile water hyacinth
NRR	Nile water hyacinth recovery rate
Q	Water-Nile water hyacinth mixture flow rate
T	Time of collecting Nile water hyacinth recovery mass
θ	Inclination angle of the pump suction cone with respect to the vertical plane
D_i/D_s	The ratio between cone inlet diameter and pump suction diameter
H/D_s	The ratio between submergence height and pump suction diameter
Q_{max}	The maximum water-Nile water hyacinth mixture flow rate and equal 22.5 m^3/hr
Q/Q_{max}	The ratio between Water-Nile water hyacinth mixture flow rate and maximum water-Nile water hyacinth mixture flow rate
M_{max}	The maximum quantities from water hyacinth that cover the area of experimental tank and equal to 2 kg
M/M_{max}	The water hyacinth concentration ratio

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