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ENERGY SAVING BY USING AN AXIAL FLOW DEEP WELL PUMP: AN APPLICATION IN THE NET FRAMES IN LAKE KARACAÖREN -2

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Abstract: Turkey is home to a large number of lakes, dam lakes and small lakes which have a great potential for growing fishery products. Growing trout in net frame systems manufactured in dam lakes is very common and economically very promising application. For growing trout, certain conditions such as certain water temperature range and minimum dissolved oxygen (DO) level must be satisfied. The water temperature required should be at 17-20 ºC to grow trout. Also, the amount of dissolved oxygen (DO) should never fall below 6-7 mg/L. As the temperature rises during the months of June-September, water temperature rises above the acceptable limits to grow trout. Producers usually use different types of internal combustion engine-pump (ICE-P) systems to provide the circulation of the colder water in the deeper parts of the lake to lake surface to grow trout in these months. But, this method is not economically feasible. In this study, as an alternative to ICE-P system, an axial flow deep well pump has been proposed for energy saving purposes. To validate the feasibility of the system, total of 40 net frame systems each has dimensions of 5x5x8 meters have been installed to grow trout in net frames in Lake Karacaören 2 in Burdur, Turkey. To grow trout in the hot seasons, it is necessary to circulate the colder water in the deeper parts of the lake to lake surface economically. For this aim, total of 10 an axial flow deep well pumps (AFDWPs) having a capacity of 300 m^3/h, head of 4 m and running at 2850 rpm which is driven by 5.5 kW deep well motor (DWM) have been specially designed and manufactured. To compare the classical water circulation method with ICE-P and newly proposed AFDWP, after every two pumps (ICE/AFDWP) are installed, mean water temperatures were measured along the water column in net frame with the depth of 8 meters and also energy consumptions have been compared during the months of June to September. AFDWP and ICE-P were used only in these months where the water has to be circulated. According to the results energy consumption by using AFDWP was about 90 MWh/year, on the other hand, energy consumed by ICE-P was about 1949 MWh/year during the months of June-September. As a result, significant energy saving of 95.3 % (1906.8 MWh/year) can be obtained by using proposed AFDWP instead of the classical ICE-P during these months for total of 40 net frames.

Keywords: Axial flow deep well pump, Energy saving; Internal combustion engine-pump, Net frame, Stratification.

EKSENEL AKIŞLI BİR DALGIÇ POMPA KULLANARAK ENERJİ TASARRUFU: KARACAÖREN-2 GÖLÜNDEKİ AĞ KAFESLERİNDE BİR UYGULAMA

Özet: Türkiye çok sayıdaki gölleri, baraj gölleri ve küçük gölleriyle balık ürünlerinin yetiştirilmesi için büyük bir potansiyele sahiptir. Baraj göllerindeki kafeslerde balık yetiştirilmesi çok yaygın ve ekonomik olarak umut vadeden bir uygulamadır. Balık yetiştirilmesinde belirli bir su sıcaklığı aralığı ve minimum çözünmüş oksijen seviyesi gibi kriterlerin sağlanması gerekmektedir. Su sıcaklığı 17-20 ºC aralığında istenirken, çözünmüş oksijen miktarı 6-7 mg/L nin altına düşmemelidir. Haziran – Eylül aylarındaki hava sıcaklık artışı su sıcaklığını kabul edilebilir sınırların üzerine çıkarmaktadır. Üreticiler bu aylarda gölün derinliklerindeki soğuk suyu yüzeye pompalamak için farklı tipte içten yanmalı motor-pompa (ICE-P) sistemleri kullanmaktadırlar. Ancak bu yöntem ekonomik değildir. Bu çalışmada, enerji tasarrufu için ICE-P sistemine alternatif olarak eksenel bir derin kuyu pompası önerilmiştir. Sistemi test etmek üzere Burdur'da Karacaören -2 gölünde 5x5x8 metre boyutlarında 40 adet kafes sistemi yerleştirilmiştir. Göl derinliklerindeki soğuk suyun yüzeye sirkülasyonunu sağlamak için 5.5 kW gücündeki dalgıç motorunun (DWM) çalıştırdığı, 300 m^3/h kapasite, 4m basma yüksekliğine sahip ve 2850 devir/dakika'da çalışan 10 adet eksenel akışlı dalgıç pompalar (AFDWPs) özel olarak tasarlanmış ve üretilmiştir. Su sirkülasyonunda;, klasik metodu kullanılan ICE-P ile yeni önerilen AFDWP ile karşılaştırmak için, her iki pompanın (ICE/AFDWP) kurulumundan sonra, 8m derinliğindeki kafeste su kolonu boyunca ortalama su sıcaklıkları ölçülmüş ve enerji tüketimleri Haziran-Eylül ayları

arasında karşılaştırılmıştır. AFDWP ve ICE-P sadece bu aylarda kullanılmıştır. Sonuçlar AFDWP kullanımı durumunda enerji tüketiminin 90 MWh/yıl olduğunu diğer yandan ICE-P tarafından tüketilen enerjinin 1949 MWh/yıl olduğunu göstermiştir. Sonuçta, klasik ICE-P yerine özel tasarlanmış AFDWP sisteminin kullanımıyla 40 kafeste %95.3 (1906.8 MWh/yıl) bir enerji tasarrufu elde edilmiştir.

Anahtar Kelimeler: Eksenel akışlı dalgıç pompa, Enerji tasarrufu, İçten yanmalı motor-pompa, Kafes sistemi, Tabakalaşma.

NOMENCLATURE

AFDWP	Axial flow deep well pump
b.e.p.	Best efficiency point
DO	Dissolved oxygen (mg/L)
DWM	Deep well motor
dh	Hub diameter (mm)
d2	Outlet diameter (mm)
βh	Blade angle in the hub (º)
βt	Blade angle in the tip (º)
b	Blade width (mm)
Hm	Head (m)
l	Blade length (mm)
ICE	Internal combustion engine
ICE-P	Internal combustion engine-pump
ns	Specific speed (rpm)
P0	Pump hydraulic power (kW)
Pe	Effective power (kW)
Pc	Power consumption of DWM (kW)
ρ	Density of water (kg/m3)
Q	Flow rate (m3/s)
$\eta_{b.e.p}$	Efficiency of b.e.p
η_{DWM}	Efficiency of DWM

INTRODUCTION

Agricultural irrigation is a concern to governments and to the international development community due to inefficient and excessive use of energy. Over-consumption of energy leads to a general shortfall of power supply to the rural sectors, as well as to a number of other problems affecting the productivity of agriculture and rural livelihoods.

Agricultural sector plays a crucial role in the overall growth of a country's economy. In many countries, high energy consumption is a major issue for irrigation in the agricultural areas. This consumption increases owing to irrigation energy requirements when using pressurized irrigation systems such as sprinkler and drip irrigations. According to a study conducted by American Hydraulic Institute, 20% of the consumed energy in advanced countries has been consumed by various pumps. It has been explained that 30% energy saving can be obtained in systems with the selection of suitable pump and optimum design of pump system (Ertöz, 2003). This situation has led to new experimental and theoretical researches to find more efficient pumps and pump systems by pump manufacturers and academia (ISO 5198 (1987), ISO 5199(1986), ISO 9905(1994), ISO 9906(1999), ISO 9908(1993)). Various studies have been carried out on energy efficiency of pumps and pump systems by Gölcü et al. (2006) and Moreno et al. (2007).

Gölcü et al. (2006) investigated the effect of the splitter blades on energy consumption in deep well pumps. They used 8 stage deep well pumps with and without splitter blades to land out the water at 90 meters deep in an agricultural application. With the usage of deep well pump with splitter blades, energy saving of 2488 kWh/year (about 10%) is obtained during an irrigation season of 1800 hours.

Moreno et al. (2007) revealed that simple electrical and hydraulic measurements at pumping stations can help to improve their management. In their study, a cost saving of 16% was obtained by changing the regulation of the pumping station. However, some research has been carried out to optimize the total cost (investment and energy costs) in pumping stations by Moradi-Jalal et al. (2003), Moradi-Jalal et al. (2004), Planells et al. (2005), Pulido-Calvo et al. (2003) and Pulido-Calvo et al. (2003).

There are various factors which affects the hydrodynamics of a lake. The major ones are the water that comes from rivers, falling, wind and the temperature. In addition, the changes in climates that results in big temperature differences and the stratification in the lake affects the hydrodynamics of the lake in a negatively. The water quality of lake significantly depends on these factors. The stratification in the lake makes trout growing impossible. In the lakes exposed to the stratification, the part in the middle of lake between the upper part of water column in which water is warm and the lower part in which water is colder is stratified.

Çalışkan and Elçi (2007) have examined hydrodynamics of a dam lake which has a depth of 15 meters and the area of 20 km^2 in respect of different weather conditions and inlet and outlet water flow rates. They investigated the effect of climate change on lake's hydrodynamics. As a research field, they have selected the dam lake which provides 40% of drinking water of the city of İzmir in Turkey. Lake Tahtalı is exposed to stratification during the summer months and this stratification has a negative effect on lake's hydrodynamics and water quality. Numerical investigation of the effect of climate change on the stratification showed that an increase of 10% in the weather temperature may cause a rise of 7% in the temperature of lake water surface.

Lakes are under the risk of deteriorating of water quality because of the increase in stratification due to change in climate and along with increasing of temperature in summer months. This increase in the temperature at the lake surface gives rise to start the stratification along the dept from upper of lake.

Lawson and Anderson (2007) have used 20 axial flow pumps each of which has 3 HP electric motors to get rid of stratification into Lake Elsinore in California. Thus, they have improved water quality and brought water temperature and DO level to acceptable limits. It has been seen that using of axial flow pump has been effective on decreasing of water temperature, increasing the DO level in the lake and getting rid of stratification.

With the increase of temperature due to season change in the months of June to September, water temperature into lake increases and DO level decreases. For this reason, water quality deteriorates and trout cannot be grown. Water temperature is very important in all steps of growing trout including oxygen level of water and metabolic speed of fish. Firstly, appropriate water conditions must be supplied for growing trout in net frames as stated by Ruhdel (1977). Water temperature which is the most important factor should be kept below 20 ºC and the amount of oxygen should be well above 6 mg/L in the mornings. In addition, water should not contain toxic materials and, the depth of water should be above 4 m. In growing trout in the net frames, Bohl (1982) stated that, trout which have been stocked as weight of 35 g can reach the weight of 300 g in two and a half months by keeping the water temperature between 17 and 20 ºC.

Turkey, having cost line of 8333 kilometers, rivers of 175715 kilometers long, 200 lakes of 906118 hectares, dam lakes of 227621 hectares and small lakes which is more than 750 of 15500 hectares has a great potential (Mert, 1991). With the aim of utilizing this potential efficiently, growing trout has been planned and net frame systems have been installed in Lake Karacaören 2. Growing trout in net frames has become widespread in Turkey, in recent years. Trout is being grown in net frames in 1% area of dam lakes.

Pumps are used in different places such as deep well, irrigation channel, lake, etc. for various purposes. It will be more appropriate to use AFDWP in areas where the flow rate is more important than the head in water circulation in the Lake. By using AFDWP, stratification into lake will be prevented and increasing water quality will be obtained, it will also be possible to bring water temperature and the amount of DO level to required values.

In this study, total of 40 net frame systems, each has dimensions of 5x5x8 meters, have been manufactured to grow trout by improving the water quality. The net frames have been installed in Lake Karacaören 2. The water temperature and DO values have been measured along the water column for every meter from the lake surface during the months of June-September. As the water temperature rises and DO level drops in these months, the water quality is deteriorated and trout cannot be grown. The stratification in the lake deteriorates the water quality .As a remedy to this situation, the colder water into the lower parts of the lake should be circulated to the lake surface to grow trout by improving the water quality. But, this operation should be economically carried out. Producers use different types of ICE-P systems to circulate the colder water to grow trout in these months. Although this method is a classical method, it is not economic due to high fuel consumption rate and cost of the diesel fuel.

Due to the aforementioned reasons, as an energy saving alternative total of 10 AFDWPs, having a capacity of 300 m^3/h, which is driven by a deep well motor (DWM) of 5.5 kW have been specially designed and manufactured. The design parameters of the AFDWP impeller were calculated by using the equations found in design book by Stephanoff (1993). An experimental test rig has been installed to test the AFDWP and the performance characteristics have been obtained. To compare the classical water circulation method with ICE and newly proposed AFDWP, after every two pumps (ICE/AFDWP) are installed, mean water temperatures were measured along the water column in net frame with the depth of 8 meters and also energy consumptions have been compared during the months of June to September. AFDWP and ICE-P were used only in these months where the water has to be circulated.

METHODOLOGY

Stracture of The Net Frame

Total of 40 net frames, each has dimensions of 5x5x8 meters, has a weight of 200 tones have been manufactured. They have been installed in Lake Karacaören 2. Total of 4 barrels, each is full of with cement have been fixed to the different points of the net frame to protect the frame systems installed in lake against to storm. Thus, the strength of the net frames to the storm has been increased. The water temperature and DO values have been measured at every meter from the lake surface along the water column in Lake Karacaören 2 during the months of June-September. The measured values belonging to the month of August, 2006 have been given in Figure 1.

The temperature and DO values have been taken at noon times at which the pump has the pick working load. As shown in Figure 1, as the depth increases, temperature decreases and the amount of DO reaches a maximum at 6 m then the level of DO decreases as the water depth gets larger. As the water in lake gets warmer and the amount of DO is not at the level required in the hot months, trout cannot be grown. The colder water in lower parts of lake should be circulated on to the lake surface to get the water temperature to the required level.

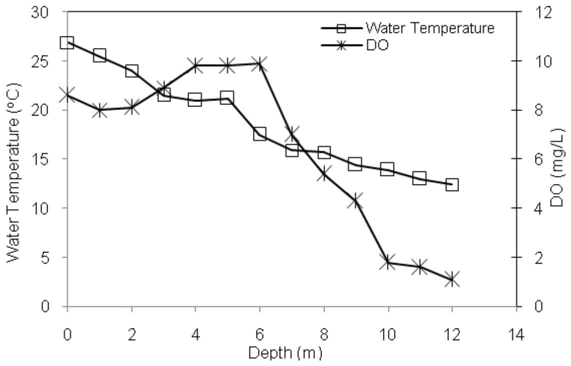

Figure 1. Measured water temperature and DO values along the water column in lake (before AFDWP/ICinstallation) (August, 2006)

In order to circulate the colder water to the lake surface and provide the colder water to all of 4 net frames, AFDWPs have been specially manufactured. Net frame systems have been divided into groups of 4. Quaternary net frame-AFDWP system has been shown in Figure 2. AFDWP has been installed at a depth of two meter from the lake surface.

As shown in Figure 2, AFDWP has been placed in the middle of the quaternary net frame system. The water at the depth of 12 m and at a temperature 12.4 ºC is pumped to the surface of the lake through the pipes of 225 mm diameter. Then, the colder water is circulated to each net frame with the pipes of 110 mm diameter.

This study has been realized at two stages. At the first stage; the circulation of colder water has been provided by ICE-P system which is the classical method. ICE-P used, is the type of Z108+SNK150-200. The engine is diesel engine with two cylinders, four strokes. The pump is the type of SNK 150-200. Specifications of the ICE-P system were given in Table 1.

Table 1. Technical features of the ICE-P system

Diesel motor type	***Z108***
Number of cylinder, cylinder diameter x stroke, cylinder volume	2, 108 x 110 mm, 2014 cm^3
Compression rate	17
Maximum torque	112 / 1700 Nm/rpm
Maximum power	28.5 kW (3000 rpm)
Capacity of fuel tank	20 L
Volume of carter oil	6 L
Pump type	***SNK 150-200***
Suction and pressure diameters	8”
Rated speed	1900 ~ 1500 rpm
Flow rate	350 m^3/h
Head	15.5 m
Suction head	7 m
Fuel consumption	6.4 L/h

At the second stage; AFDWP has been used. The AFDWP has been driven by a DWM of 5.5 kW. An AFDWP having a capacity of 300 m^3/h, head of 4 m and running at 2850 rpm was designed and manufactured. Specific speed of the manufactured pump is 290.2 rpm.

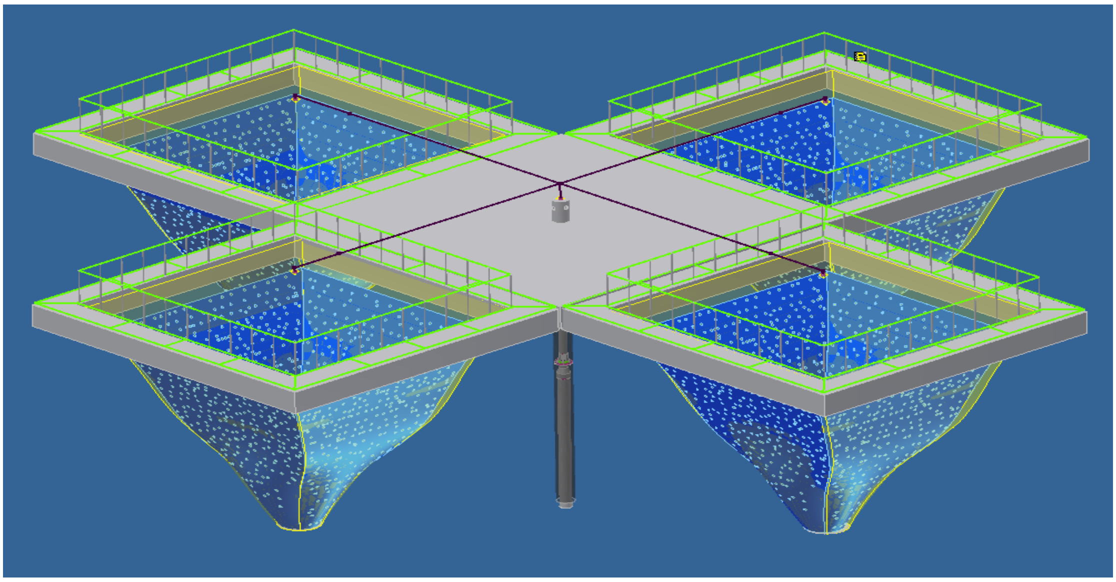

Figure 2. Quaternary net frame-AFDWP system

Geometry of The Axial Impellers

The AFDWP has been manufactured as an alternative to the existing of ICE-P for energy saving purposes and to grow trout during the months of June-September by improving the water quality. AFDWP's design capacity is 300m^3/h, head is 4 m and speed is 2850 rpm. Figure 3 shows the dimensions of the principal impeller while Figure 4 shows the picture of AFDWP impeller with three blades.

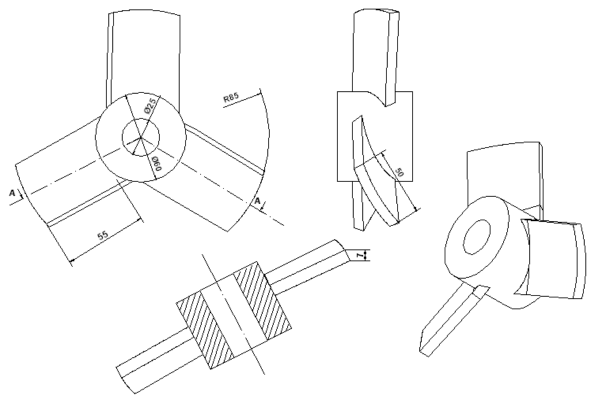

Figure 3. Dimensions of the AFDWP impeller.

Figure 4. Axial impeller with three blades.

Technical drawings of the AFDWP impeller were performed under Autodesk Inventor Professional program. The important specifications of the impeller were given in Table 2.

EXPERIMENTAL APPARATUS

Experimental test rig of deep well pump has been installed to obtain the performance values of AFDWP and power consumption. The AFDWP has been driven by a DWM of 5.5 kW and it has been run at 2850 rpm. The efficiency of DWM is 72%. The experimental test rig consist of deep well pump, deep well motor, filter, pressure and vacuum transmitters, magnetic flow meter, gate valve, control panel, tank and pipe system. The operation condition is controlled by a gate valve in the discharge pipe.

Measurements and Uncertainties of The Experimental Data

AFDWP suction pressure was measured by a vacuum transmitter and its discharge pressure was measured by a pressure transmitter. The vacuum and discharge pressures were measured using WIKA Type S-10 transmitter model and its accuracy was ±0.5%. The uncertainty of the head measurements was estimated to be ± 1.04%. The flow rate of the pump was measured by a magnetic flow meter. The accuracy of magnetic flow meter was ± 0.15%. The uncertainty of the flow rate measurements was estimated to be ± 1.14%.

The power consumption of the DWM was measured by using Entes model MPR-60S network analyzer. Flow rate, suction and discharge pressures, and active power values have been recorded in computer by interface program for the various valve positions during the experiments. The accuracies of voltage, ampere, and power factor were ±0.5%. The uncertainties in power and efficiency were calculated as ± 0.86% and ± 1.01 %, respectively.

RESULTS AND DISCUSSION

The results are presented in three parts; first cost analysis of the AFDWP and the ICE-P system are presented. The second part is related to characteristics of the AFDWP. Finally, energy consumptions of DWM and ICE have been compared.

Cost Analysis

As the cost of the specially manufactured AFDWP is $5000, the cost of the ICE-P having 350m^3/h is $7500. The type of the ICE-P is Z108+SNK 150-200. The AFDWP is cheaper and more sensible to environment compared with the ICE-P.

Characteristics of The AFDWP

An experimental test rig installed in Figure 5 has been used to obtain the performance characteristics of the AFDWP. Figure 6 shows the comparison of the head-flow rate, effective power-flow rate, efficiency-flow rate characteristics of the AFDWP.

Table 2. The design point values of the AFDWP

Q(m^3/h)	H_m (m)	n (d/d)	n_s (d/d)	z	d_h (mm)	d_2 (mm)	L (mm)	b (mm)	$\beta_{1,t}$ (°)	$\beta_{1,h}$ (°)	$\beta_{2,t}$ (°)	$\beta_{2,h}$ (°)
300	4	2850	290.2	3	Ø60	Ø170	50	55	12	26	15	32

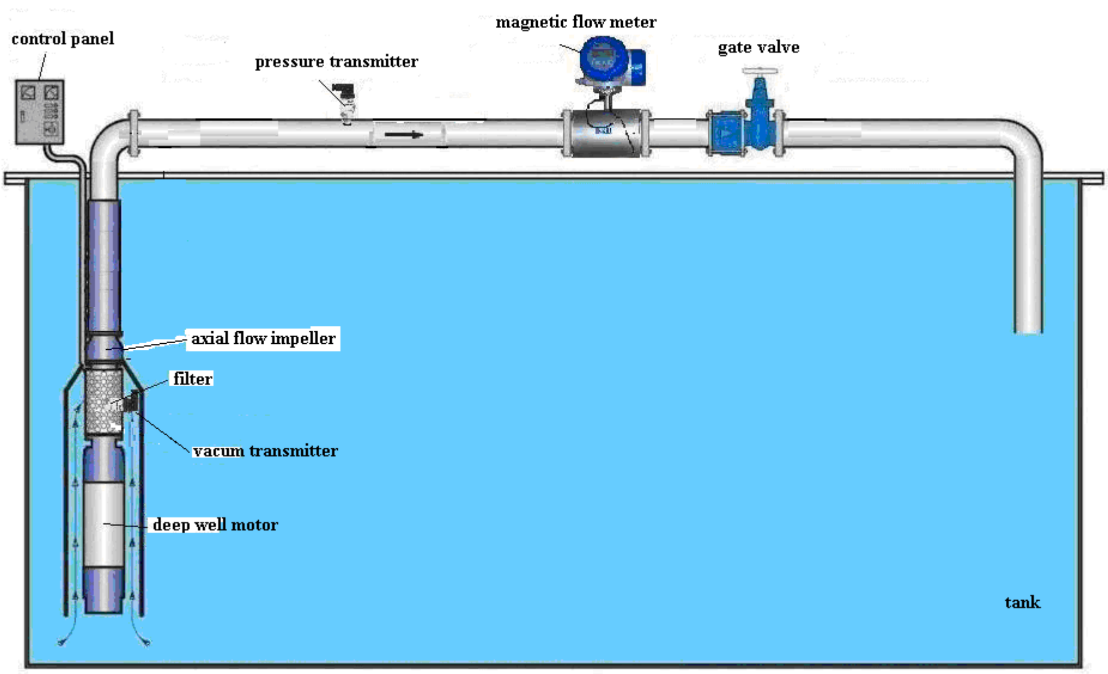

Figure 5. Deep well pump test rig

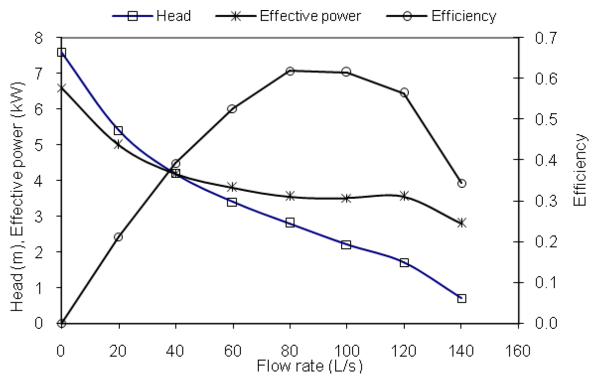

Figure 6. The performance characteristics of the AFDWP.

The best efficiency point (b.e.p) has been occurred at flow rate of 80 L/s. As shown in Figure 6, at b.e.p; the head, the effective power, and the efficiency are 2.8m, 3.55 kW, and 61.90%, respectively.

Pump hydraulic power (P_0) can be calculated as follows:

$$P_0 = \rho \cdot g \cdot Q \cdot H_m \tag{1}$$

By using constant thermo physical properties for water ($\rho_{water} = 1000$ kg/m^3), $P_0 = 2.197$ kW was obtained. The best efficiency of the pump is determined to be 61.90% (Figure 6) then effective power which is the inlet power of the pump $P_e \cong 3.55$ kW can be obtained from

$$P_e = \frac{P_o}{\eta_{b.e.p}} \tag{2}$$

By dividing the effective power (Pe) by 72% DWM efficiency:

$$P_c = \frac{P_e}{\eta_{DWM}} \tag{3}$$

Which is the power consumption of the DWM and its value is about 5 kW.

An Application In The Net Frames And Comparison of Energy Consumption

According the measurements obtained in the month of August, 2006 (as shown in Figure 1); the average water temperature in net frames which has a depth of 8 m along the water column was 21.02 ºC and the amount of DO was 8.38 mg/L. In order to reduce this temperature to 17-20 ºC which is the level required, for the life conditions of trout, the circulation of colder water at the depth of 12 m and 12.4 ºC has been provided with the AFDWP. The circulation of the colder water in the other quaternary net frame system has been provided with the ICE-P system. The measurements of water temperatures

Table 3. Input parameters for energy consumption classes

Pump type	Power supply	Fuel type	Annual operation	Head	Flow rate	Energy consumption
ICE-P	ICE	Diesel	1800 hours/year	15.5 m	350 m^3/h	63kWh
AFDWP	DWM	Electricity	1800 hours/year	2.8 m	288 m^3/h	5 kWh

and DO values have been taken after half an hour following the AFDWP and ICE-P start up. Measurements have been obtained for every meter along the water column. Measured water temperatures and DO values have been given in Figure 7.

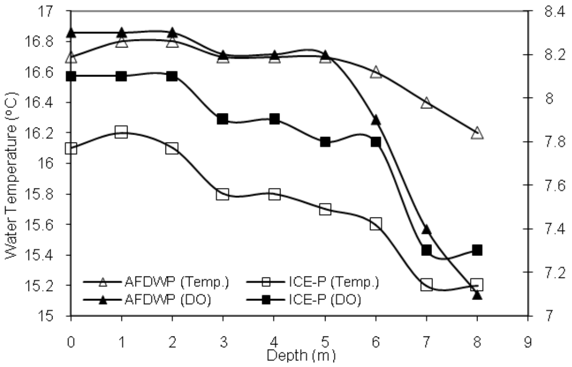

Figure 7. Measured water temperature and DO values along the water column in lake (after AFDWP/ICE-P installation)

By using the temperature and DO values for the AFDWP and the ICE-P in Figure 7, the average water temperature and the average DO values along the water column in the net frame through the depth of 8m have been obtained as 16.62 ºC, 15.74 ºC and 7.98 mg/L, 7.81 mg/L, respectively. When the AFDWP and the ICE-P were used to circulate the colder water, it has been obtained a decrease of 20.9% and 25.1% at the average water temperature, respectively.

The AFDWP and the ICE-P were used to circulate the colder water; energy consumptions were calculated for two systems and compared with each other. The comparison has been carried out for the months of June-September in which the water temperature is high and trout cannot be grown. Classification of effective input parameters on energy consumption has been shown in Table 3.

Commercially manufactured ICE-P groups are generally centrifugal type and have specific speed values below 150 rpm (low specific speed pumps). On the other hand, for the circulation of cold water in the lake, high flow rates are desired and flow rate is more important than head in this kind of applications. For this reason, ICE-P groups having higher specific speed are needed and they are not commercially manufactured. Therefore, consumers have to choose ICE-P groups with low specific speeds and these ICE-

P groups usually have higher head values. In the current study, as an alternative to low specific speed ICE-P group, AFDWP were specifically manufactured and comparisons were made for these two systems. Specific speed of the manufactured AFDWP is 290.2 rpm.

The AFDWP and the ICE-P provide a flow rate of $288m^3/h$ at a head of 2.8m and $350m^3/h$ at a head of 15.5m, respectively. A typical producer who wants to grow the trout should run the AFDWP and the ICE-P for 15 hours each day during the months of June-September, adding up 1800 hours of operation in a year. Comparison of energy consumptions of the AFDWP and the ICE-P were given in Table 4. Energy saving of 95.3% in AFDWP compared to ICE-P was obtained during months of June-September per year.

Table 4. Comparison of energy consumptions during the months of June-September for total of 40 net frames

Type	Energy consumption (MWh/year)
ICE-P	1949
AFDWP	90

CONCLUSIONS

Two different systems have been used to provide the circulation of colder water in net frames and to improve the water quality. The first one is ICE-P, while the second one is AFDWP. ICE and DWM were used as power supply in ICE-P and AFDWP systems, respectively. Yearly energy consumption for total of 40 net frame systems (water of $8000m^3$) has been calculated during the months of June-September. According to the results energy consumption by using AFDWP was about 90 MWh/year, on the other hand, energy consumed by ICE-P was about 1949 MWh/year during the months of June-September. As a result significant energy saving of 95.3 % (1906.8 MWh/year) can be obtained by using AFDWP instead of the classical ICE during these months for total of 40 net frames.

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