Prospects of Application of Solar Energy in Irrigation Systems

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Abstract. The reduction of fuel and energy resources around the world leads to a continuous increase in the prices, besides, their use creates serious environmental problems. In developed and developing countries, measures are being taken to develop renewable energy technologies. Currently, photovoltaic plants are used in Armenia, in which case 5 m^2 of area must be allocated for the production of 1 *kW* of electricity, and the cost of a system with a capacity of 1 *kW* is still significantly high. In the country poor in land resources, such “luxury” is not acceptable. In this paper, it is proposed to use a system for irrigation of agricultural lands, which includes a solar energy accumulator with a power of 6.0 *kW*, pressure chamber with pressure of up to 7.57 *MPa* for 20-35% aqueous solutions of ammonia having a lower boiling point, diaphragm pump with a capacity of 500 *l/min* or pump with a capacity of 35.4 *l/sec* connected to a 5.2 *kW* engine running on compressed gas. The proposed solar-powered irrigation system will enable to solve the problems of efficient management and use of irrigation water.

Introduction

Nowadays, the reduction of reserves of fuel and energy resources in the world creates many environmental problems on the one hand, and on the other hand leads to a continuous increase in the prices [1-3]. Therefore, even in countries rich in these resources, measures are being taken to develop alternative energy technologies, especially solar energy. There are sufficient conditions for the development of solar energy in Armenia, which will allow to obtain low cost electricity [4, 5]. Currently, photovoltaic stations are used, but it is known that 5 m^2 of area must be allocated for the production of 1 *kW* of electricity, and the cost of a system with a capacity of 1 *kW* is still significantly high, amounting to 400-500 thousand AMD. In a country poor in land resources, such extravagance is certainly not acceptable. Taking into account the above mentioned, it is possible also to develop helioenergy in parallel with them. It allows to get 1 *kW* of energy from 1 m^2, which is an important factor for the solar energy development. On the other hand, it can be used in irrigation systems, significantly increase the efficiency of irrigation water management, which is currently very important, and agricultural production. There are also problems that need to be solved.

The aim of this work is to suggest equipment for the use of solar energy in irrigation systems, which will increase the efficiency of irrigation water management and use.

Methodology

The problems of irrigation water availability, the disadvantages of mechanical irrigation, such as the increase in the cost of irrigation water in the case of pumps installation have been studied. Mechanical irrigation often has no alternative in the process of solving irrigation problems. In particular, when it is necessary to transfer water from a low level to high level or to use drip or sprinkler irrigation, can not be carried out without the use of pumps. In fields, in the absence of grid power, of course, pumps driven by internal combustion engines can be used, but in this case the cost of irrigation water increases significantly [6,7].

Advantages of solar collectors

Prospects of using solar energy collectors in irrigation systems were considered.
Solar energy collectors are currently widely used to convert solar radiation into heat energy, which solves a number of practical problems [8, 9]. Parabolic trough collectors are most often used (Fig. 1-I), which can be fixed at an angle of 30° to the horizon and orientate to the south. The coefficient of performance of such collectors may be 75%. It has a mirror surface that concentrates solar energy on a parabola-focused tube into which a liquid is poured, which can heat up to 400 °C. This system allows it to be used in hot water supply, electricity generation, as well as in irrigation systems [10]. For this purpose, spherical collectors are also used, which have a plate-shaped structure (Fig. 1-II). The main advantage of spherical collectors is that, firstly, it is possible to implement accurate positioning to the direction of the sun and, secondly, the temperature there is significantly high and can be up to 800 °C, as the rays of the sun are concentrated at one point.

In irrigation systems, depending on the problem, both can be used [11, 12].

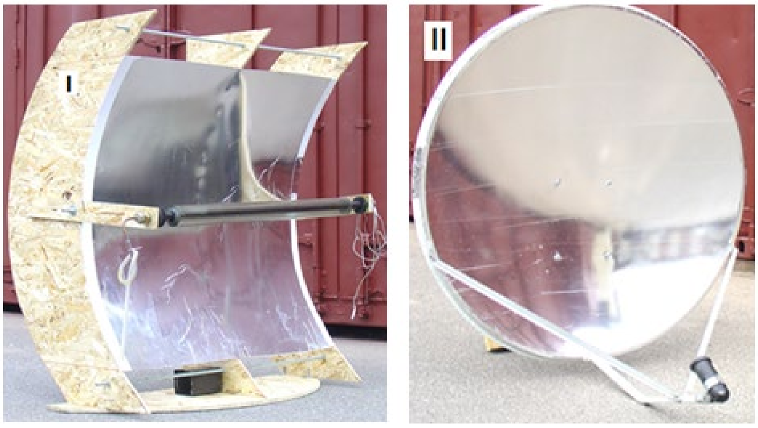

Fig. 1. Parabolic trough and spherical solar collectors

Liquids converting thermal energy into pressure energy

The efficiency of using liquids with lower boiling points instead of water in the process of converting thermal energy into compressive energy has been studied.

In practice, many liquids are produced for this purpose, which allow the conversion of heat energy into pressure energy. It is known that water is mainly used for this purpose, but in this case there are significant complications, because it has a high boiling point, and it is necessary to use sophisticated technologies to cool the high-temperature steam coming out of the turbine, to use it in a new cycle. Problems arise in the process of removing the received thermal energy. Therefore, especially when dealing with low capacities, it is more efficient to use liquids with lower boiling point. Among them, mainly ammonia, freons and other liquids of organic origin are used [13, 14]. The choice of these liquids takes into account their safety, a number of thermodynamic parameters, environmental impact, availability, cost, etc. Freons, which contain carbon, fluorine, chlorine and other organic compounds, have a high molecular weight (100-200), which allows to reduce the turbine speed from 100000 to 1500-3000 rpm, which allows significantly simplify the operation of steam turbines and reduce equipment amortization costs. However, for example, diaphragm pumps require a certain amount of gas circulation, which is a limiting factor for high molecular weight liquids.

Gas powered diaphragm (membrane) pump

The principle of operation of a gas powered diaphragm pump has been studied. This is a volumetric pump that works due to the elastic deformation of the membrane. The diaphragm pump operates with the principle of scheme presented in Fig. 2. The separation in the suction and injection chambers in these types of pumps is implemented with a check valve. As a result of the membrane bending, a vacuum is created, and water enters the pumping chamber. Afterwards, suction valve closes and the water is forced out of the pump under the pressure. The membrane bending occurs in the gas pressure chamber, where the gas periodically compresses the membrane under the pressure and after that, it's pushed from the pump into the cooling chamber [15, 16].

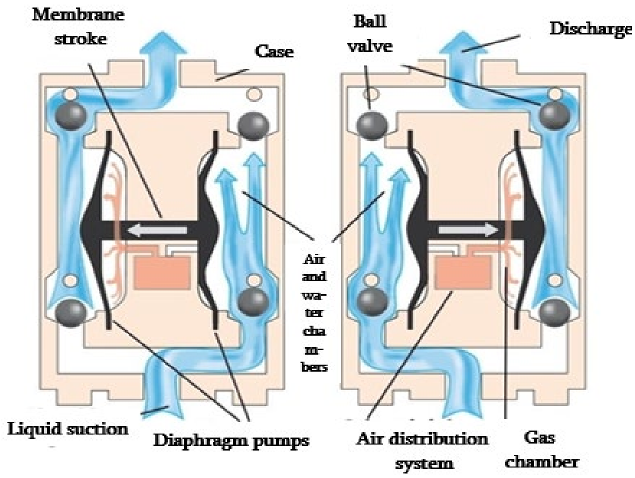

Fig. 2. Diaphragm pump structure and working principle

Table 1 shows the technical parameters of the FT15A-AA-BBAB-B2 diaphragm pump according to the corresponding parameters.

Table 1. Technical parameters of FT15A-AA-BBAB-B2 diaphragm pump

Pump parameters	Technical indicators
Productivity	500 l/min
Maximum pressure	8,3 MPa
Absorption peak height	8,5 m
The volume of gas required for a cycle	1,2 l
Maximum gas consumption	25 m^3/hour
Permitted gas temperature	88 ºC

Application of engines operating with compressed gas

For surface irrigation, in particular, applying waters from fish farming lakes in Ararat Valley for irrigation purposes, it is important to provide high discharge rate due to relatively low ejection heights. Compressed gas engines are proposed to solve the problem. They can be either paddle or piston. Fig. 3 shows the LZL 35 paddle engine with a power of 5.2 kW, and Table 2 presents its technical characteristics.

Fig. 3. LZL35 compressed gas engine

Table 2. Technical characteristics of the LZL35 compressed gas engine at maximum load

Engine parameters	Technical indicators
Rotational speed	2500 RPM
Torsion torque	20 N*m
Gas consumption	130 l/c
Power	5,2 kW
Weight	20 kg

Within the framework of the work, new technological schemes has been developed, calculations have been done to justify their effectiveness. The prospects of using the proposed methods in Armenia were shown.

Results

Provision of access to irrigation water

In field conditions, where electrical power is not available and pumps driven by internal combustion engines (gas or diesel engines) are used, significant increase in irrigation water cost is observed. For example, in Armenia, about 2 litres petrol for operation of generator engines with a capacity of 5 *kW* per hour and 10 litres per 20 hours is required, the cost of which currently is about 8,000 drams.

During this time, 54 m^3 of water can be ejected, the cost of which will be 148 drams, or 13 times higher than in case of a gravity irrigation system.

To solve the problem of providing access to irrigation water at a low cost, the scheme presented in Fig. 4 is proposed. The irrigation system operates with the following principle: *1* evaporation chamber, filled with a liquid with a lower boiling point, is heated by *2* parabolic trough solar collector. Pressure gas is given to the *4* diaphragm pump from the *3* pressure tube. The pump pushes water through the *5* pipeline to the *6* irrigated field. The gas removed from the pump passes through *7* tube to *8* refrigerator, where it liquefies and through *9* absorption pipe is pumped (through *10* pump and *11* tube) to *1* evaporation chamber and the cycle is repeated.

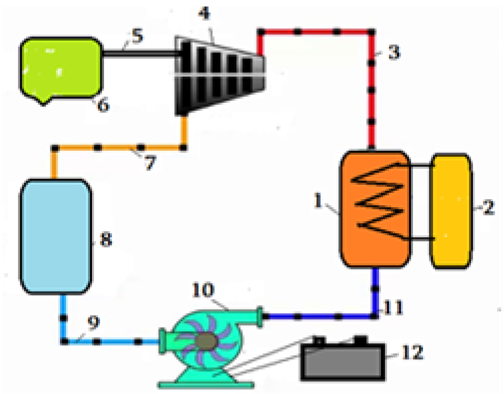

Fig. 4. Irrigation water pumping method using solar energy

1-liquid evaporation chamber, 2-parabolic trough solar collector, 3-gas supply pressure tube, 4-diaphragm pump, 5-ejection pipe, 6-irrigated field, 7-tube for gas removal from pump, 8-refrigerator, 9-liquid absorption pipe, 10-injection pump, 11-liquid ejection tube, 12-pump feeding battery

Solar collector project. Within the frames of the work, calculations of a 5 *kW* parabolic trough collector have been done and its scheme has been developed. Since the collector is immovable, therefore, to obtain 5 *kW* of power, it is necessary to increase the power by 20%, resulting in 6 *kW/hour*. The following structure was proposed for the collector: 6 *m* long metal frame with 115 *cm* long parabolic arc. To facilitate the transportation of the collector, the metal frame is divided into 3 parts, each 2 meters long. The focal length was calculated by the following formula:

$$F = R^2/4d,$$

where R is the radius of the parabola - 57.5 *cm*,
d is the depth - 24 *cm*.

To obtain a mirror surface, a tin plate with a silver-plated membrane is used, which fully reflects rays of the sun. A copper pipe with a diameter of 28 *mm* is installed in the focus of the parabola. Afterwards, 3 parabolic collectors are connected in a spatial frame (Fig. 5).

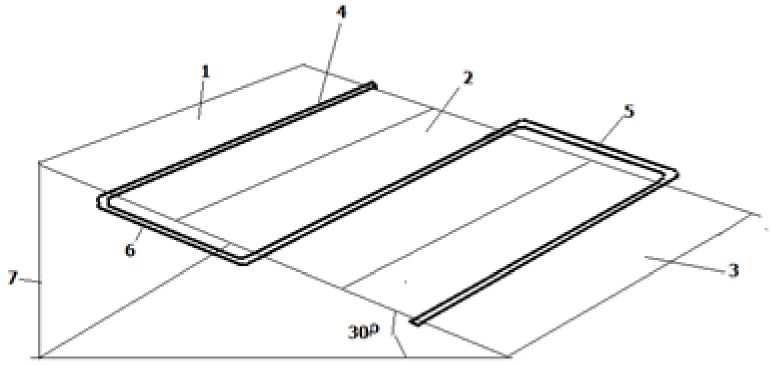

Fig. 5. Scheme of proposed solar collector
1, 2, 3 - parabola sections, 3, 4, 5 - pipes passing through focus and their connections, 7 - spatial frame

Application of aqueous solutions of ammonia in the process of converting thermal energy into compressive energy. The volume of gas from the evaporation of 1 *l* of liquids of ammonia and R141b refrigerant was calculated. The molecular mass of ammonia is 17, and refrigerant's is 117. Since 1 mole of gas occupies a volume of 22.4 litres, 1317 litres of gas is obtained from 1 *l* of ammonia, and 192 litres of gas from refrigerant or about 7 times less. Considering this fact ammonia has been chosen. Ammonia aqueous solution is suggested to simplify the constructions and ensure the safety. Table 3 shows the concentrations of aqueous solutions of ammonia and the values of their vapour pressure at different temperatures.

Depending on what power is required to pump relevant volume of water, 20-35% of aqueous solutions of ammonia can be used. Since diaphragm pumps allow up to 80 ^oC of gas temperature, therefore, 3.09-7.57 *MPa* of pressure can be obtained from ammonia solutions, which is sufficient to pump water in field conditions. The next problem is the safety of working with ammonia. It has been proven that it is safe when there are also water vapour along with ammonia vapour. Table 4 shows the content of water vapour contained in the evaporation of ammonia in solutions with different concentrations. It is shown that in case of evaporation of 20-35% ammonia solutions, ammonia vapours contain 6-10% water vapour, which makes the use of ammonia safe. The ammonia is very soluble in water and the gas returned from the pump after freezing is repeatedly dissolved in water and ready for use in the next cycle.

Table 3. Pressure of ammonia vapour on aqueous solution depending on concentration and temperature

Concentration, %	Liquid temperature, ^oC								
	30°	40°	50°	60°	70°	80°	90°	100°	110°
	Vapour pressure, kg/cm² (*MPa*)								
5	-	-	-	-	-	0,923	1,83	2,49	3,33
10	-	-	-	-	1,05	1,48	2,07	2,8	3,73
15	-	-	-	1,12	1,59	2,20	2,99	3,99	5,24
20	-	-	1,14	1,63	2,27	3,09	4,15	4,18	7,08
25	-	1,14	1,64	2,28	3,11	4,24	5,64	7,34	9,45
30	1,13	1,63	2,28	3,16	4,29	5,71	7,19	9,62	-
35	1,57	2,25	3,14	4,27	5,76	7,57	9,73	-	-
40	2,17	3,07	4,24	5,70	7,55	9,70	-	-	-
45	2,91	4,08	5,55	7,36	9,56	-	-	-	-
50	3,79	5,24	7,09	9,26	-	-	-	-	-

Table 4. Content of ammonia by mass (%) in an aqueous solution and in vapour

In solution	41	34.6	28.2	25	20	15	10	5
In vapour	95	94	93	92	90	85	67	37

Efficiency of the use of diaphragm pumps driven by gas pressure. Maximum capacity of the pump is calculated by the following way:

$$N = 9.8 \cdot Q \cdot P = 9.8 \cdot 500 \cdot 10 - 3 \cdot 83/60 = 6.8 \text{ kW}.$$

Taking into account that 1.32 m^3 of gas is obtained from the evaporation of 1 litre of 35% ammonia, the required amount of evaporation of the solution in 1 hour can be calculated: 25:1.32 = 19 *l*.

The proposed method can be applied in field conditions in drip irrigation systems. In the Republic of Armenia, it will take about 1 million AMD, which can be compensated in 1 year in case of high-value crop cultivation.

Efficiency of the use of compressed gas engines. The maximum volume of water pumped by the proposed engine pump, if the pumping height is 15 *m*, has been calculated:

$$N = 9.8 \cdot Q \cdot H, \quad Q = N/9.8 \cdot H = 5.2/9.8 \cdot 15 = 0.0354 \text{ m}^3/\text{min} \text{ or } 127 \text{ m}^3/\text{hour}.$$

Thus, 127 m^3 of irrigation water is possible to pump in an hour with a pump connected to such an engine. If taken into account that an average 800 m^3 of water is required for irrigation of hectare, it will take 800/127 = 6.3 hours. If we assume that the average duration of intensity of natural sunlight in the irrigation season is 8 hours, it is possible to provide irrigation of an area of 1.3 hectares in a day. $127 \cdot 8 \cdot 30 \cdot 6 = 182880$ m^3 of water will be pumped in 1 season, the cost of which will be $182880 \cdot 11 = 2011680$ AMD. If we take into account that about 1.2 million AMD will be spent on the implementation of the system, the invested expenses will be compensated within 5 months.

Thus, the use of solar energy in irrigation systems will solve the problems of efficient use of irrigation water, due to the effective management of the system.

Conclusion

The possibilities of using solar energy in irrigation systems, with the use of collectors converting solar radiation into heat energy, were observed. A technological scheme for irrigation water pumping using solar energy has been developed to provide availability of irrigation water at a low cost.

The efficiency of using lower boiling point liquids instead of water in the process of heat energy conversion into pressure energy. The efficiency of using an aqueous solution of ammonia for this purpose has been substantiated by the calculated method.

The principles of diaphragm pumps driven by gas pressure and compressed gas have been studied. Their efficiency in case of solar energy application in the Republic of Armenia has been calculated and substantiated.

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