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2004

First published in:

Journal of Applied Irrigation Science, Vol. 39. No 1/2004, pp. 83 - 91
ISSN 0049-8602

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Low-pressure irrigation system powered by wind energy

Niederdruck- Bewässerungssystem angetrieben durch Windenergie

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Stichworte

Bewässerungsverfahren, Niederdruck-Bubler-Bewässerungssystem, Computerprogramm LHBIS, Mobile Windkraftanlage, MoWEC

Keywords

Irrigation techniques, low-head bubbler irrigation system, computer program LHBIS, mobile wind energy converter, MoWEC

Zusammenfassung

Der Weltenergiebedarf nimmt kontinuierlich zu. Gründe hierfür sind die Zunahme der Weltbevölkerung, das Wirtschaftswachstum und der Energieverbrauch. Die Kombination eines windelektrischen Systems mit einer ihr angepassten Bewässerungsanlage für Obstbäume kann in Regionen ohne öffentliches Stromnetz sowohl für die Bewässerung als auch für die allgemeine Stromversorgung eingesetzt werden. Die Zielsetzungen der Untersuchungen sind: Auswahl, Simulation und Labortest einer für die Windenergie geeigneten wasser- und energiesparenden Bewässerungstechnik für kleine Obstbauplantagen. Das Computerprogramm LHBIS wurde geschrieben, um die Dimensionierung eines Niederdruck-Bubler- Bewässerungssystems einfacher und schneller zu berechnen. Laborversuche wurden zur Überprüfung des LHBIS-Computerprogramms durchgeführt. Das Computerprogramm wurde benutzt um Faktoren zu ermitteln, wie die Verteilerschlauch-Auslasshöhe entlang des Verteilerrohres, die notwendige Druckhöhe am Beginn jeder Feldzuleitung oder den Neigungswinkel des Verteilerrohres.

Abstract

World energy needs are increasing continually due to the increase of the world population, economic growth, and energy usage. The combination of a wind-electric system with suitable irrigation equipment for watering fruit trees, could also open the supply of electricity for common applications in regions without a public electrical grid. The objectives of the investigations described in this paper were the selection, simulation and laboratory testing of a water- and energy saving irrigation technique for small orchard farms, suitable for wind energy use. The computer program LHBIS was written to make low-head bubbler irrigation design simpler and faster. Laboratory experiments were conducted to validate the LHBIS computer program at three lateral slopes. Also, the computer program was used to investigate certain factors influencing the elevation of distributor hoses along the laterals and the pressure head required at each manifold inlet of the irrigation system.

1. Introduction

The development of new irrigation techniques has become rare in recent times, because research and development usually concentrate only on the improvement of existing procedures. In the research reported in this paper, work concentrated on the adaptation of a low-pressure irrigation system for watering fruit and nut trees. The work must be considered in connection with the attempt to use wind-electric power for the water pumping system. Energy costs are more significant than water costs in most countries. Today most irrigation techniques have been developed for conditions under which fossil energy sources deliver pump energy as needed. In contrast, a wind energy plant in stand-alone use converts use energy only according to the present wind velocity. Thus a wind energy driven irrigation system with an energy store, here a water tank, is required.

The combination of a wind-electric system with an irrigation system for watering fruit trees could open up vast regions of land so far untapped due to the lacking availability of electricity. It is necessary to choose an irrigation system which is reliable and can be operated with the energy source available. This paper describes the selection, simulation and laboratory testing of a water- and energy saving irrigation technique for small orchard farms which is suitable for wind energy use. Information on the energy, technical, power and operational characteristics of the mobile wind energy converter (MoWEC) has been presented by IRPS and OMARA (2003).

This paper is part of Mr. Omara's graduate work at the Department of Agricultural Engineering at the University of Rostock, Germany, in cooperation with the Federal Agricultural Research Center in Braunschweig.

2. Selection of an irrigation technique

Irrigation systems fall into three categories: surface irrigation, micro irrigation and sprinkler irrigation, see Figure 1.

Every irrigation system requires a special energy supply. We chose a water and energy saving irrigation technique suitable for a MoWEC application on small orchard farms. According to the comparison of the irrigation methods and the characteristic data, the micro irrigation technique is suitable for wind energy or photovoltaic application for sparsely planted crops, like orchards or vineyards. Any other irrigation methods (sprinkling) either require too-high operating pressures or are unsuitable for small farms because of the size of the machines or the output per unit area. Also, the surface irrigation has lower application efficiency and it cannot function automatically.

Micro irrigation is the broad classification for frequent, low volume, low-pressure application of water on or beneath the soil surface by drippers, drip emitters, spaghetti

tubes, subsurface or surface drip tubes, low-head bubblers, and spray or mini sprinkler systems.

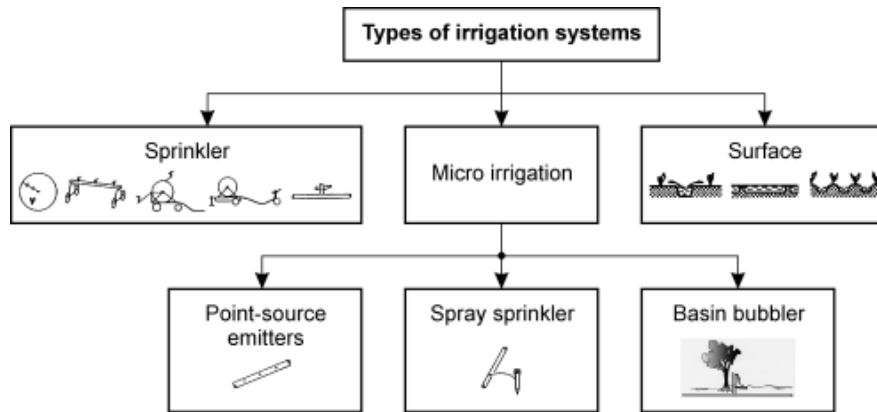


Figure 1:
Irrigation systems (after SOURELL, 1998)

Low-head bubbler irrigation enables the economical use of water, and its low operating pressure makes it particularly well-suited for combination with alternative energy such as wind energy water pumping systems. This irrigation system is particularly well-suited for orchard crops and requires very low-pressure heads to distribute irrigation water to the trees. It is based on gravity flow and has large orifice opening to deliver water directly to the root zone, thus eliminating the elaborate filtration systems and pumps required by other micro irrigation systems. Despite these advantages, bubbler systems have not been widely used.

If the total orchard field area is approximately 10 ha, the field is divided into four large plots; each plot with an area of 100 x 250 m. The water storage tank is constructed individually for the center of each plot. In a wind-energy water storage tank systems, water is pumped year-round into a storage tank with an electric or mechanical wind-powered water pumping system. The tank and the wind plant are sized so that the crop's water needs are met throughout the year. The water level in the tank might not be constant at all operation times, and in this case it a constant head device must be used to obtain the manifold constant design pressure head at all operation times. Figure 2 displays the layout of the orchard low-head bubbler irrigation system.

3. Hydraulic basis of low-head bubbler irrigation system

Hydraulic analysis of low-head bubbler irrigation system, and the analysis and design of low-head bubbler irrigation systems, requires three equations, namely: an energy equation, friction loss and flow rate.

The energy equation is useful to size the pipe diameters of a bubbler system by determining the piezometric heads for the upstream and downstream ends of the bubbler system. The energy equation, or Bernoulli equation, is the primary hydraulic equation used for basin bubbler irrigation system analysis [REYNOLDS (1995)].

$$\frac{P_1}{\gamma} + \frac{V_1^2}{2g} + Z_1 = \frac{P_2}{\gamma} + \frac{V_2^2}{2g} + Z_2 + \sum h_f + \sum h_{mc} \quad (1)$$

where P is pressure within the pipe [N/m²]; V is flow velocity of water in pipes [m/s]; Z is elevation of pipe centreline with respect to a reference datum [m]; h_f is friction head loss in pipes [m]; h_{mc} is minor losses at pipe fittings [m]; γ is specific weight of water [N/m³]; and g is gravitational constant [9.81 m/s²].

Friction loss equation: there are many equations that approximate the friction losses associated with the flow of water through a given section. Using dimensional analysis, the Hazen-Williams equation is most frequently used in the design and analysis of pressure pipe systems. The equation was developed experimentally, and therefore should not be used for fluids other than water [WALSKI (2002)]. The Hazen-Williams equation is:

$$h_f = \frac{1.22 \times 10^{10} L}{D^{4.87}} \left(\frac{Q}{C_{HW}} \right)^{1.852} \quad (2)$$

where h_f is the friction loss along the pipeline [m]; L is the length of pipeline [m]; D is the inside diameter [mm]; Q is the total pipeline flow rate [L/s]; C_{HW} is the Hazen-Williams coefficient.

Flow rate equation: the mass continuity must be applied at each outlet such that: $Q = Q_c + q_{oh}$, where Q is the discharge in the pipe upstream of the distributor hose; Q_c is the discharge continuing downstream in the pipeline; and q_{oh} is the discharge from the distributor hose.

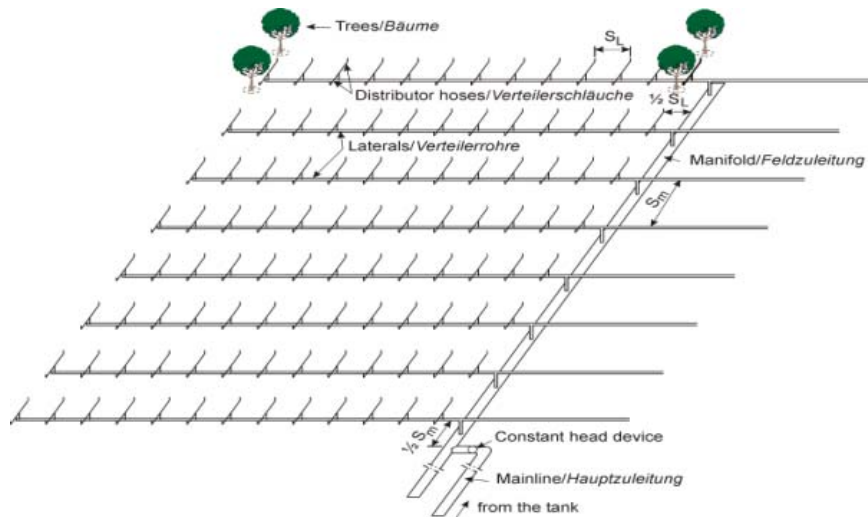


Figure 2:
Layout of the orchard low-head bubbler irrigation system

4. Low-head bubbler irrigation system (LHBIS) model

The computer program LHBIS was written to make low-head bubbler irrigation design simpler and faster than the traditional method of using charts and calculators. It allows a user to determine the distributor hose's outlet elevation or distributor hose's length, and required head at constant head device for a given discharge per tree and field condition. Figure 3 shows the data flow diagram.

5. Laboratory tests

Laboratory experiments were conducted to validate the LHBIS computer program at three lateral slopes (level, uphill and downhill) by measuring the hose's flow rate, the pressure heads upstream and downstream of each hose inlet. Figure 4 shows the irrigation experiments planned to verify the computer program. The lateral diameter and distributor hose diameter were 32 and 6 mm respectively. The distributor hose's spacing and length were 4 and 2.5 m respectively, and the number of the distributor hoses per lateral side was 13. The experimental work was conducted in the irrigation laboratory at Institute for Production Engineering and Building Research, Federal Agricultural Research Centre (FAL), Braunschweig, Germany.

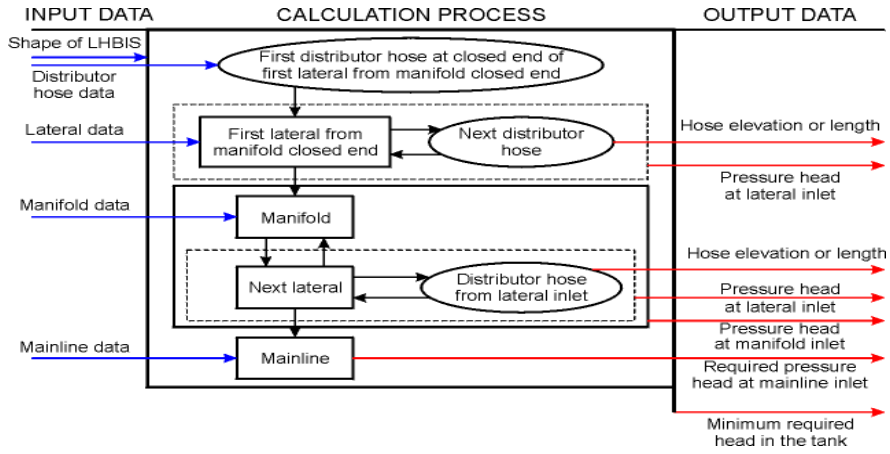


Figure 3:
Data flow diagram of the computer program

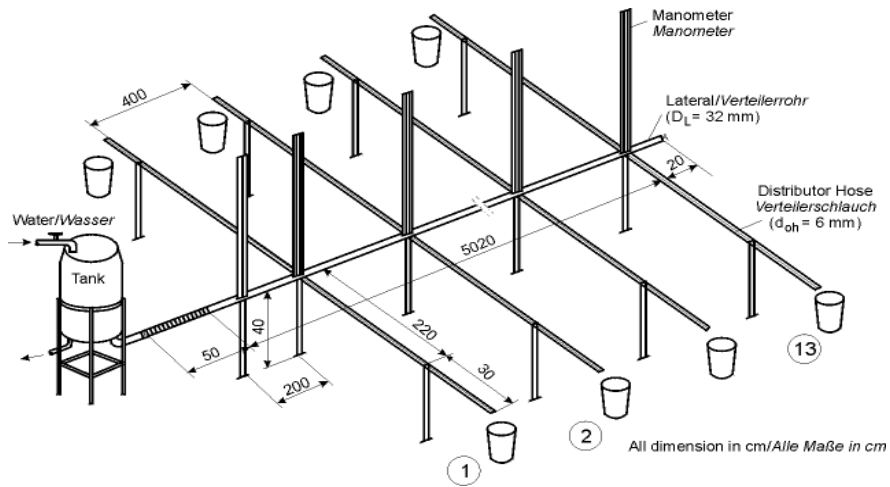


Figure 4:
Irrigation experiments planned to verify the computer program

6. Result and discussion

The distributor hose's elevation (or length) and required pressure head at lateral inlet were calculated with the computer program. This data was applied in a laboratory experimental system with three lateral slopes and three hoses' discharge in two trials. First, with the laterals located in two manifold sides, and secondly, with the laterals located only in one manifold side.

Figure 5 shows the mean measuring and theoretical distributor hose's outflow along one lateral with different distributor hose outlet elevations. Figure 6 shows the measured pressure head just before the distributor hose's and calculated distributor hose's outlet elevation along one lateral, with both figures based on one lateral, with the laterals on both manifold sides, the with distributor hoses on two lateral sides. Hazen-William coefficients of the lateral and distributor hoses were 140 and 115 respectively, the longitudinal slope of the lateral pipeline was 0.0%, + 0.5% or - 0.5% and the distributor hose's theoretical discharge was 60 L/h.

The distributor hose's emission uniformity and flow variation were calculated from the laboratory experimental data in two cases: low-head bubbler irrigation system with different distributor hose elevations or with different distributor hose lengths along one lateral. The emission uniformity values were higher than 97% at all distributor hoses discharges. On the other hand, the flow variation values were 5% to 7%. KELLER (1974) recommended that EU values of 94% or more are desirable, and in no case should the designed EU be below 90%.

The results of running the computer program and of laboratory experiments on low-head bubbler irrigation systems with different distributor hose outlet elevations or with different distributor hose lengths, allow us to recommend the use of irrigation systems with different distributor hose outlet elevations. These are more practical than a system using different hose lengths for irrigating tree crops, especially orchards.

The computer program was used to investigate certain factors influencing the distributor hose's elevation along the laterals and the required pressure head at each manifold inlet of the irrigation system. The results of analysis of a large range of bubbler irrigation systems indicate that the minimum distributor hose elevation is achieved with a small lateral downhill slope of - 0.5%. The hose's elevation can be decreased by using moderate hose discharge of 40 to 60 L/h, short laterals with small number of hoses d'' 13 hose per lateral side, large lateral diameter e'' 32 mm, large manifold diameter e'' 75 mm and small number of the lateral d'' 9 lateral per manifold side. The hose's diameter doesn't effect the hose's elevation, but it has a large effect on the required pressure head of the irrigation system. The pressure head achieved increases rapidly as the hose's diameter decreases by < 4 mm. Hoses with a diameter of more than 8 mm have only a small effect on the required pressure head at manifold inlet (REYNOLDS, 1995).

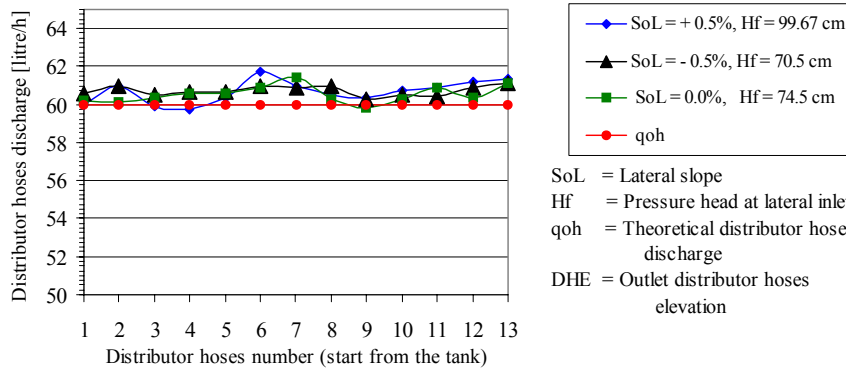


Figure 5:
Mean measuring and theoretical distributor hose outflow along one lateral with different distributor hose outlet elevations

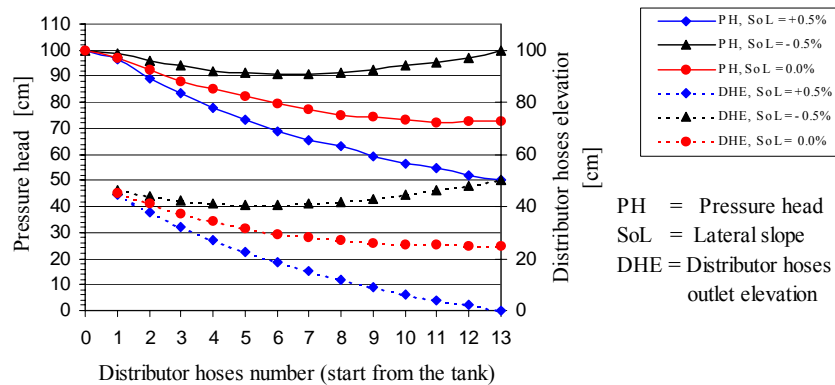


Figure 6:
Measured pressure head just before distributor hoses and calculated distributor hose outlet elevations along one lateral

In the next article (in preparation) we will present the combination of a low-head bubbler irrigation system for watering fruit trees on the northwest coast of Egypt with the mobile wind energy converter (MoWEC) as a renewable energy source.

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