Bachelor Degree Project

UNIVERSITY OF SKÖVDE

RENEWABLE ENERGY WATERPUMP

Bachelor Degree Project in Mechanical Engineering
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Acknowledgement

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Sammanfattning

Målet med det här projektet är att bygga ett tillförlitligt pumpsystem som inte är beroende av elektricitet eller icke förnyelsebara bränslen. Pumpen ska klara att pumpa 50-100 liter per dygn till en höjd av 10 meter. Konstruktionen ska placeras i indianbyn El Vergel i Amazonas, Colombia. Pumpen ska pumpa orent vatten till vattenreningstunnor de månader som invånarna i byn inte har tillgång till regnvatten.

Olika koncept arbetades fram och utvärderades. Det som valdes var en cykeldriven vattenpump, vilken uppfyllde alla krav.

Pumpens axel är kopplad till bakhjulets fälg med en kilrem. När tramporna snurrar så överförs kraften från det främre kugghjulet till det bakre med cykelkedjan och sen med kilremmen från fälgen till pumpaxeln. Konstruktionen är enkel och den är lätt att laga om den går sönder. Resultaten är en tillförlitlig pump som pumpar med ett jämt flöde.

Nyckelord: Vattenpump, cykeldriven, Colombia, Amazonas

Abstract

The aim of this project was to build a reliable pump system that was not dependant on electricity or non renewable fuel. The pump should be able to pump 50-100 litres in 24 hours to a height of 10 meters. The location for this project is set to the Indian village El Vergel in the Amazon Basin, Colombia. The pump is meant to be used for pumping water those months that the inhabitants does not have access to rainwater.

Different system concepts were evaluated. The concept that was finally chosen was the bicycle water pump, which fulfilled all requirements.

The pump shaft is connected to the back wheel rim with a v-belt. While pedalling there will be a transmission between the front and the back gear wheel with the bicycle chain, and between the rim and the pump shaft with the v-belt. It is a simple construction which is easy to repair. The result is a reliable pump that pumps water with a steady flow.

Keywords: Water pump, bicycle water pump, Colombia, Amazon basin

Resumén

El objetivo de este proyecto es construir un sistema de bombeo de agua que sea confiable, que no dependa de electricidad o de combustibles no renovables. El sistema de bombeo debe ser capaz de bombear 50-100 litros en 24 horas a una altura de 10 metros. La ubicación de este proyecto se establece en el pueblo indígena de El Vergel en la cuenca del Amazonas, Colombia. El sistema de bombeo está destinado a ser utilizado durante los meses que los habitantes no tiene acceso al agua de lluvia (época de sequía).

Diferentes conceptos de sistemas se evaluaron; el concepto de que se optó finalmente fue la bomba de agua a pedal (tipo bicicleta), que cumple con todos los requisitos.

El eje de la bomba está conectado a la llanta de la rueda trasera con una correa en "V".   Mientras se pedalea, hay una transmisión entre la parte delantera y la rueda dentada trasera con la cadena de la bicicleta, y entre la llanta y el eje de la bomba con la correa en "V". Es una construcción sencilla, fácil de reparar. El resultado es un sistema de bombeo fiable de que las bombea agua con un flujo constante.

Palabras claves: bomba de agua, bombeo de agua, bomba a pedal, bomba de agua tipo bicicleta, Colombia, cuenca del Amazonas

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1. Introduction

1.1 Background

Colombia is a country rich in natural resources, and it has a diverse climate and nature (Behrens, et al., n.d). But the country has major social differences; the rural areas are poor and undeveloped. Colombia has been highly affected by many internal conflicts between guerrilla, paramilitary groups and the government. These are caused by the cocaine trade (SIDA, 2009).

The Amazon River runs from the Andes to the Atlantic Ocean. In Colombia the area around the Amazon River is called the Amazon basin (Forsman, n.d.). The river can be up to 10 km wide (Graf, 2004) and has a fluctuation of 15 meters (Erdtman, 2009). Even though the river does not have a drop in this area the force of the river is strong, and make large trees and objects follow its stream (Erdtman, 2009). The water has a brown colour due to the large amount of sediment parts (Clavijo, 2010).

The small Indian villages in the Amazon area are poor and they make their living by hunting, fishing and tourism. To get drinking water they harvest rain water about nine months of the year. The rest of the year they drink unhygienic and hazardous water that is collected from the river or natural springs. These months stomach complaints like diarrheal diseases increase (Erdtman, 2009).

The villages have access to electrical supply a few hours every day. Due to their isolated location, there can be a blackout for months if something is broken. Some of the villagers also have diesel aggregates but diesel is expensive, non environmental, and not always available to buy in Leticia (Erdtman, 2010).

1.2 Aim

The aim of this project was to build a reliable pump system that was not dependant on electricity or non renewable fuel, such as diesel or gasoline.

1.3 Method

An analysis of different methods to produce electricity to pump water and different types of pumps was made. Concepts of different systems were evaluated; a number of criteria were tested

The chosen system was built and tested:

1. How high the water is pumped;
2. Flow measurements;
3. How long time it takes to pump the minimum required amount of water.

2. Requirement specifications and Delimitations

2.1 Requirement specifications

To reach the goal of this project, the requirements were established together with Börje Erdtman, director of Ankarstiftelsen. The requirement specifications for the pump are:

- To pump the quantity of 50 – 100 l/ 24 h;
- Be able to pump the water 10 m up;
- Inexpensive to run;
- Simple construction that could be copied easily.

2.2 Delimitations

The delimitations for the pump and the project are:

- Pump without electricity or gasoline;
- Not from a drilled well;
- Not knowing anything about the premises of the village where the pump is going to be placed.

3. Purpose

The purpose of this project is to implement a simple, inexpensive to run, reliable way to pump water to water cleaning barrels. By doing so, there will always be access to pure drinking water. There should also be a possibility for the inhabitants to easily copy the construction.

4. Project area

The Amazon Basin has a tropical climate with high humidity. The forest recedes with 1-2 % every year; there is small, if not no, chances for re-growth. The result is reduced evaporation and the precipitation reduces. This changes the area and is an environmental threat (Hubendick, n.d.). The closest town, Leticia, has a precipitation of approximately 3253 mm a year and the average temperature is 25° C (Weatherbase, n.d.).

The area is low populated and the inhabitants often live in small villages of 50-200 persons. The houses are traditionally built in bamboo or wood with palm leaf roofs. Nowadays, most houses are built of wood and have tin roofs.

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Figure 4.1 Map of South America

El Vergel is a small village in the Amazon area with 232 inhabitants. The inhabitants are Ticuna Indians. They make their living from fishing, handcrafting, and tourism. The local school have about 80 pupils, and they get their drinking water from collecting rainwater 9-10 months a year. The remaining months, water is fetched from a small natural spring (Martinez, 2010), see figure 4.2.

The spring is reconstructed with a roof to avoid contamination from animal faeces and surface water. The water is pumped from the spring to a simple water purification barrel. The pure water is then safe to consume.

Figure 4.2 Left; Natural spring in El Vergel Right; Reconstructed

5. Different concepts

Different concepts were evaluated before a solution was chosen. The different alternatives were:

- Sun panels;
- Water turbine;
- Water wheel;

- Wind pump;
- Underwater turbine;
- Ball-string pump;
- Bicycle water pump;
- Ram pump;
- Loop pump.

The sun-panel system was rejected because it did not fulfil the project requirements. It is not a reliable system to put in the rainforest where the sun can be absent for days (Erdtman, 2009). It is expensive and may not be easy to repair if it is broken.

The Amazon River does not have a large variety in height, there are no falls and the height difference between the source and the outflow into the Atlantic Ocean is only 65 meters (Forsman, n.d.). Therefore it is not possible to have water turbines or a Ram pump without making a dam because they both need a drop of about 2-3 meters to work properly (Lundgren, 2009).

When it comes to the water wheel construction, it is set to the water surface. Not knowing how the area looks like, but knowing that the river often brings large objects; this project needs a pre-study. It would also be a larger and more expensive project.

An alternative that came to mind was wind power. This was eliminated for the lack of wind in the Amazon (Erdtman, 2009).

For the under-water-turbine construction information about the village and the river is required in an early stage of the project to attain a good result. Such information was not available (Lalander, 2009).

The Ball string-pump is not able to lift the water more than 2-3 meters. The requirements are 10 meters so this was not a possibility.

An interesting alternative was the Loop pump which is sold by the Swedish company ACCIO AB. The pump uses the force from the flowing water in the river to pump it up (Accio, 2010). The problem with the pump is that sediment clogs it and it needs to be cleaned with high pressure air (Lundgren, 2009). The small villages do not have that kind of equipment (Erdtman, 2009).

The concept that was chosen was the bicycle water pump which fulfilled all the requirements.

6. Bicycle water pump

6.1 Construction

A small pump is connected to a larger shaft that is stabilised with two ball bearings. At the end of the shaft a pulley is placed.

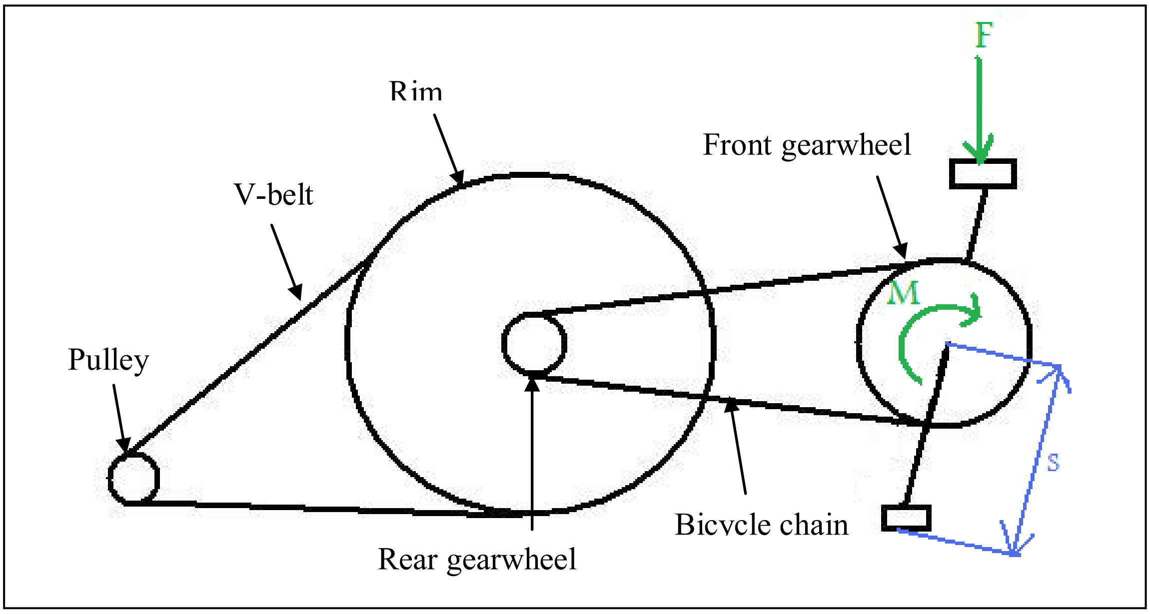

Figure 6.1 Power transmission

The power is transmitted from the pedals to the rear gearwheel with the bicycle chain. From the rim to the pulley the power is transmitted with a v-belt, see figure 6.1. The friction between the rim and the v-belt is important for the v-belt to work and drag the pulley around.

It is important to have the right tension in the v-belt and therefore the bicycle and the pump need to be mounted with the right distance to each other. The elongated pumpshaft and the v-belt need to be perpendicular, it is also important that the two ball bearings are mounted on a straight line. If not, the v-belt is going to pull to one of the sides of the pulley, and the required friction is not received. A v-belt is constructed to have even friction on both sides to work properly. The shaft cannot rotate if the ball bearings are not mounted on straight line, as can be seen in figure 6.2.

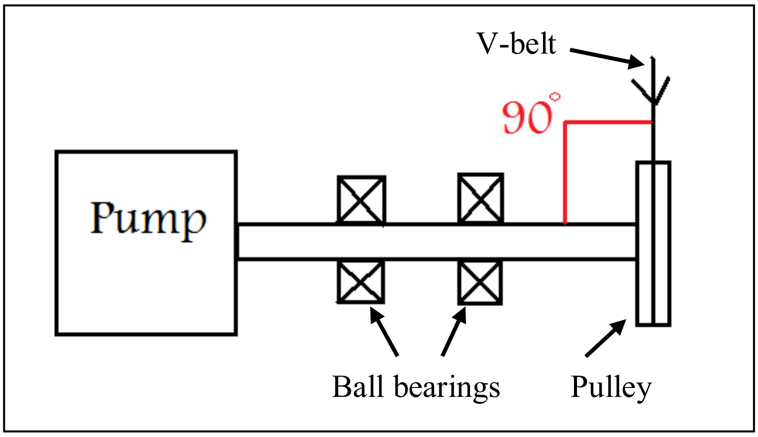

Figure 6.2 Relation between the shaft and the v-belt

6.2 Pump

The pump used is a self priming side channel pump which originally was intended to be connected to an electrical drill. The pump material is bronze and stainless steel, AISI 304. The quantity and the height that the pump can manage is depending on the rotational speed (rpm), as can be seen in table 6.1 and 6.2 (Tellarini, 2006).

Table 6.1 Pump height at 1900 rpm

1900 rpm (*Hmax*=13 m)			
H (m)	1	5	10
Q (l/min)	17	11	4

Table 6.2 Pump height at 2900 rpm

2900 rpm (*Hmax*=28 m)			
H (m)	1	10	20
Q (l/min)	32	21	9

6.3 Pre-calculations

Calculations were made to make sure that the bicycle pump works in theory. All equations are taken from *Thermal fluid science* (Cengel et.al. 2008). The pump connections are 3/4" in size, and the height is set to 10 meters. To spare time, pumping the minimum quantity should not exceed 10 minutes; therefore the mass flow is 5 kg/min. The relation between the mass flow, m', and the average velocity, v_a, of the water is calculated in equation 1.

$$v_a = \frac{m\prime}{\rho A} \qquad (1)$$

With the mass flow m'=5 kg/min and the ¾" tubes area $A = 2.85 \times 10^{-6}\ m^2$, the average velocity of the water in the tube is 0.3 m/s.

Reynolds number decides if the flow is turbulent or laminar and this effect further calculations.

$$Re = \frac{\rho v_a D}{\mu} \qquad (2)$$

With the assumption that the water has a temperature of 20°C, the density ρ= 1000 kg/m³ and dynamic viscosity $\mu = 1.002 \times 10^{-3}\ kg/(m \times s^2)$. With the average velocity from equation 1 and the diameter *D*= 3/4" = 1.905 cm the value of Reynolds number Re= 5703.6. This is a value between turbulent and laminar flow.

The friction f in the hose is depending on Reynolds number, the material, ε, and its diameter, *D*, as can be seen in equation (3). The friction is important to know to calculate the head loss, *h*, in the system.

$$\frac{1}{\sqrt{f}} = -1.8 \log\left(\frac{6.9}{Re} + \frac{\left(\varepsilon/_D\right)^{1,11}}{3.6}\right) \qquad (3)$$

From equation (3) we get the friction value to 0.0362, using Reynolds number from equation (2) and emissivity $\varepsilon = 0$ due to plastic in the hose.

In reality there is always losses in a system, these are calculated with equation (4).

$$h_L = \frac{v_a^2}{2g}\left(f\frac{L}{D} + \sum K_L\right) \qquad (4)$$

When *L*=40 m is the length and K_L=5.05 is the loss coefficient the head loss is 0.37 m. The values of K_L is picked from *Fundamentals of Thermal-fluid Science*, Cengel, et al. (2008) and is calculated on two sharp intakes, two sharp outlets and one ball valve.

The effect, $\Delta E'$, that is required to move the water can be calculated with equation (5), it is a relation between the mass flow and how high the water needs to be pumped.

$$\Delta E'_{mek.fluid} = m'\left(\frac{P_2 - P_1}{2} + \frac{v_2^2 - v_1^2}{2} + g(h + h_L)\right) \qquad (5)$$

The surface pressure $P_1 = P_2$ and the water velocity $v_1 = v_2$ eliminate their self. The gravity g = 9.81 m/s², the mass flow m' = 5kg/min, the height between the surfaces h =10 m, and the head loss in the system $h_L = 0.37\ m$ gives the result of 8.5 W. The effect $\Delta E'_{mek.fluid}$ that is needed to move the water is therefore the same that the effect from the pump, W'_{shaft}, if there is no losses in the construction. The pump effect is in relation with the moment that needs to be applied. Assuming that there will be no loss in the construction the same moment that will be needed at the pump shaft should be applied to the pedals. The relation between the moment, pump effect, and the rotational speed on the front gearwheel can be seen in equation (6).

$$M = \frac{W'_{shaft} 60}{2\pi n'} \qquad (6)$$

When the effect $W'_{shaft} = 8.5\ W$ and the rotational speed n'= 60 rpm, the moment M is 1.35 Nm. The value of the n' is an assumption of which speed that could easily be pedalled.

The moment on the front gearwheel depends on the distance between the pedal and the centre of the gearwheel as well as the force that is applied to the pedal. In equation (7) is this relation showed, the placement on the construction can also be seen in figure 6.1.

$$M_{max} = Fs \qquad (7)$$

With the moment from equation (6) and the presumption that the distance between the pedal and the centre of the front gear wheel is about 0.2 m the force F=6.75 N is obtained. With losses in the construction a safety factor of three was chosen, and the final result for the force that needs to be applied is 19.5 N. This equals approximately a weight of two kilograms to the pedals which is practicable force to pedal with.

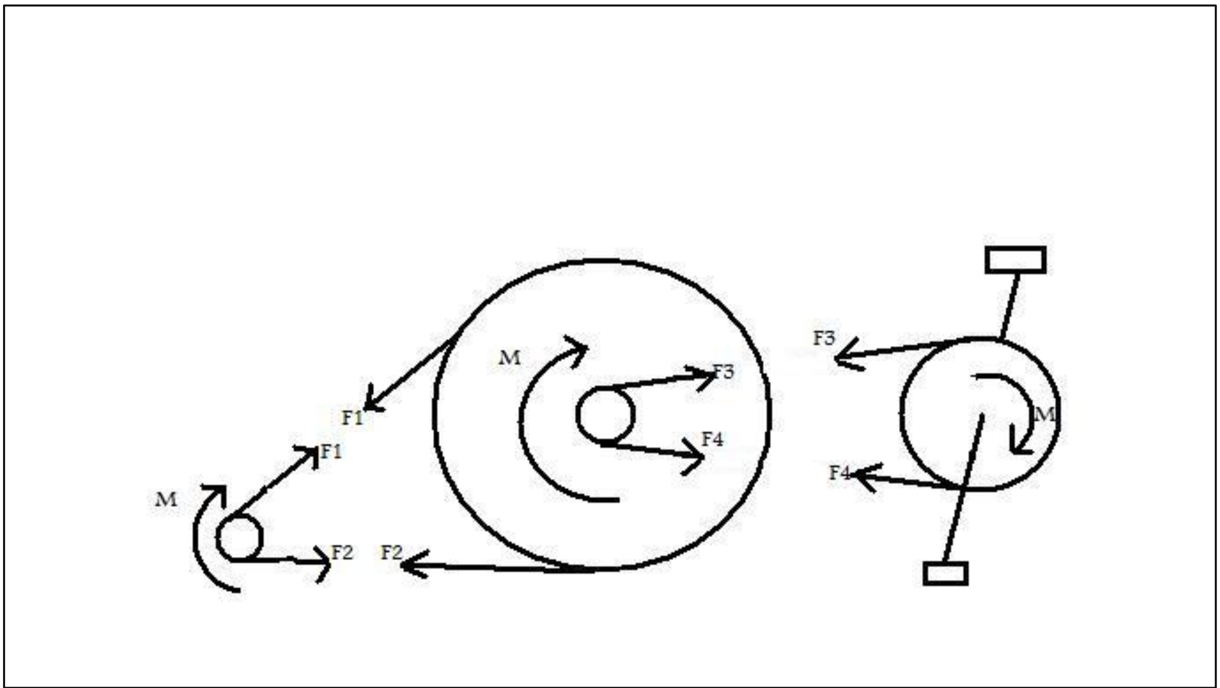

Figure 6.3 Forces and moments in the construction

The ideal outcome would be to have 100 percent friction between the v-belt and the rim. If the rpm is somewhere in the middle of the two curves in diagram 6.1; there will be a satisfying flow (5 l/min) and the required height will be reached. The curves in diagram 6.1 visualise table 6.1 and 6.2 that is from the pump specification folder (Tellarini 2006). If the relation between the front and the back gearwheel is 2:1 and the rim and the pulley is 20:1; the relation between the front gearwheel and the pulley is 40:1, and the pump shaft is rotating with 2400 rpm if pedalling with 60 rpm.

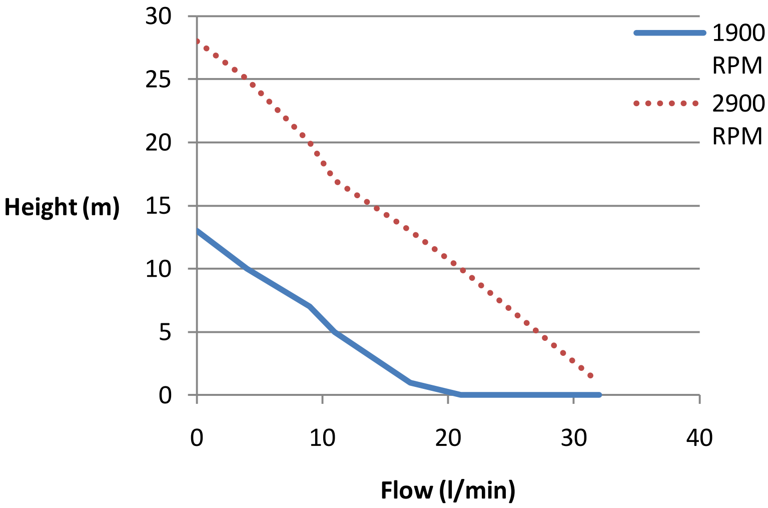

Diagram 6.1 Pump height with different rpm

7. The bicycle pump in reality

7.1 Calculations

In reality the relation between the front and back gear wheel is 2.4:1 and the relation between the rim and the pulley is 11.5:1, which gives the relation between the front gearwheel and the pulley 27.6:1. For the pump shaft to rotate at 2400 rpm it is necessary to pedal at 87 rpm if there is a hundred percent friction. This is not possible and therefore 2400 rpm would not be reached.

7.2 Problems with the construction

The rim of the bicycle used is made of aluminium and has a rectangular cross section. This leads to absence of friction between the rim and the v-belt. To get needed friction, part of an inner tube was glued to the rim and by so, higher friction was received.

Figure 6.2 The rim with the glued inner tube

The construction was fixed to a simple wooden deck to get the right distance between the rim and the pump shaft. If the v-belt starts to slack the distance can easily be changed with the bicycle supports. The supports have oval holes which make it possible to adjust continuously without taking the whole construction apart (see Appendix 2 for drawings of the supports).

A problem that was detected was that if the shaft and the ball bearings are not perpendicular to the v-belt and the bicycle; it is not manageable to pump the water.

7.3 Experiments/tests

When the construction was mounted simple tests were performed. The water was pumped 5,5 meters up and the time to pump 2 litres were measured. The ideal rpm somewhere in the middle between 1900 rpm and 2900 rpm was not reached; during test 1 a flow of 6 l/min was received as can be seen in table 7.1. This is visualised as the green line in diagram 7.1. The curve is created from the point (5.5; 6) with the same slope as the original curves. The rpm is under 1900 because of low friction between the rim and the V-belt.

Table 7.1 Test result for the flow

Test	Height (m)	Flow (l/min)	Minimum quantity (min)	Maximum quantity (min)
1	5.5	6	8.3	16.7
2	5.5	12	4.15	8.35

To increase the friction one more layer of rubber was glued to the rim. This gave a result of 12 l/min in test two, as can be seen as the purple line in diagram 7.1. The required rpm over 1900 was reached.

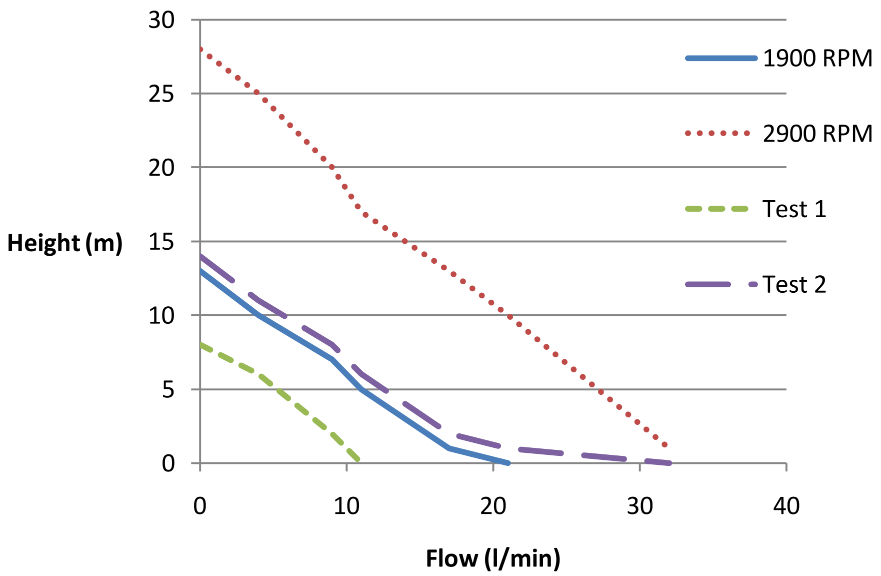

Diagram 7.1 Test results

8. Budget

The pre-calculated cost for one bicycle water pump station was 2815 SEK or 402 USD. (1 USD= 7 SEK) (1000 COP= 4SEK) The actual cost for one station became 3271 SEK or 467,2 USD. One reason for the miscalculation could be that the plan was to buy a second hand bicycle and there was no possibility to do that in Leticia. If all the work like cutting the boards and the drilling is done by oneself instead of in a workshop, the cost of the wooden deck and screw post will decrease.

Table 8.1 Budget for the pump station

	SEK	USD	COP
Pump	380	54,3	95 000
2 Ball bearings	200	28,6	50 000
Shaft and pulley	250	35,7	62 500
V-belt + 1 extra	250	35,7	62 500
Bicycle	850	121,4	212 500
Supports	600	85,7	150 000
Hose	500	71,4	125 000
Wooden deck and screws	241	34,4	60100
Total	3271	467,2	817600

It is hard to calculate a pay-back time. This is because the original purpose of the project was to supply one household with the pump. As it turned out; the whole school could benefit from it. Because it is only a backup system, it is hard to calculate how much money the village earns from it. The noticeable change would be in health, as they have access to pure water all the time of the year.

9. Risk analysis

The major risk in this project is the attitude of the villagers. They are used to donations and development projects carried out by the state and NGO:s. Many projects have failed and many of the villagers seem to be impassive. Around the time for elections, the government and politicians donate supplies to the villagers, sometimes they get double sets of material they do not need. No one ever asks them what they really need (Martinez, 2010).

The construction of the bicycle water pump is easy to repair if it is broken and no special tools are needed. All components are cheap to replace if broken. The risk is that they would not make an effort because of their impassiveness.

10. Result

The result is a simple and reliable pump system that pumps water with a steady flow in El Vergel, the height between the water surfaces in the spring and in the tank is about 6-7 meters. When the pump station was installed tests were performed. The flow received was 15 l/min. Pumping 50 litres would take 3 minutes and 20 seconds, as can be seen in diagram 10.1. All the requirements are fulfilled and the aim of the project is reached.

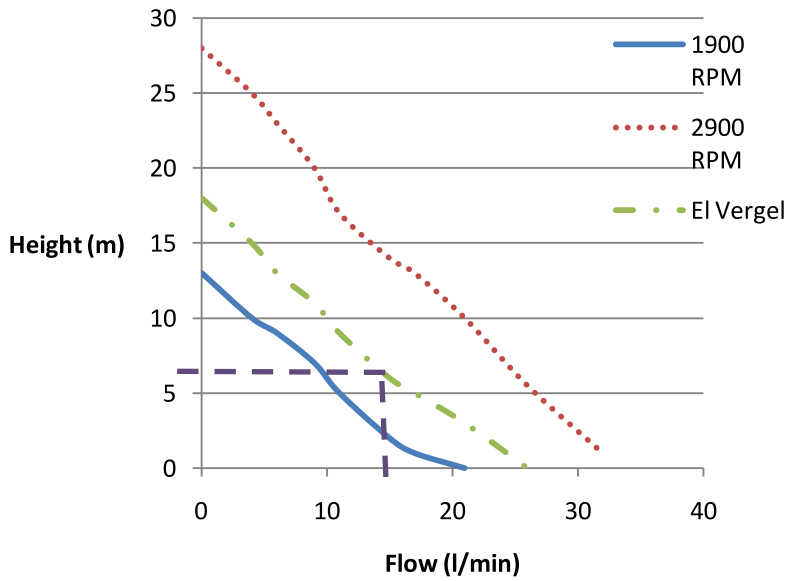

Diagram 10.1 Results from El Vergel.

11. Discussion

There have not been any major problems, only some small unexpected difficulties. While setting the budget the plan was to find a cheap bicycle, but in reality this was not possible. In Leticia there is no market for second hand bicycles, because the inhabitants of Leticia use motorcycles for transportation.

The pump, the V-belt, the shaft, and the ball bearings were bought in Sweden because of the insecurity in finding the proper sizes and the right components in the area. In Leticia it is sometimes hard to find the right components because of the city's location; supplies are brought in either by air or by boat on the river.

During the planning of the project the information available stated that there was no electricity in the villages. This information turned out to be incorrect. If the information about the electricity had been discovered earlier in the project a different solution or a different location may have been chosen. An electrical pump is faster and more convenient than a manual one, and would therefore be preferable.

If there is an absence of electricity, the bicycle pump could be used as a backup system; fresh water can be received and the children can stay healthy. The pump is easy to move because it is mounted on a wooden deck. If the pump is placed by the river, the whole construction can easily be lifted when the water is rising.

The inhabitants of El Vergel tested the pump and were pleased with its results before it was properly placed. After the spring was reconstructed and the pump was placed, the pupils of the school were eager to test the pump. They thought it was interesting to see how they with their own strength were able to pump water.

To avoid the problem with the friction between the v-belt and the rim; a different construction could be considered. If the rim was replaced with a big gearwheel and connected with a chain to a gearwheel at the pump shaft, there would be much lower loss due to friction. The problem is to find that size of gearwheel for a low cost.

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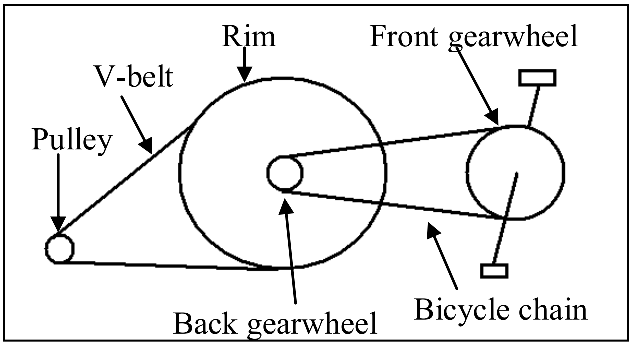
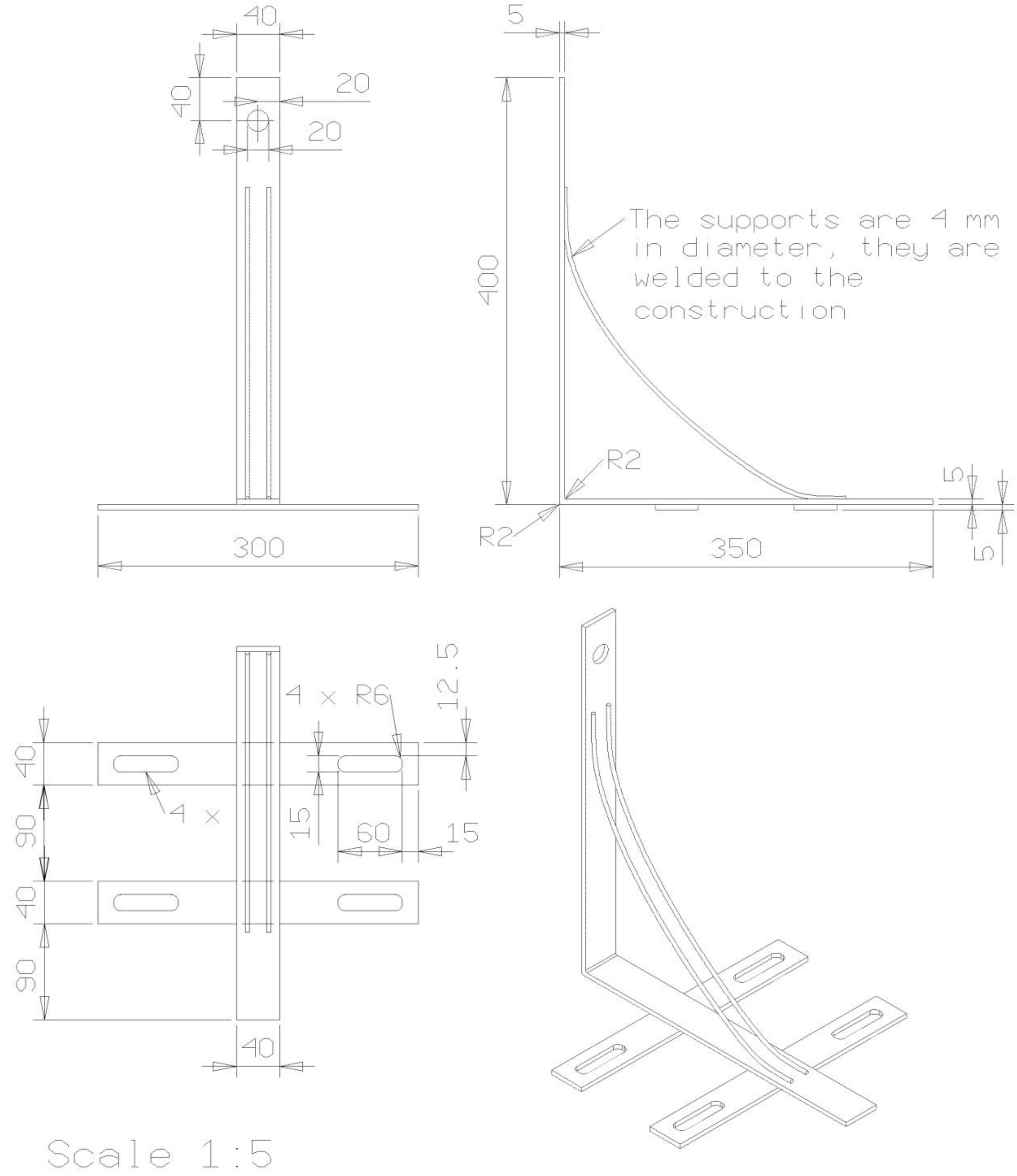
How to build a bicycle pump

1. Remove the bicycle's front wheel.
2. Remove the inner tube and the tire from the back wheel.
3. If necessary; glue material to the back wheel's rim to attain higher friction (Recommended: an inner tube of rubber).
4. Connect a large shaft to the pump (Recommended: Self priming pump TR14/TR from Tellarini & C or similar).
5. Stabilise the shaft with two ball bearings.
6. Connect the pulley to the outer end of the shaft.
7. Connect the pulley and the rim with a v-belt.
8. Arise the back end and stabilise the bicycle with iron supports (For example see Appendix 2).
9. Mount on a wooden deck to get the right distance between the bicycle and the pump; the v-belt will then have the right tension.
10. It is very important that the shaft and the rim are perpendicular to each other.
11. To get the right RPM at the pump shaft the exchange between the front gearwheel and the shaft should be at least 1:25 (If using the recommended pump).
12. Connect a hose to the pump.
13. Start pedalling (with 60-80 RPM) and the pump will pump the water.



Drawing of the supports



Pictures of the pump