

A small propeller turbine to supply drinkable water to the small town of Kahemba (RDC)

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Introduction

The paper describes the hydro project implemented at the small town of Kahemba in Congo RD in order to supply it with a remarkable amount of drinkable water (346 m³/day) pumped from a spring located 10 km far from it and 120 m under the average level of the town.

The scarcity of drinkable water in the town is one of the causes of the remarkable incidence of the *konzo* on the population, a severe pathology caused by the cyanide contained in the manioc roots eaten without a proper treatment, which requires water.

The hearth of the project is a simple mechanical unit, made by a propeller turbine directly coupled with a 5 stages centrifugal pump, exploiting the hydro potential of the small Kayoke stream running near the spring.

Despite the relevant construction cost of the installation - comprehensive of 25 km of pipelines for the water distribution in the town, 44 twin fountains and 145 m³ stored in 2 overhead reservoirs – the managing costs are low, thanks to energy supplied for free by the stream. Thus the fees for the water service can be cheap (from 3.3 to 6.6 \$/month every family) and affordable even for the poorest fraction of the inhabitants.

The project was a part of a bigger one financed by the European Union within the Food Security programmes.

The specific project of Kahemba was financed for the main part by the FONDAZIONE RENATO GRANDI of Lugano (CH), and for the remaining ones by I.S.CO. SC of Mestre (IT), and ACRA ONG of Milano (IT).

The designers were:

- Studio Frosio S.r.l. of Brescia: conceptual, hydraulic and construction design;
- TechHydro of Vimercate (IT): design and manufacturing as well of the turbine-pump unit.

The construction, which lasted a bit more than two years, has been carried out by the people of Kahemba with the local supervision of an Italian technician for the most complex activities on site.

Finally, a very satisfying outcome of the project is that last year no new case of *konzo* has been recorded.

1. Background

The project is located in the small town of Kahemba, in the Bandundu province, in Congo DR. Kahemba has a few more than 20.000 inhabitants, many of them having a lot of difficulties in accessing water, because the town is approximately at 1.000 m a.s.l., higher than the surrounding land and therefore far from the water courses; in fact the nearest of them is ~9 km far from it and anyway its water is not drinkable.

The best available water is that of Shamusenge source, realised by the NGO ACF, located ~10 km far from the centre of the town and 120 m lower.

In the past years, in order to solve this problem, both the Government and international NGOs carried out many drillings, down to more than 100 m underground, with unsuccessful results. In fact the best working well was able to provide a very small discharge and it was subject to frequent silting problems.



Fig. 1 - Map of Congo RD with the Kahemba town.

Moreover the pump had been repaired many times due to electrical and mechanical problems.

When we arrived there were 5 fountains, connected to a overhead metallic reservoir, with a 20 m³ capacity; it should have been supplied by the last realised well, but it was out of order due to pump problems.

Definitively the water needed to survive was mainly represented by rainfalls, collected in any possible way, supplemented by the water from the aforesaid river 9 km far from town and, for the wealthiest, by the underground water from Shamusenge source, transported in barrels by cross-country vehicles or motorbikes.

In addition to the usual health problems due to the drinkable water scarcity, a typical consequence for Kahemba and other villages in similar conditions is a serious pathology named *konzo*, caused by the accumulation in the brain of cyanide, taken by eating manioc and its derivatives without an appropriate treatment, which would actually require the availability of clean water to wash the tuber after grinding it.

This pathology paralyses the body, starting from the legs, and it mainly strikes the poorest people, who don't have any possibility to vary their diet and neither have the time nor the water needed to wash away from the manioc its natural content of cyanide.

Taking into account the considerable number of inhabitants and the difficulties to realise and manage deep wells capable of supplying a sufficient quantity of water, we considered the idea of pumping water from the source to the town, creating also a reservoir for night time accumulation and a capillary distribution grid to facilitate the water uses in every quarter of the city, which is very dispersed in plan.

Before developing the detailed project of the pumping and distribution systems, we checked the eligibility of the source, from a quality and quantity viewpoint, for drinking water supply.

For the first issue, the chemical analysis on a sample of water confirmed its drinkability according to the WHO standards, except for one parameter: its strong acidity (pH 4,2). Actually all the water in this region has this feature, because it seeps through important layers of siliceous sands. Luckily it's not difficult nor expensive to correct this parameter: it's enough to put in the reservoir some loaves of lime, that dissolve themselves correcting the water pH by buffer effect.

The quantity issue has been analysed by regularly measuring for one year the instantaneous flow rate of the source with the volumetric method, which is very accurate.

The following table shows that the source flow rate is remarkably constant and little affected by the seasonal rainfall trends.

Date	Pipe 1			Pipe 2			Pipe 3			Pipe 4			Pipe 5			TOTAL
	Volume [l]	Time [s]	Flow [l/s]	Volume [l]	Time [s]	Flow [l/s]	Volume [l]	Time [s]	Flow [l/s]	Volume [l]	Time [s]	Flow [l/s]	Volume [l]	Time [s]	Flow [l/s]	
04/06/2011	15.0	6.61	2.27	14.5	18.90	0.77	15.5	4.81	3.22	15.0	6.34	2.37	15.0	5.62	2.67	11.3
09/06/2011	15.0	6.75	2.22	15.0	20.20	0.74	16.0	5.08	3.15	15.0	6.30	2.38	15.5	5.98	2.59	11.1
12/06/2011	13.5	6.12	2.21	14.0	18.49	0.76	14.5	4.81	3.01	15.0	6.12	2.45	15.5	5.98	2.59	11.0
18/06/2011	15.0	7.02	2.14	15.0	20.47	0.73	14.0	4.45	3.15	15.0	6.89	2.18	14.0	5.04	2.78	11.0
25/06/2011	14.0	6.16	2.27	14.5	19.48	0.74	15.0	5.04	2.98	15.0	6.30	2.38	14.5	5.44	2.67	11.0
02/07/2011	14.5	6.57	2.21	14.0	19.53	0.72	14.5	4.59	3.16	13.5	6.07	2.22	15.0	5.67	2.65	11.0
09/07/2011	15.0	6.93	2.16	14.5	21.46	0.68	15.5	5.53	2.80	14.5	6.97	2.08	16.5	5.08	3.25	11.0
24/07/2011	15.0	7.47	2.01	12.0	17.37	0.69	14.5	5.26	2.76	13.0	6.16	2.11	16.0	4.95	3.23	10.8
30/07/2011	14.0	6.93	2.02	13.0	18.55	0.70	15.5	5.62	2.76	15.0	7.24	2.07	16.0	4.63	3.46	11.0
07/08/2011	12.5	6.01	2.08	12.5	18.58	0.67	12.5	4.45	2.81	10.5	5.16	2.03	12.5	4.76	2.63	10.2
15/08/2011	13.5	6.58	2.05	14.0	22.09	0.63	14.0	5.17	2.71	13.5	6.79	1.99	14.0	4.99	2.81	10.2
22/08/2011	13.5	7.02	1.92	13.5	21.95	0.62	14.0	5.26	2.66	13.0	6.66	1.95	14.0	4.63	3.02	10.2
29/08/2011	12.5	6.75	1.85	13.5	21.73	0.62	13.0	4.95	2.63	12.0	6.07	1.98	13.5	4.36	3.10	10.2

Fig. 2 - Flow rate measured at the spring.



2. Options for supplying energy to the pump

Once ascertained that the water from Shamusenge source was eligible from the quality and quantity viewpoint, we faced the problem of deciding which was the most appropriate energy source for the pump.

Typically the options can be grouped in three categories:

1. connection to the national electric grid
2. gen-set
3. renewable energy sources (RES)

The analysis of this option and the choice of the most suitable one is described in the following paragraphs.

2.1 National grid

The nearest village connected to the national electric grid is 200 km far from Kahemba and, anyway, the pumping cost in this option would have been too high for the actual spending capacity of most inhabitants. Therefore it was immediately evident that this was not a viable energy supply option.

2.2 Gen-set

The operating cost was the main source of concern for the gen-set option. It must be kept in mind that bringing fuel to Kahemba is very expensive, its cost being more than twice the price in Kinshasa; its transport further worsens the environmental impact of this solution, because for every litre of fuel burned in the engine one must also take into account the necessary quantity to bring it into town, with a 850 km trip from Kinshasa, 350 km being on tracks hardly practicable by small trucks.

2.3 RES

Among the different Renewable Energy Sources, the available ones identified in this case were solar and hydraulic energy.

2.3.1 PV option

Photovoltaic is the “zero option” of the RES ... because the sun is normally found everywhere.

In our specific case, actually, the obliged place of installation of the pumping system was in a recessed position among the surrounding hills and also bordered by high trees which limited the insulation hours.

Moreover we considered that the availability of a energy source for a limited number of hours per day/year would imply the necessity to store it as electrochemical potential (by means of batteries) or as a water reserve in a big reservoir in town.

A first evaluation, carried out by optimising the two aforesaid storage systems, gave very high costs, due to both the electrochemical batteries and even more to the hydraulic structures (pump, pipes, storage reservoirs at the source and in town) which should have been designed to supply the town in just 8 hours, with the water available at the source in 24 hours.

The analysis of the related costs and the presence of a favourable mini-hydro option cause the rejection of the PV option as a RES for pumping.

2.3.2 Mini-hydro option

The option of using a mini-hydro systems derives from the presence, near the aforesaid Shamusenge source, of the Kayoke stream where, approximately 3 km upstream of the source, there was an old intake with its hydraulic wheel which used to operate a volumetric pump for supplying a small discharge to a nearby Catholic mission.



Fig. 3 - Existing intake structure on the Kayoke torrent.

Meanwhile the mission was abandoned, but the intake works remained in a good conservation state.

Unluckily the geodetic head available from the intake to the source was very small (approximately 17 m) compared to the distance of 3 km. Though it was evident that a penstock would be expensive, it was an attractive chance to have a RES with a suitable power, available all day and for every day of the year, with low operating costs.

Therefore we decided to study more in detail the actual feasibility of this option, in terms of costs and performances. For this purpose a topographic survey was carried out, to check the actual geodetic head and consequently the dimensions and costs of the penstock.

As to the available flow rates for the plant, they were measured for long enough, including the dry season. The measurements were very straightforward to carry out, thanks to the presence of the intake, which represented a broad-crested spillway, allowing us to easily compute the instantaneous flow rate by simple level measurements.

The following table shows that the flow rate never goes under 90 l/s during the year.



ID	Date	R [cm]	H [cm]	h [cm]	Q [l/s]
1	24/03/2011	-	-	11,0	136
2	01/06/2011	-	40,0	9,7	111
3	03/06/2011	-	40,5	9,2	103
4	06/06/2011	119,8	41,0	8,6	95
5	09/06/2011	120,1	40,7	8,9	99
6	12/06/2011	119,6	41,2	8,4	91
7	18/06/2011	119,6	41,2	8,4	91
8	25/06/2011	119,6	41,2	8,4	91
9	02/07/2011	119,6	41,2	8,4	91
10	09/07/2011	119,6	41,2	8,4	91
11	24/07/2011	120,0	40,8	8,8	98
12	02/08/2011	216,5	40,8	8,8	98
13	07/08/2011	216,5	40,8	8,8	98
14	15/08/2011	216,4	40,9	8,7	96
15	22/08/2011	216,8	40,5	9,2	103
16	29/08/2011	218,3	39,0	10,7	129

Fig. 4 - Torrent flow rate measures.

3. Hydro project description

After the topographic survey and the flow rate measurements, the mini-hydro power plant was designed as follows.

3.1 Plant layout

3.1.1 Intake structures

The existing intake structures have been modified to realise the penstock inlet under an appropriate water height, In this occasion the spillways' length has been nearly doubled to increase safety in case of intense rainfalls.



Fig. 5 - Intake structures rehabilitated and upgraded.

3.1.2 Penstock

At first a GRP penstock was considered, but there were problems with the selected supplier, so the PE with nominal pressure PN5 was chosen instead. The total length is approx. 2.880 m. equally divided in three diameters, i.e. DN 500, 450 and 500 mm, in order to reduce the transport cost by nesting them.

The joints are welded and the installation is usually under the ground, except for some particular points, which have anyway been protected to avoid the damages due to insulation.

The design features of the penstock are the following.

- Water level of the spillway crest: 981.50 m a.s.l.
- Level of the turbine axis: 965.80 m a.s.l.
- Total length of the penstock: 2,879.62 m

1st branch:

- Material: PE

- DN: 500 mm
- PN: 5 bar
- Thickness: 15.30 mm
- Internal diameter: 469.40 mm
- Length: 960 m

2st branch:

- Material: PE
- DN: 450 mm
- PN: 5 bar
- Thickness: 13.8 mm
- Internal diameter: 422.40 mm
- Length: 960 m

3rd branch:

- Material: PE
- DN: 400 mm
- PN: 5 bar
- Thickness: 12.3 mm
- Internal diameter: 375.40 mm
- Length: 959.62 m

3.1.3 Power house

Near the source a small and simple masonry shelter was built to protect the pump - turbine group. Since there are no electric cubicles, the building has very small dimensions.

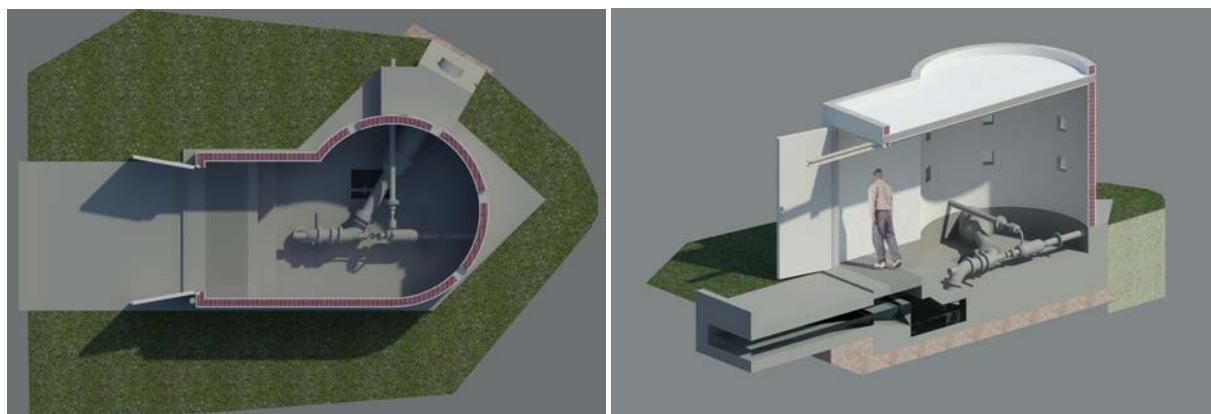


Fig. 6 - Plan and section of the power house.

3.1.4 Tailrace

The proximity of the power house to the stream has allowed for the realisation of a tailrace just about 10 m long, dug in the ground with no lining.

3.1.5 Supply of the aqueduct

Also in this case different diameters were used for the PN 10 PE pipes to optimise the transports. Furthermore the first 590 m, characterised by a high pressure, are made of galvanised steel with a special mechanical joint which avoids welding on site.

The main features are the following.

- Length of the steel pipes DN 100 (thickness = 3.6 mm) 590 m
- Length of the PE pipes DN 110: 3,000 m
- Length of the PE pipes DN 125: 60 m
- Length of the PE pipes DN 140: 6,000 m
- Total length: 9,650 m
- Rated flow: 4 l/s
- Level of the pump axis: 965.80 m a. s. l.
- Level at the water tank inlet: 1,078.70 m a. s. l.
- Gross head: 112.90 m

Directly on the aqueduct 3 fountains (6 taps) were inserted to supply the hamlets of Shamusenge and Muloshi and the *chefferie* (traditional chief's house).

3.1.6 Distribution in town

The pipes for supplying the town with the water pumped from the source start from two reservoirs. The lower part of the town is supplied by the 5 fountains (10 taps) connected to the old 20 m³ reservoir, while the remaining part is supplied by the 44 fountains (88 taps) connected to the new 125 m³ reservoir built at an higher elevation. The lower reservoir, having a smaller capacity, is gravitationally filled by the spilling of the upper on and it has a overflow to discharge any excess of incoming flow.

In the end the features of the distribution system are the following.

• Number of fountains (each one with 2 taps);	44
• Length of the PE pipes DN 160:	253.66 m
• Length of the PE pipes DN 140:	759.70 m
• Length of the PE pipes DN 120:	1,021.78 m
• Length of the PE pipes DN 100:	2,582.92 m
• Length of the PE pipes DN 90:	3,833.54 m
• Length of the PE pipes DN 75:	5,578.40 m
• Length of the PE pipes DN 50:	7,196.27 m
• New storage reservoir:	125 m ³
• Old rehabilitated storage reservoir:	20 m ³
• Daily distributed water volume:	346 m ³

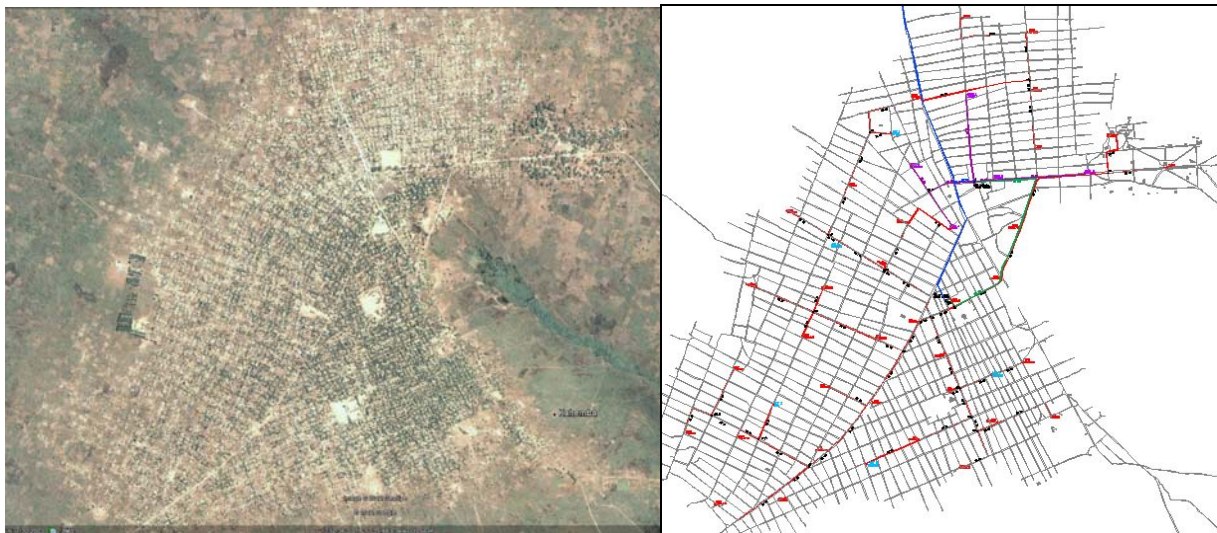


Fig. 7 - Plan view of the town and water distribution pipelines.

3.2 Flow rate

For obvious reasons of plant simplicity, the turbine geometry had to be fixed (propeller) to avoid auxiliary equipments for regulation and control.

Consequently the rated flow of the plant had to be less than the minimum available in the watercourse, which never goes under 90 l/s, as it can be seen in the table of Fig. 4.

Considering a tolerance margin, we established the rated flow of the plant in 85 l/s.

We point out that, a little downstream of the intake, there are many sources which enrich the stream flow with contributions close to or even higher than the 85 l/s diverted by the plant, thus preventing the possible adverse environmental effects of the diversion.

3.3 Head

On the basis of the penstock layout, it's possible to compute the total head losses and the resulting net head.

Branch 1 DN 500

- $\Delta H_1 =$ 0.43 m

Branch 2 DN 450

- $\Delta H_2 =$ 0.73 m

Branch 3 DN 400

- $\Delta H_3 =$ 1.37 m

Total head losses

- $\Delta H_{\text{tot}} =$ 2.53 m

Consequently the gross and net head of the plant are:

- Gross head = 16,50 m
- Net head = 13.97 m

3.4 Project performances

Since the turbine and the pump are joined on the same shaft, the driving power of the turbine is transferred unmodified to the pump. Consequently the free parameter of the system is the pumped discharge, that is the one requiring exactly the same power produced by the turbine.

In the end the performances of the turbine-pump system are the following ones:

Turbine

- Turbine typology: propeller
- Rated flow: 85 l/s
- Water level of the spillway crest: 981.50 m a.s.l.
- Average water level in the tail race: 965.00 m a.s.l.
- Gross head: 16.50 m
- Net head: 13.97 m

Pump

- Level of the pump axis: 965.80 m a.s.l.
- Level at the water tank inlet: 1,078.70 m a.s.l.
- Gross head: 112.90 m
- Rated flow (iteratively computed by trials): 4.0 l/s

With a 4 l/s discharge 24 hours per day it's possible to supply the town with a total water volume of 346 m³.

If water is supplied 14 hours per day, the distribution systems needs an accumulation facility to store the 144 m³ of water corresponding to the remaining 10 hours. Therefore the distribution system, made of 25 km of pipelines with different diameters supplying 44 double water (88 taps), has been provided with a new 125 m³ reservoir in addition to the 20 m³ existing one, for a total of 145 m³ available for night time accumulation.

In the end, thanks to the hydraulic force of the small stream flowing near Shamusenge source, it's possible to supply the town with a significant quantity of drinkable water, available for all the population with no distinction of wealth.

4. Characteristics of the pumping unit

The horizontal-axis pumping unit is made up of two main components: a propeller turbine and a centrifugal multi-stage pump. Turbine shaft is directly coupled to the pump shaft through a mechanical joint; this direct connection results in the pump being driven by the turbine whose rotation provides the pump with the power to lift the drinkable water from the spring to the storage tank. This fully mechanical pumping unit avoids any electrical equipment or any external energy supply to run the system which represents a remarkable advantage in the project context. As for the hydraulic layout of the plant, which is roughly showed in Fig. 8, water is caught from the Kayoke torrent at 981.50 m a.s.l. and, after passing through a 2.9 km-long penstock, enters the turbine which is designed to operate with a fixed flow rate of 85 l/s under a net head of 13,97 m.

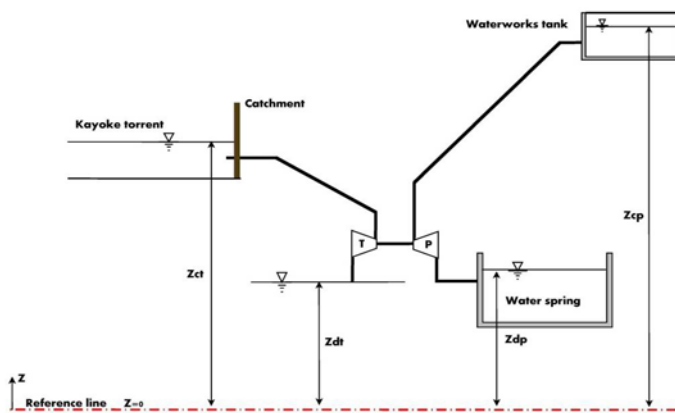


Fig. 8- Hydraulic circuit scheme.

After passing through the turbine water is discharged into a canal which is not in contact with the drinkable spring where the pump suctions from.

The centrifugal pumps is designed to provide 4 l/s under a net head of 132 m.

4.1 Turbine

The runner of the turbine is made up of 5 fixed blades and has an external diameter of 170 mm. The turbine features also a distributor with 9 fixed blades whose task is to guide the flow properly before entering the runner.

The turbine is designed for these operating conditions:

• H_g = gross head:	16.5 m
• H_n = net head:	13.97 m
• Q_t = turbine fixed flow rate:	85 l/s
• N_t = turbine rotation speed:	2,900 rpm
• P_t = power at turbine axis:	9.3 kW
• η_t = turbine efficiency:	0.80

4.2 Pump

The pump is a commercial centrifugal pump, 5 stages horizontal-axis with the impeller external diameter of 142 mm, designed for the following operating conditions:

• H_{pg} = geodetic head:	113 m
• H_{pn} = discharge head:	132 m
• Q_p = pump flow rate:	4.0 l/s
• N_p = pump rotation speed:	2,900 rpm
• P_p = power at pump axis:	9.3 kW
• η_p = pump efficiency:	0.55

4.3 Turbine construction

The turbine is an horizontal-axis fixed-blades Kaplan turbine, known also as propeller turbine. In this case the propeller turbine belongs to the group of the so-called Tubular Axial Turbine (TAT).

Getting into mechanical aspects of the turbine, its main features are: runner with 5 fixed blades, a distributor made up of 9 fixed blades, one grease-lubricated guide bearing, one grease-lubricated thrust and guide bearing and a mechanical joint with rubber teeth for the connection between turbine and pump. One of the main challenges to face when the turbine design started, was to provide a solution that could make ordinary maintenance as easy as possible, so that the local team, properly instructed, could easily run the plant and do the ordinary maintenance.

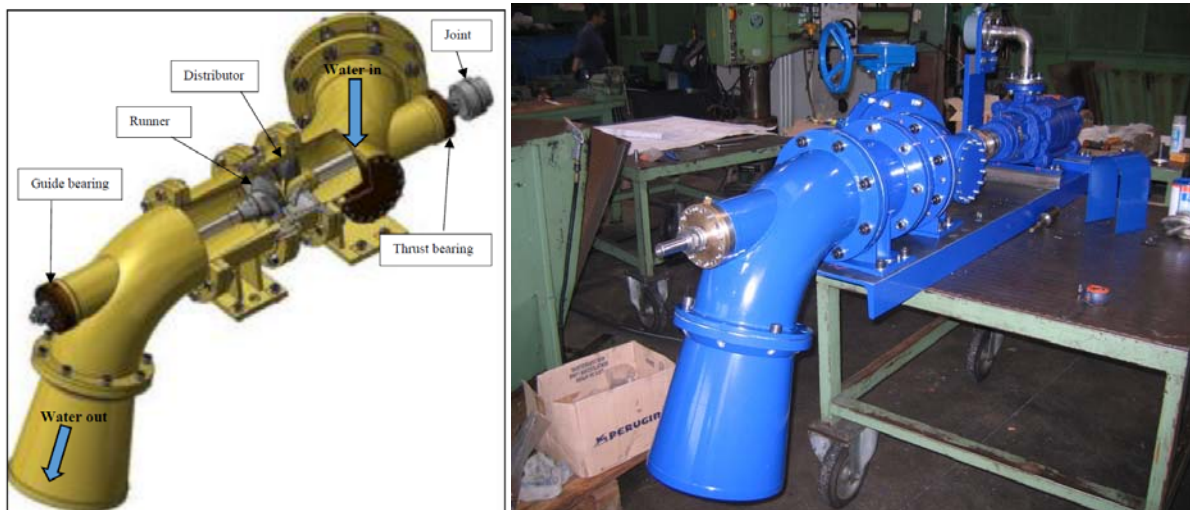


Fig. 9 - CAD 3D turbine section and pumping unit during assembling and alignment in workshop.

By following the criteria of easy maintenance, it was decided to lodge both guide and thrust bearing within a tailor-made flanged casing, connected, as shown in Fig. 9, through bolts to turbine piping. This enables to change bearings by simply unscrewing the casing from the piping and replacing the casing containing the damaged bearing with a spare one that must be always available within the plant. As for the lubrication, both bearings can be refilled with grease by simply connecting a piston grease gun to the threaded hole placed on the external part of the casings of both guide and thrust bearings.

To simplify the transport to Congo RDC, and minimize all the risks tied to a bad assembling and alignment of pump and turbine, the entire pumping unit was fixed on a steel basement and it was completely assembled and aligned in workshop, installing plugs to maintain the position of both pump and turbine. In this way the only procedure to do locally was to connect both the turbine and the pump to their flanged penstocks.

5. Project constraints

5.1 Transport difficulties

The town of Kahemba is very difficult to reach, because the last 340 km are sandy tracks, impracticable in the rainy season and anyway impossible to travel by trucks with more than 3 axes.

This required a particular care in the design, which took into account the maximum dimension of a 20 feet container, quite constraining especially with respect to the penstock pipes.

In this regard, the pipeline has been divided into 3 equal sections of different diameter, designed to be nested into one another, in order to reduce the transport costs, particularly high because of the poor conditions of the roads connecting Kahemba with the rest of the country.

5.2 Unavailability of appropriate vehicles for the working site

In Kahemba area there's no working site vehicle available to carry out the preliminary works of topsoil excavation for the erection of the pipes on often uneven grounds.

Therefore we had to provide for single pieces to be assembled with a compatible weight for exclusively manual operations and also for appropriate methods for laying the pipes on the ground.



Fig. 10 - Penstock erecting activities.

5.3 Unavailability of specialised personnel and materials

In Kahemba area there are no special construction materials, such as expanding or waterproofing mortars, therefore they have been shipped from Italy, while the cement has been bought in Angola, whose border is a few tens km far from town. This difficulty was taken into account in the design of the works, providing for an extensive use of low performance local materials, integrated by small amounts of high performance special materials, because the effect of the transports on the final cost suggested us to decrease the quantities while increasing the quality of what had to be necessarily imported.

Also the lack of highly specialised local manpower has been taken into account in the design by avoiding complex works such as the welding of structural steel parts. As to the necessary specialisation for welding and erecting the PE pipes and the relevant fittings, an Italian technician taught the procedures to local teams, who worked first under his control and then in total autonomy, while the only task of the Italian technician was to check the final quality of the installation.

5.4 Acidity of the source water

As previously written, all the water in the province of Kahemba is characterised by a significant acidity, due to the features of the soil through which it seeps, mainly made of siliceous sands.

In order to correct this parameter loaves of lime were used, which have a buffer effect on the pH and also provide calcium salts, improving the quality of the supplied water.

6. Problems faced during the first year of operation

6.1 Misalignment of the turbine - pump in the assembly phase

In spite of the cautions taken in the design and construction phase, around one week after the first commissioning, which took place in December 2015, the elastic joint between the pump and the turbine was damaged by a strong

misalignment occurring in the transport or in the assembly phases. Steps were taken to substitute the joint, realign the shaft and then put the unit back to work.



Fig. 11 - Coupling joint damaged on left and the new one on right.

6.2 Presence of extraneous material in the turbine

The day after the new commissioning, a strange anomaly happened, which caused a malfunction of the unit, turning at only 1,500 r.p.m. instead of 2,700 r.p.m. as the day before. The most reasonable hypothesis was the presence of extraneous material in front of the fixed guide vanes.

Once opened the hand-hole provided for this purpose, a first inspection of the fixed guide vane didn't reveal any obstruction, but looking more carefully at the runner a sort of rag could be seen, wrapped in the runner blades.

When we extracted it, we realised it was a long snake, whose hard skin had resisted the shearing effect of the blades turning at nearly 3,000 r.p.m.!

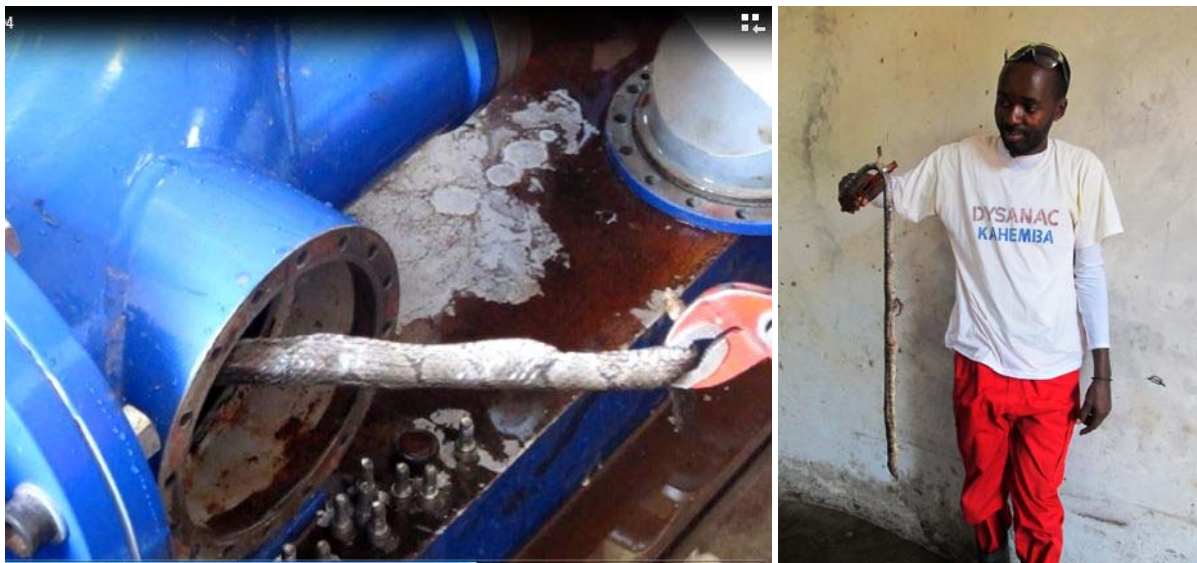


Fig. 12 - Snake in the runner.

Nevertheless the head losses in the penstock kept 40% higher than expected. By manometric measurements in different points of the pipeline, the critical point was identified in the final stretch of the penstock. Therefore we decided to open it and actually we found and removed a rag and a big piece of wood, that evidently entered in the penstock during the erection works, as the inlet is protected by a 20 x 20 mm screen.



Fig. 13 - Extraneous materials in the penstock ...

6.3 Presence of air bubbles in the penstock

Other noteworthy anomalies concerned the penstock, which had been erected with some counter-sloping sections because of the unfavourable ground morphology and subsequently trapped air bubbles, which reflected in an excess of head losses, shown by the manometric pressure measurements at the turbine.

Consequently 12 air vent valves were inserted, which open to let the air go out and also to prevent depression phenomena in the emptying phases. Moreover, in order to completely empty the penstock, 11 sluice valves were placed in the lowest points of the penstock profile.

Anyway the filling of the penstock is a complicate operation, to be performed slowly and then checking the actual expulsion of the air trapped in the pipes by manually opening the air vent valves.

6.4 Presence of earth and sand in the distribution pipes

Another faced problem was the presence of earth and sand in the drinking water distribution pipes, due to their stay on the ground during two rainy seasons. This implied toilsome sluicing operations in the commissioning phase and in the first operating months of the aqueduct.

For the same reason we had to provide for frequent cleaning of the accumulation reservoir, in order to prevent the drinking water to take a reddish colour and an unpleasant smell.

7. Conclusions

7.1 Lesson learning

7.1.1 Topographic survey

The topographic surveys carried out by local people proved to be scarcely reliable, although performed by high level modern equipments and by technicians qualified on paper.

What was missing in our case - but we had analogue experiences in other projects - is the capacity of the surveyors to understand which points had to be taken and how to represent them to effectively describe the actual ground profile in relation to the works which must be realised. On the contrary we were given a lot of useless data, while the really necessary ones were missing.

In the end, since the topographic data quality determines the final project quality, this issue must be faced with the greatest attention, investing the necessary resources to check first of all if the surveyed data are correct and then if there are all the necessary ones.

7.1.2 Air in the penstock

On the basis of the topographic survey we had decided to lay the penstock on a plan route allowing for a constant downwards slope. Actually the difficulties of the erection without mechanical equipment to appropriately prepare the ground and some incongruities in the topographic data originated a series of counter-sloping branches.

These problems became evident only on the plant commissioning, when manometric measurements pointed out the presence of air trapped in the penstock. Identifying the most suitable points to install the air vent and sluicing valves was no easy task, because the penstock already was mostly buried.

The learnt lesson was the necessity to have a better topographic representation of the ground and to choose a route easing the erection, providing since the design phase for the possible counter-sloping sections and for the necessary air vent and sluicing valves.

7.1.3 Correct assembly of the turbine - pump unit

The pumping unit was perfectly assembled in the workshop on a unique steel frame in order to avoid any alignment operation on site. Actually a misalignment occurred, probably caused by the difficult transport conditions or during the assembling operation of the last pipe close to power house.

The design approach is suitable, but a stronger care during the transport and erection would have been needed to avoid the problems we faced on site.

7.2 Actual results of the projects

Thanks to the use of a RES to provide energy for the pump, the management costs are very low and therefore compatible with the paying capacity of all the people in Kahemba.



Fig. 14 - Water distribution in the town.

In the end we decided to ask for a monthly fee of 4,000 CDF (equal to approximately 3,30 \$) to every family for 3 water barrels/day (25 l/s each); the amount can be doubled for large families. Anyway a free daily supply of barrels was provided for people in difficult economic conditions.

As a conclusion, we underline the most important result of the project, i.e. that in the last year no case of *konzo* was recorded. This is a source of great satisfaction for us and for the financing NGOs.

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