4.Results Analysis and Discussion

4.1 Factors Affecting Pelton and Cross-Flow Turbine Efficiency

The improvement of efficiency of a turbine heavily depends on its design and manufacturing process. The friction within the Pelton buckets, the interaction of the water jet with the buckets, and the method of welding of the buckets to the runner all have major roles in the efficiency of a turbine. Working with the NGO engineers and the site visits to and interviews of key personnel at the workshop where Non-governmental organisation turbines are manufactured revealed the following as the process followed in the production of Pelton turbines.

A. Design and Manufacture of Pelton Turbine

The head and flowrates were collected from each of the four study sites. This data was used to calculate the gross power output hence the size of the runner, number of buckets, number and size of water jets. The efficiency of the turbine is designed at 60%. Two of the four sites that were analysed have Pelton wheel turbine working on them. Data from the sites is given in Table 2.

Table 2: The two MHS sites that have the Pelton wheel turbine installed on them

SITE	**GROSS HEAD (m)**	**FLOW RATE (m^3/s)**	**CAPACITY (kW)**	**TURBINE TYPE**	**EFFICIENCY (%)**
A	51	0.325	88	Pelton	60%
B	138	0.035	20	Pelton	60%

The capacity for each site is the actual power output that was determined using Equation 2. Technical drawings are then made. Patterns of Pelton buckets are then made. This is a very crucial stage and is done by specialised skill. A pattern has to be perfect, having the exact dimensions of the required products. Sand casting then follows. Buckets are sand cast individually and bolted to a runner. Figures 3 to 5 show this process.

Figure 3: Pelton bucket that has been sand cast and after it has been machined

Figure 3 is showing a single bucket that has been sand cast. The feeder and the riser are still attached to the bucket and the bucket after being machined to remove the feeder and riser. It has 2 holes drilled through it for bolting to the runner. It is important to have the holes expertly drilled otherwise the buckets will not sit on the runner perfectly and the turbine is misaligned. This reduces the efficiency of the turbine as some energy is lost to heavy vibrations and noise since the water jet will not be hitting on the correct spot anymore.

Figure 4: Alignment of buckets on the runner and a complete turbine

Figure 4 shows how individual buckets are aligned on the runner and a finished turbine. They sit at an angle to each other. This allows for the full force of the jet to be applied on each bucket one after another without hindrance from the previous bucket. This ensures maximum efficiency of the turbine. Seventeen buckets are bolted onto the runner. The number of buckets per runner is important in making sure there is enough space between the buckets to allow the water jet to hit individual buckets with the same force. For Non-governmental organisation turbine sizes 17 or 18 buckets are used per turbine.

Figure 5 shows the turbine housing being welded together and the inside of the turbine housing.

Figure 5: Turbine housing being welded together and the inside of the turbine showing the nozzle

The individual parts of the turbine housing were cut using a cutting torch. The nozzle through which the water jet goes through to the turbine is seen in the picture. The sizing of the nozzle is important in having the correct size water jet, hence the right amount of force on the turbine that ensures maximum efficiency.

B. Effect of Roughness Due to the Manufacturing Process

The turbines at the NGO operate are designed to operate at 60% efficiency and the processes used to manufacture them are sand casting, oxyacetylene welding and flame cutting. Each manufacturing process has a different roughness. This combined with material roughness determines the friction of a turbine and it will then translate to turbine efficiency, in particular hydraulic efficiency. As indicated in Equation 11 hydraulic efficiency affects overall turbine efficiency directly: Table 3 compares different manufacturing processes against the overall turbine efficiency associated with each process.

Table 3: The turbine efficiencies associated with roughness of different manufacturing processes (Ramsdale R., 2012)

	Manufacturing Process	Turbine Efficiency	Roughness
Pressure die casting	A	85.0	1.6
Investment casting	B	85.0	3.2
Milling	C	85.0	6.3
Laser	D	80.0	6.3
Electron beam	E	80.0	6.3
Oxyacetylene welding	F	60.0	25.0
Sand casting	G	60.0	25.0
Flame cutting	H	60.0	50.0

Figure 6 shows a graph that relates this roughness to the turbine efficiencies.

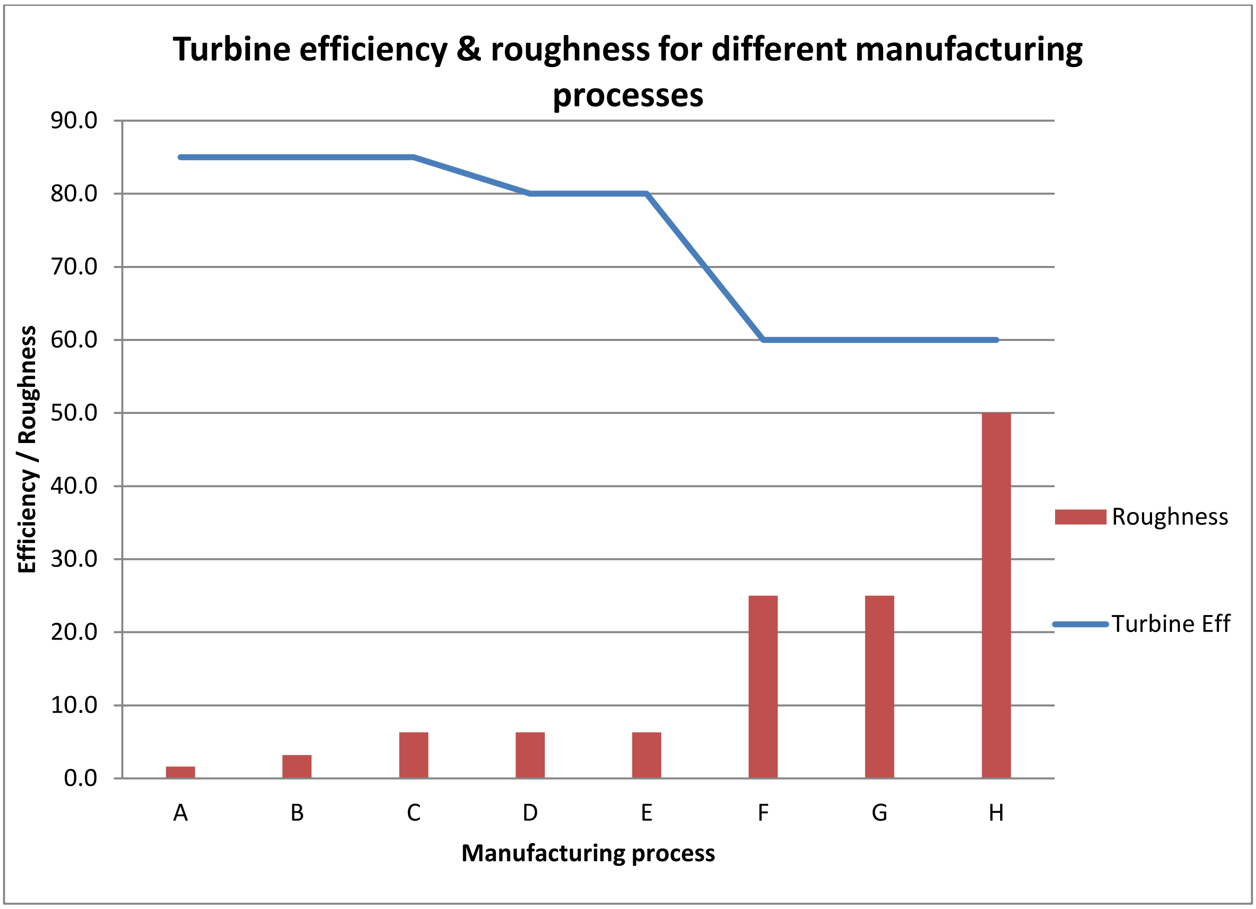

Figure 6: Turbine efficiency & roughness for different manufacturing processes

The graph indicates that as the manufacturing process roughness increases the overall efficiency of the turbine produced decreases. This emphasises the need to use manufacturing processes with minimal roughness.

This indicated that the flow friction in the Pelton buckets has a substantial impact on the system efficiency of the turbine. The efficiency drop resulting from the flow frictions represents the greatest part in the total loss in the system efficiency of a Pelton turbine. Mechanical efficiency is the other determining factor of the overall efficiency. One way to improve this efficiency in casting procedures is to cast segments comprising of a number of buckets or whole runners, comprising the runner and all the buckets.

C. Effect of the Water Jet Movement

Of great importance in the mounting of the Pelton turbine is its interaction with the water jet. For the NGO the mounting of turbines is done expertly, by the manufacturer of the turbines and inspected by the engineers. To maximise efficiency the jet must hit precisely the centre of each Pelton bucket. That way the jet gives the maximum drive to each bucket as noted earlier in the design of the buckets that the rotation of the turbine depends on the water jet velocity.

D. Turbine Material

The type of material used to fabricate a turbine affects its efficiency. Good materials are hard and must be able to resist erosion and corrosion. This ensures that the turbines will function at their best efficiency for the expected life span on the micro hydro power plant. At the NGO Stainless Steel is mainly used for Pelton turbines. Mild Steel is mainly used for casings.

However this study revealed that other materials that maybe used for turbines are Aluminium, Cast Iron, Copper based alloys such as Brass and Bronze, and Sheet steel. The properties of these materials and their prices per kg are tabled (Table 4).

Table 4: Properties of different materials and their prices per kg (Ramsdale R., 2012, MetalCorp, 2012)

MATERIAL	MATERIAL	ROUGHNESS ($x100^{-2}$)	BRINELL HARDNESS (x100)	PRICE/KG (US$/kg)
A	Aluminium	0.2	1.2	1.32
B	Grey cast iron	25	3.02	0.83
C	Brass	1	3.6	5.54
D	Bronze	1	3.6	5.54
E	Stainless steel	3	4.15	1.47
F	Sheet Steel	15	4.5	0.29

Figures 7 and 8 show the relationships between roughness and price per kg of material and hardness and price per kg of material respectively.

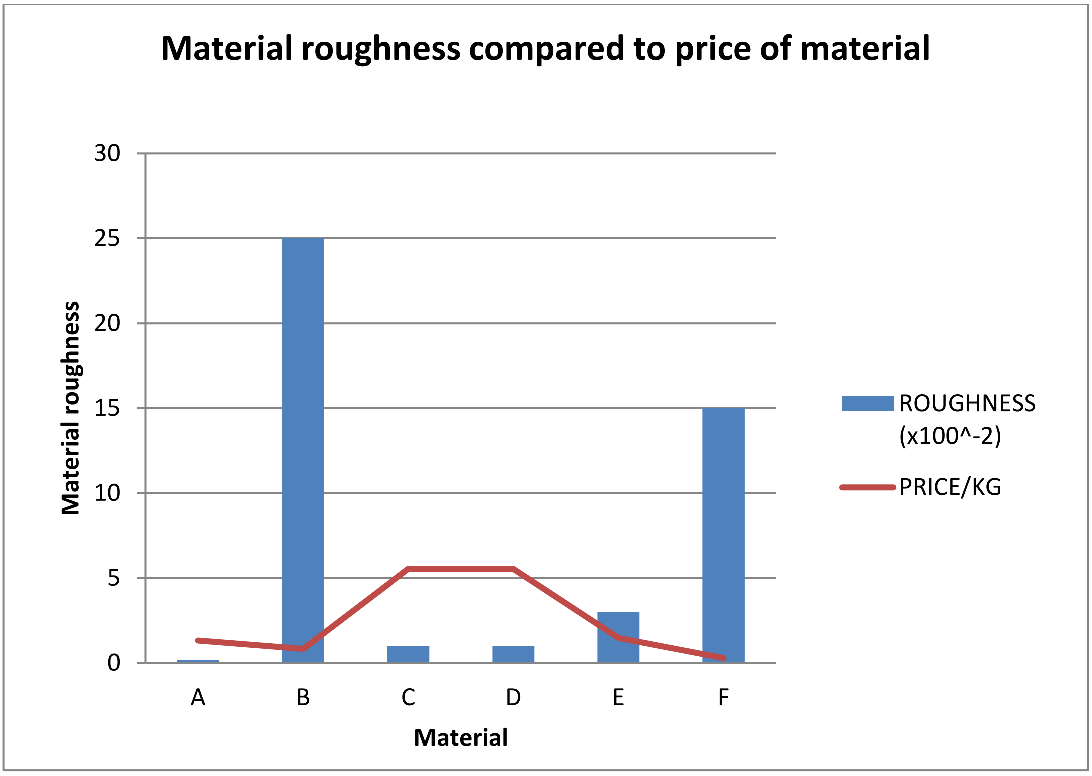

Figure 7: Material roughness compared to material price

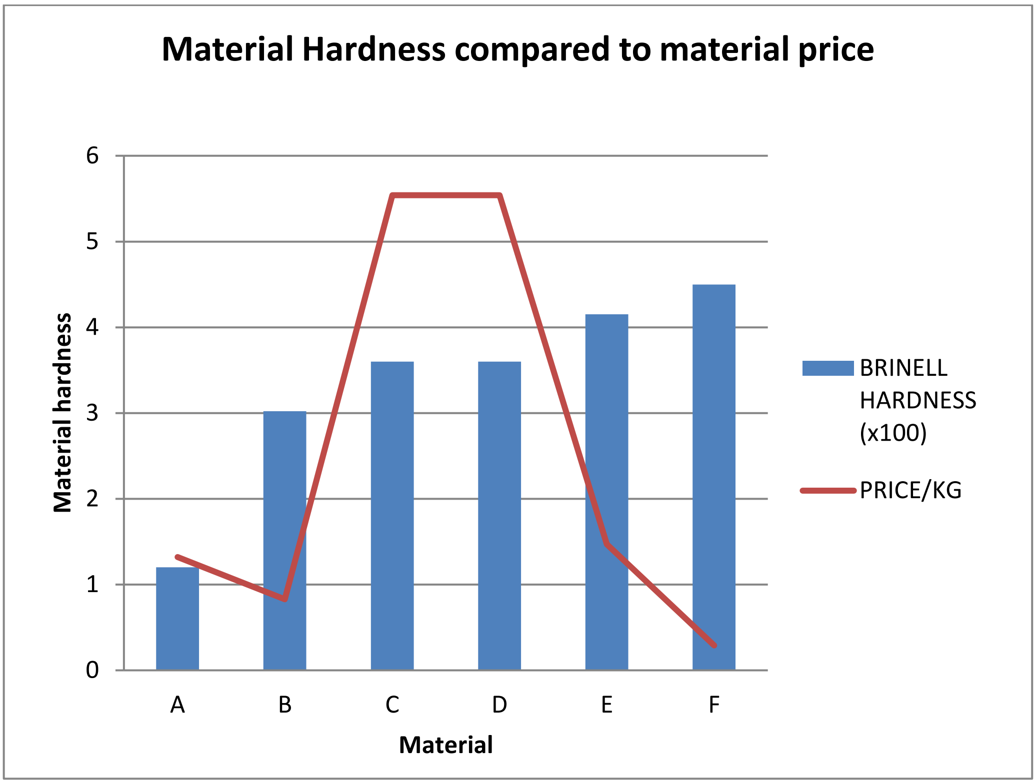

Figure 8: Material hardness compared to material price

The two graphs shows why Stainless steel is the most commonly used material in the manufacturing of turbines for MHS. It has a high hardness, a very low roughness and price is close to the lowest. Sheet Steel maybe the cheapest and its hardness is slightly higher than that of stainless steel but its roughness is much higher than Stainless Steel. Such a roughness means that it has a much higher friction than Stainless Steel and this is not good for the hydraulic efficiency of the turbine and hence the overall efficiency. Brass and Bronze are too expensive for MHS. This is because they are alloys of Copper which is a very expensive metal. Its price is about $8 per kg. (Metalcorp, 2012)

Aluminium has a price close to Stainless Steel and the lowest roughness, but is susceptible to damage if debris such as stones and sand find their way to the turbine. This is because it has the lowest hardness. The roughness of Grey Cast Iron is too high. This compromises the turbine efficiency despite having a low price and a fairly high hardness.

4.2 Performance Measurements

After the turbine has been set up and the micro hydro is just starting to run, it is of utmost importance to measure the efficiency of the turbine in order to verify if it is meeting the expected efficiency. This is done using a tachometer. This is done at the initiation of a project and after it has run for six months to check if all is performing as expected. During the period of study the tachometer was used to check the performance of the turbine at Site B where the project had been running for six months.

4.3 Effect of Increasing Turbine Efficiency on the Micro Hydro Scheme Power Output

Turbine manufacturers who use manufacturing processes that give the least roughness possible using Stainless Steel supplied quotations and their superior Turbine efficiencies. Two MHPS being constructed by the NGO were analysed further looking at the change that these turbines will bring in terms of the power output. The change in actual power output due to increase in turbine efficiency of the two MHPS that were studied is shown in the Table 5.

Table 5: Differences in power output due to increase in turbine efficiency

Site	Turbine Type	Current Tubine Eficiency	Current Power Output (Kw)	New Turbine Efficiency	Possible Power Output (Kw)
(A)	PELTON	0.60	88.00	0.85	124.67
(B)	PELTON	0.60	20.00	0.85	28.33

In both cases there is a remarkable increase in power output coming from the same resources. MHS are small projects that are usually donor funded. Therefore using the materials and manufacturing processes that give the highest possible yield from each site and resources is most ideal. The prices of turbines in the quotations supplied were such that the project costs remained within the budgets.

5. Conclusion & Recommendations

This study has revealed that turbines of better efficiencies can be manufactured, made available for MHS and the projects remain financially viable. This was achieved through the comparison of current fabrication methods used at the NGO to methods used by different suppliers of turbines. Even though the better efficiency turbines are more expensive than the ones being used currently the overall benefit is clear. More electricity is generated hence the cost per unit kW actually decreases making the projects even more viable. The financial viability of a project was determined by the project cost per kilowatt produced. Use of better efficiency turbines will make it possible to harness more electrical power from the same resources.

The NGO is highly recommended to consider investing in processes that produce turbines with higher efficiencies such as:

- Pressure die casting of turbines. They may be cast as whole turbines or as segments made up of a number of buckets.
- Investment casting of whole turbines.
- CNC milling of Pelton buckets.
- Cutting of Pelton runner and Cross-flow runner and blades using CNC laser, CNC plasma.
- Electron beam and laser welding of blades to runners.

These processes offer far less roughness compared to current methods that include sand casting, flame cutting and oxyacetylene welding. That reduction in roughness lessens friction and the overall efficiency of a turbine is increased.

6. References:

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