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Quality improvement and productivity enhancement of a single screw HDPE pipe extrusion machine: A case study

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ABSTRACT

In the HDPE pipe manufacturing industry, power consumption is the main factor that increases the product's manufacturing cost. This paper aims to reduce the power consumption and increase the surface finish of the HDPE pipe. This work highlights the increase in production efficiency of HDPE pipe factory. First, consider power consumption reduction by using gearbox in the place of no. of pulleys and belt drive and also by this gearbox, the motor size has also reduced which reduces the power consumption and increases the plant's efficiency. Second, to improve the surface quality of the pipe, a cooler is used as a cooling tower to reduce the temperature of the water used to cool down the temperature of the pipe. Results after Modifications around 50% cost of power consumption is reduced per machine and overall power consumption of the plant is reduced by 45.45%.

Selection and peer-review under responsibility of the scientific committee of the International Conference on Innovation and Application in Science and Technology

1. Introduction

The growth in thermoplastic marketplace is rising very speedy as a substitution of cement, wooden, and metal products. Around 80% of the consumed plastic is thermoplastic. HDPE pipes are extensively used thermoplastic for water pipelines, industrial pipelines, mining, cable ducts, etc., because they do not require high maintenance and repair costs. The most important thing is that it is a biodegradable source like fossil fuel it only requires a huge area for degradation. Nowadays, due to the high requirement of HDPE Pipes, Production planning should be applied for the optimum utilization of effective uses machines, manpower, material, and other resources considering all the variables involved in the production of HDPE pipes. In this case study, Productivity enhancement is done for the HDPE pipe factory.

Assaf et al. [1] presented an application of Design of Experiments (DOE) in optimizing the Extrusion process of High Density Polyethylene Pipes (HDPP). It shows that the defect rate is over 20% and is far better than before with the best parameters set. This work's restriction is that it only pays attention to one product and mainly one defect type. More complications would need a bigger set of experiments; the study recommends it be worth it as the defective product's percentage rate is elevated.

Jadayil et al. [2] concluded that the HDPE pipe manufacturing process's environmental brunt was conceded out in an Indian manufacturing organization. Two-phase (i.e. manufacturing and EoL) of HDPE pipe life cycle also influences approximately all sets of environmental impact assessment. Therefore, the research should pay attention to the raw material part of the HDPE manufacturing process and EoL. The most important phase for HDPE material manufacturing process value chain is raw material because it has shown the most influencing period in the Indian industry. Hailemariam et al. [3] concluded about a leather manufacturing company, where they studied the improvement of the production capacity through making a proficient production planning and control system.

Pisuchpen et al. [4] presented a study to adapt the plastic vision lens manufacturing line to enhance productivity. First, work study and line balancing techniques were in work to improve the bottleneck point in the manufacturing process. However, it could not attain the target capacity. Then they implemented three other techniques; using lowest unit production cost circumstances, additional labour and machines were added into the bottleneck point of the production line. The productivity was then augmented to attain the target value.

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Table 1
Specifications for the Old belt drive arrangement.

S. No.	Specifications	Dimensions
	Diameter of pulley 1 (driver)	101.6 mm
	Diameter of pulley 2 (driven)	406.4 mm
	Speed Ratio for the Pulley 1 and pulley 2	4
	Countershaft Speed	240 r.p.m.
	Diameter of pulley 3 (driver)	152.5 mm
	Diameter of pulley 4 (driven)	660.4 mm
	Speed Ratio for the Pulley 3 and pulley 4	4.33
	Third Shaft Speed	55.42 r.p.m.

Table 2
Old belt drive arrangement with cost.

S. No.	Particulars	Specifications
1	No. of Pulleys (Double V Groove, C Type)	04
2	Pulley 1 (Diameter)	101.6 mm (320 Rs.)
3	Pulley 2 (Diameter)	406.4 mm (960 Rs.)
4	Pulley 3 (Diameter)	152.4 mm (480 Rs.)
5	Pulley 4 (Diameter)	660.4 mm (1560 Rs.)
6	Belt Price Total (04 Belts)	4000
	Total Price	7320 **Rs.**

*Rs. = INR (Indian Rupee).

Table 3
Specifications for the New belt drive arrangement.

S.No.	Specifications	Dimensions
	Diameter of pulley 1 (driver)	177.8 mm
	Diameter of pulley 2 (driven)	660.4 mm
	Speed Ratio	3.714
	Input shaft r.p.m. of the second gearbox	65 r.p.m

Table 4
Gear Box Specifications.

S. No.	Particulars	Specifications
1	Gear Ratio	1:7 (Reduction)
2	Price	Approx. 30000/-
3	Specifications (LXWXH)	381 mm × 342.9 mm × 368.3 mm

Table 5
New Belt Drive Arrangement Price.

S.No.	Particulars	Specifications
1.	Pulley 1 (Diameter)(Motor)	177.8 mm (560 Rs.)
2.	Pulley 2 (Diameter)	660.4 mm (1560 Rs.)
3.	Belt Price Total (02 Belts)	2500 Rs
	Total Price	**4620** Rs.

Table 6
Motor Specifications (New).

S. No.	Particulars	Operating Characteristics
1	Power Supply	5.50 kW- 7.5H.P.
2	R.P.M.	1450 R.P.M.
3	Price	**15000/-** Approx.

Table7
Motor Specifications (Old).

S. No.	Particulars	Operating Characteristics
1	Power Supply	11 kW-15H.P.
2	R.P.M.	960
3	Price	**40000/-** Approx.

Table 8
Cooler Specifications.

S. No.	Particulars	Operating Characteristics
1	Motor Power	500 W
2	Specifications(LXWXH)	914.4 mm × 914.4 mm × 1828.8 mm
3	Motor Price	3500
4	Cooler Price (Stainless Steel Body) Total	**25,000**

Table 9
Temperature of Water (Before) (Tank Type, 2133.6 mm depth × 609.6 mm diameter).

S. No.	Water Flow	Temperature
1	Inlet Temperature (From machine to well)	41° C(Around 2:00 PM insummer days)
2	Outlet Temperature (From well to machine)	40° C (Around 2:00 PM in summer days)
3	Pump Motor	1.5H.P.
4	Pump Price	**3000**

Table 10
Temperature of Water (After installing a cooler).

S.No.	Water Flow	Temperature
1	Inlet Temperature (From machine to Cooler)	28 °C
2	Outlet Temperature (From Cooler to machine)	21 °C
3	Pump Motor	1.5H.P.
4	Pump Price	3000 Rs

Table 11
Electricity Consumption by Motor.

S. No.	Old Arrangement (Units Consumed)	New Arrangement
1.	5280	2640

Table 12
Electricity Consumption with Cooler Arrangement.

S. No.	Equipment	Old Arrangement (Units Consumed)	New Arrangement(Units Consumed)
1.	Motor	5280	2640
2.	Exhaust Fan	Nil	240
		5280	**2880**

Al Jubury et al. [5] concluded a case study of Finnish Company (Eurofins Viljavuuspalvelu Oy), factors affecting the production capacity had been studied and analyzed. They used diverse techniques like bottleneck analysis, Overall Equipment Effectiveness (OEE), and Just in Time production. Using lean principles to enhance the production capacity has been done by many researchers. Fahmi et al. [6] used lean manufacturing principles for the enhancement of production in steel industry. Also, Nurrasjid et al. [7] implemented lean manufacturing principles in the Indonesian pharmaceutical industry to progress production capacity.

After going through the literature review, it is found that the various process implemented by the researchers are very beneficial in several ways to enhance productivity. Hence, some of them are analysed and implemented for this existing case study.

2. Methodology

Following approach is used for the enhancement of productivity of HDPE pipe extrusion machines under various operating parameters:

a) Selection of HDPE single pipe extrusion machine in industry.
b) Collection of data regarding the various defects in extrusion process.
c) Selection of parameters which is responsible for the productivity reduction.
d) Prediction of parameters which has to be optimized. Compare the data with previous productivity results.

2.1. Design of power transmission system

(i) Old belt drive arrangement:

Therefore, to reduce this r.p.m upto 10 r.p.m, a 1:6 reduction gearbox is used. After that, the output r.p.m. of this gearbox is 9.23, which is required for the extrusion process.

(ii) New arrangement of gear drive

For the new arrangement, a 1:7 reduction gearbox is placed; hence the output r.p.m of the gearbox shaft is 207.14 r.p.m

Hence to reduce this r.p.m up to 10 r.p.m, a 1:6 reduction gearbox is used.The output r.p.m. of this gearbox is 10.83 required for the extrusion process.

That's why we used a 1:7 reduction ratio gearbox, which can work satisfactorily.

(iii) For new arrangement of Belt Drive (New)

As per the power transmission specifications, a belt drive arrangement is used in the old one and has four pulleys and the

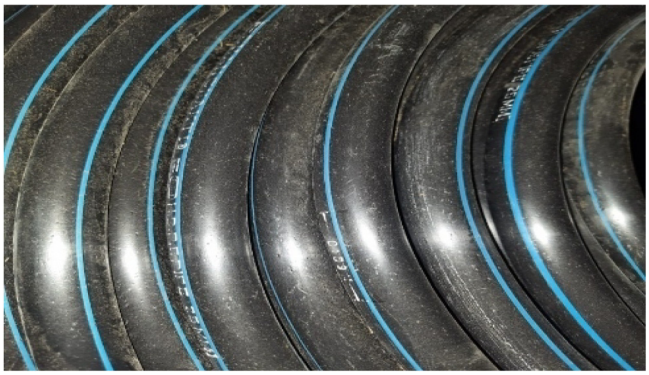

Fig. 2. Surface Finish before cooling arrangement.

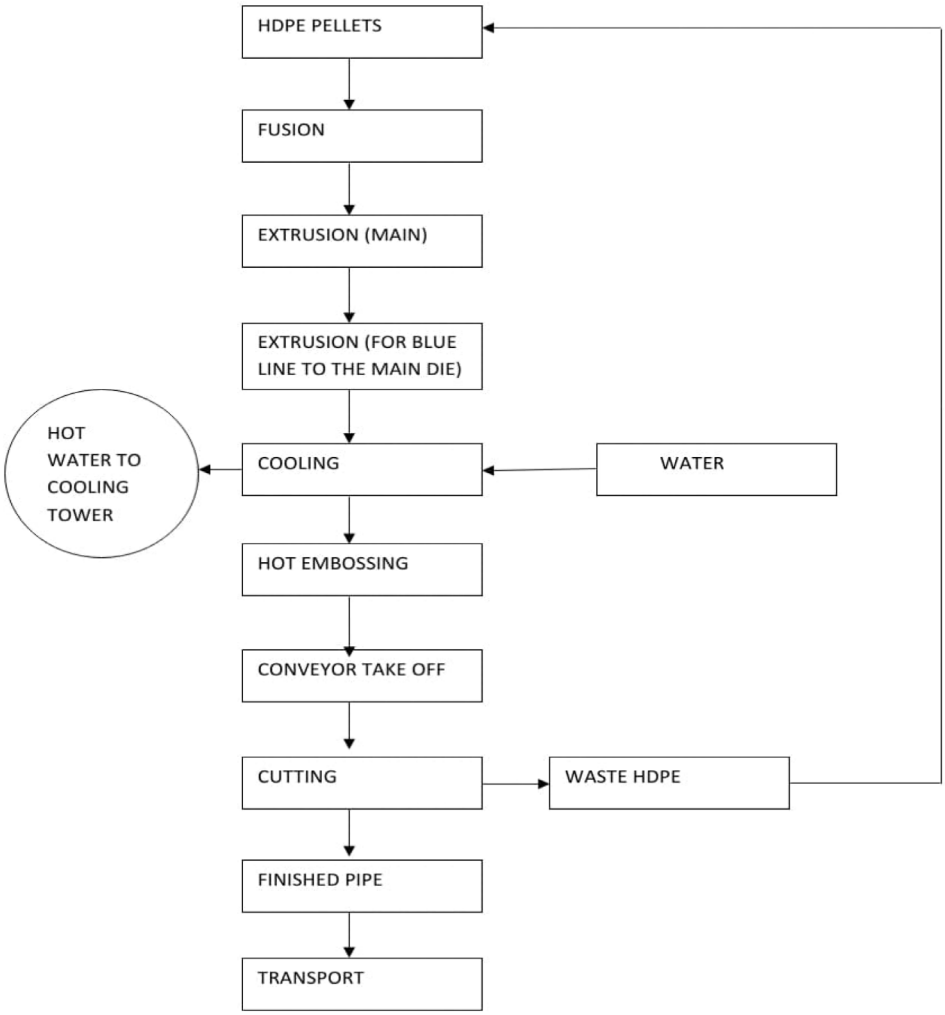

Fig. 1. Flowchart of production of HDPE Pipe factory.

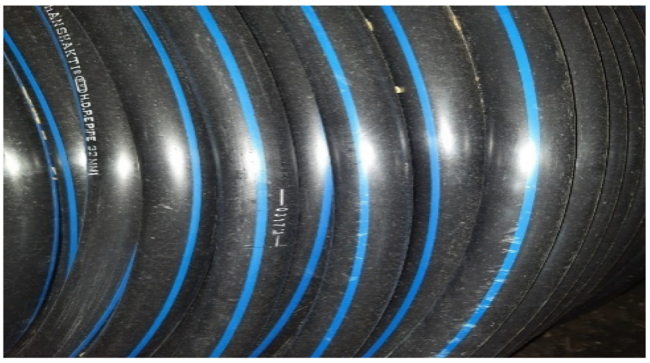

Fig. 3. Surface Finish after cooling arrangement.

price is around 7320/-, but in the new arrangement on the place of 4 pulleys, only two pulleys along with a reduction gearbox are used. Almost 25000/- price reduction is also seen by using 1450 r.p.m motor (see Tables 1-8 shows the details about old belt drive arrangement , New gear drive arrangement with cost, New and old motor specifications with cost, Cooler Specifications, Temperature of water before and after installation of cooler and Electricity consumption.).

As per the surface finishing point of view, surface finish of HDPE pipe is also improved after using cooling arrangement. The particulars of the arrangement are also given in Table 9. (Tables 10-12.)

New Arrangement Fabrication Cost: 8000 (Approx.)

Machine Run Time per Month: 20 Days (480 Hours)

Total Units Saved by new arrangement with new motor and gear Box per Month: 2640.

Total Units Saved by New Arrangement with new motor and gear Box with Cooler per Month: 2400.

The complete production process of the HDPE Pipe is illustrated in Fig. 1; In Fig. 2 shows the pipe's surface quality when the plant runs without cooler (ie. water directly recirculated to die and pipe cooling tank by pump) or the water temperature is 40 °C.

In Fig. 3, the pipe's surface quality when the plant runs with cooler (cooling of water by cooler) or the water temperature is 21 °C. Fig. 4 shows the cooler arrangement that directly decreases the temperature of hot water. This cooler decreases the 19 °C temperature.

In Fig. 5 it shows that the new motor which consumes 5.50 kW @ 1450 R.P.M. and gear box which has a 1:7 reduction that totally placed in the old arrangement which consumes 11 kW @ 960 R.P. M.as shown in Fig. 7 which has an intermediate shaft and two pulleys. Fig. 6 shows the direct connectivity of gear box and main gear box pulley.Fig. 8 and 9.shows the layout of the Plant and Fig. 9. shows the graph between power consumption and No. of Working Hours.

3. Results and discussions

As per the experiments done, the cost of new arrangement is 57,620 Rs, including gearbox for the reduction in power consumption and the cost of old arrangement was 55,320 Rs. Hence, cost of new arrangement is increased by 2300/- Rs only. As per the new arrangement, 50% cost of power consumption is saved per machine.

Fig. 5. Reduction Gear Box Arrangements (New).

Fig. 6. Reduction Gear Box Arrangements.

Fig. 4. Water Tank with Cooling Arrangement (New).

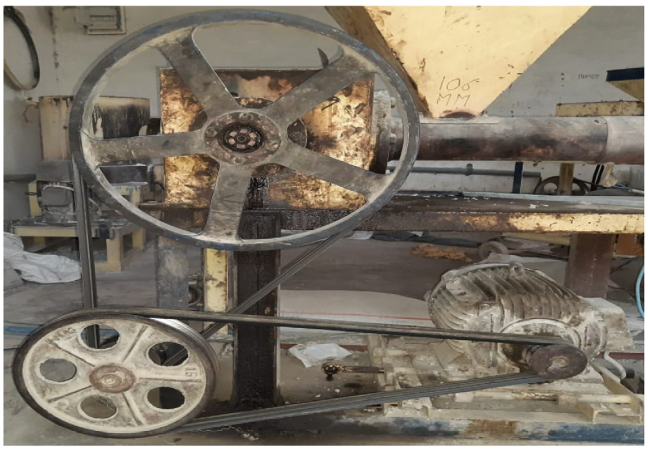

Fig. 7. Pulley Motor Arrangement (Old) Arrangements.

Fig. 8. Plant Layout (New).

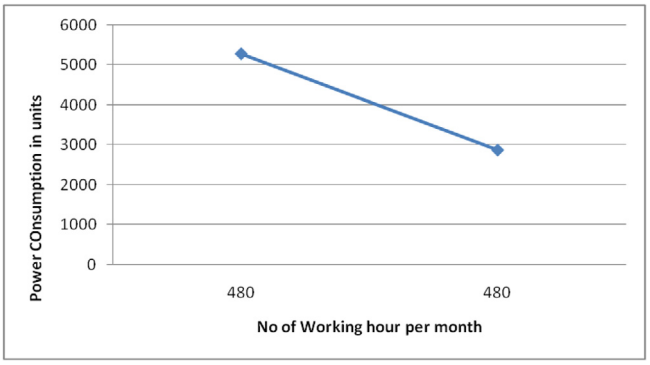

Fig. 9. Power Consumption V/s No. Of Working Hours.

Secondly, after doing work on the surface finish quality of the HDPE pipes, the cooling arrangement is made, and the above figure shows the improvement in quality and approx 240 units consumed monthly in cooling arrangement and the cost of this arrangement is approx 25000/- Rs and it is a onetime investment only. It means after using this arrangement, around 2400 units of electricity are saved per month, including the cooling arrangement; this cooler arrangement also cools the plant atmosphere by less temperature of air circulated by the cooler. Finally, the electricity consumption is reduced by 45.45% and it reduces the overall manufacturing cost of the HDPE Pipe.

4. Conclusions and recommendations

- Plant's electricity consumption is very high, and it increases the cost of production of HDPE Pipes.
- This paper evaluated all the aspects of new design, which reduces the manufacturing cost of HDPE Pipe.
- Implementations of findings reduce 45.45% of the total power consumption.
- Surface finish quality of the HDPE pipe is also increased by using a cooling water arrangement with the help of cooling tower (Cooler).

As per the analysis done, It is suggested to the R.K. Industries that:

- To replace the conventional pulley and belt drive system with the reduction gearbox. Motor size is also reduced by the reduction gearbox, reducing power consumption and increasing the plant's efficiency.
- It is suggested to use a normal desert cooler as a cooling tower to reduce the temperature of the water used to cool down the temperature of the pipe and improve the surface finish of the pipe.

CRediT authorship contribution statement

Neelam Baghel: Data curation, Conceptualization, Methodology. **Ajeet Singh Sikarwar:** Visualization, Investigation, Writing – original draft. **Anil Kumar:** Writing – review & editing, Supervision.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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