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Minimization of Air Consumption and Potential Savings of Textile Denim Fabric Manufacturing Process

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Abstract

One of the most important aspects of Bangladesh's textile industry is denim. Bangladesh now has a new opportunity thanks to the global demand for denim among fashion industry professionals. Entrepreneurs from Bangladesh provide denim products to well-known international merchants all over the world. The worldwide denim market is predicted to expand by roughly 8% through the year 2020. We must raise the standard of denim if we are to keep up with the expanding industry. In contrast to projectile and rapier systems, air-jet weaving machines nowadays can weave practically all types of yarns without any issues and at higher rates. Due to this, air-jet looms are an excellent substitute for other weft insertion techniques. This kind of device still has one significant flaw, though, and that is the enormous power consumption brought on by the creation of compressed air. Researchers and manufacturers of air-jet looms have therefore worked very hard to find a solution to this issue and achieve a huge reduction in air consumption without compromising loom performance or fabric quality. Therefore, the purpose of this project is to look into ways to decrease air consumption and reduce auxiliary selvedge waste without any decrease in loom performance and fabric quality on existing air-jet weaving looms which reduce the manufacturing costs with process improvement. Just updating the air pressure allowed a weaving mill to reduce air usage by 11 cfm. So, with just almost no cost, a company with 100 looms could save $0.15 M each year, on compressed air. Two new methods for decreasing process costs on air jet looms have also been developed by this project work.

Keywords

Denim, Woven Textiles, Weaving Machine, Air Consumption, Cost Reduction, Waste Reduction, Potential Savings

1. Introduction

One of the most successful and prolific weaving machines in the textile business is the Air Jet. Air-jet weaving machines have a higher manufacturing cost than Rapier and Projectile weaving machines due to the addition of compressed air costs. This results in energy problems. As a result, numerous manufacturers and researchers are constantly trying to increase the effectiveness of air jet weft insertion. The goal is to look at how much air is used during air jet weaving in industrial settings. The distance between the compressor and the weaving machine, the number of joints, unneeded valve openings, pipe leaks, etc. are the main causes of the difference in air-jet consumption on air-jet weaving machines, which results in an increase in compressed air consumption. Despite their high production speeds, this is making air jets less desirable due to the problem with energy costs.

Despite the fact that practically all machines come from the same manufacturer and model, air usage differs. Before being used in a machine, the air is filtered and compressed. The manufacturing cost of air-jet weaving increases as a result of substantial compressed air consumption and increased electricity costs.

The air jet generates the forces needed to move and accelerate the weft yarn. These pressures need to be greater than the sum of the forces of the yarn bobbin's resistance, inertia, and reserve system. Weft yarn characteristics and the physical parameters of the airflow are taken into account while defining the carrier and resistive force characteristics. Due to their characteristics, such as turbulent and laminar airflow, yarn diameter, linear density (count), and elasticity, air velocity, and yarn structures have intricate interrelations.

Another part of the work reported in this project is an account of wastes generated in air-jet weaving mills. The wastes were mainly divided into two categories: 1) wastes related only to the warp, such as gera cones, knotting waste, gaiting/tying-in, loom setting, beam residue after sizing and weaving, warping, in the sizing zone, and the warp yarns in the auxiliary selvedge, etc.; and 2) wastes related only to the weft, such as cut fringe, defective cones, waste due to loom set. This work includes gathering information from the air jet weaving mills on auxiliary selvedge warp waste. Following that, the amounts of waste were expressed as percentages of the total amount of warp waste.

2. Project Work Area

In my organization, there are so many departments from raw materials to final inspection such as Materials Testing, Yarn Processing, Fabric Manufacturing, Fabric Finishing, Fabric Dyeing, Fabric Washing, Fabric Testing, and Fabric Inspection. Among these departments, I want to complete my project work in the Fabric Manufacturing/Weaving section. The purpose of this project work is to reduce fabric-making process costs by updating machine materials and process routes. Various factors are involved to reduce process costs but I am working with two prime factors air consumption reduction and raw-materials optimization.

Firstly, air consumption reduction, there are more than 250 air-jet weaving machines which is the major consumption of compressed air. The cost of producing compressed air and maintenance of the compressor is very high which can impact on the product cost. We can reduce the utilization of compressed air by updating some components which are shown in this project work.

Secondly, waste reduction is an important factor to minimize cost reduction and potential savings. By applying some settings, we can retrench the waste and also save the raw materials. This will help us to decrease the ultimate product cost. We will complete this task that how can we reduce waste by optimizing raw materials in our project work.

3. Objective

3.1. Broad Objective

This report's major goal is to lower process costs through the modernization of machine components and workflows. There are many elements that affect process costs, but I am focusing on the main ones: decreased air use and improved raw material utilization. This report, which demonstrates the assignment I was given during my research work, is presented as an experiential report. My results in this report are consistent with what I discovered throughout my research.

3.2. Specific Objective

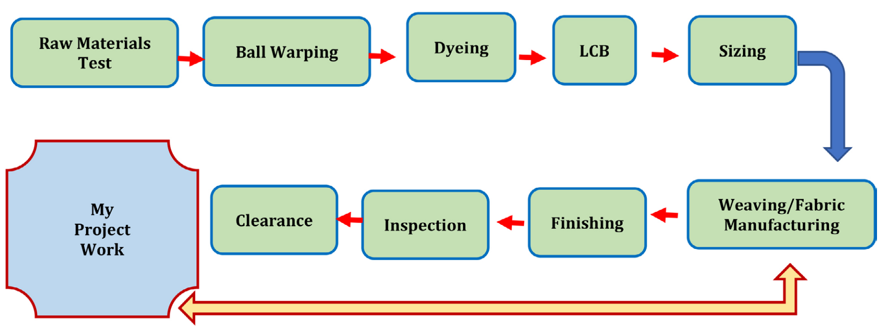
- To reduce the compressed air consumption cost
- To calculate the volume of air used in the insertion area
- To minimize the air consumption by updating machine materials
- To reduce the waste by raw materials optimization

4. Methodology

In a cotton twill fabric like denim, the weft weaves underneath two or more warp threads. Weft threads in a denim fabric are left white while the warp threads are indigo colored. Due to its remarkable durability, denim was first utilized for work garments.

One of the successful and highly productive shuttle-less weaving machines in the textile industry is the air-jet machine. On an air jet loom, an air-jet is a device that uses high air pressure to enter the weft yarn. Prior to being used on a loom, the air is compressed and purified. The manufacturing cost of air-jet weaving is higher than that of other weaving technologies due to the large compressed air consumption and added compressor electricity expense. This is the reason why, despite their high production speeds, air-jet weaving is becoming less popular where energy costs are an issue [1]. According to how the weft is inserted, weaving machines are divided into four groups: shuttle, projectile, rapier, and jet (also known as air and water jet) looms. The air jet weaving system is frequently used because it produces goods more quickly than other systems. Low air consumption will be achieved without sacrificing product quality by updating machine components and maintaining the air pressure of the air jet loom along the main valve & relay valve drive time. By enhancing some relay nozzle and selvedge pattern parameters, the primary goal is to reduce air consumption. In order to achieve this, the weavers will alter the relay nozzle type throughout the course of the study [2]. Experiments regarding relay nozzle diameter and waste reduction by raw materials optimization will conduct on the Tsudakoma loom which originated in Japan. This is a very high-speed loom and the maximum speed is 2500 RPM but we can use ZAX 9100 model due to our availability which speed is around 850 RPM. For denim fabric, we need to run the machine at around 800 RPM because of the coarser count of yarn is used in this type of fabric. Compressed air is one of the key energy-consuming utilities in any sector and is sometimes referred to as the "4th Utility" (after electricity, water, and steam). Despite being one of the most expensive utilities, many consumers find it challenging to calculate their cost per cfm. The first thing to realize is that compressed air uses three to four times as much energy as electricity. However, compressed air's extremely adaptable nature, it improves the productivity and safety of many industrial processes [3]. Relay nozzles are the main focus of the study because they use 80% of compressed air. I think we can save more than 15% of compressed air through this project experiment. In addition to this, we can save a lot of amounts by raw materials optimization and construction & process improvement. I can't say the exact value but I assume that it will be 10% more profitable than the previous one.

Process Flow Chart of Denim Textile:



5. Findings

5.1. Air Consumption Reduction

5.1.1. Experimental Details

The main function of compressed air in an air-jet weaving machine is to insert the weft by using the main nozzle and relay nozzle to complete the weave structure. Here the main nozzle is used to hold the weft yarn and pass it into the profile reed. There are fifteen sets of sub nozzle/relay nozzle attached with profile reed to complete the insertion system. A schematic of air-jet weaving using a multiple nozzle system and a profiled reed, the most popular design on the market, is shown in **Figure 1** [4].

The filling feeder draws yarn from a filling supply package, and a stopper measure each pick for the filling insertion. The filling is supplied into the reed tunnel by the relay and primary nozzles once the stopper releases the filler yarn. While the high air velocity across the weave shed is provided by the relay nozzles, the initial acceleration is provided by the sub and main nozzle combination. The filler yarn and warp are separated by profiled reed, which also guides the air. After the yarn has been inserted all the way, it is cut with a cutter [5].

In this experiment, we used two types of sub nozzles named energy savings nozzle which is made by our own requirements, and regular nozzle which is provided with the machine. We used these nozzles in 20 machines and calculated our experimental data on saving compressed air.

5.1.2. Relay Nozzle Hole Diameter

The diameter of a regular nozzle hole is 1.4 mm and it is straight to the reed profile. On the other hand, the diameter of energy saving nozzle is 1 mm and it's slightly angled to the insertion direction which is shown in **Figure 2** and **Figure 3** [6]. The main difference between these two types of nozzle is diameter, angle direction, and also the cost of energy savings nozzle is lower than a regular one.

5.1.3. Machine and Fabric Parameter

For both types of nozzles, we preserved identical machine and fabric specifications

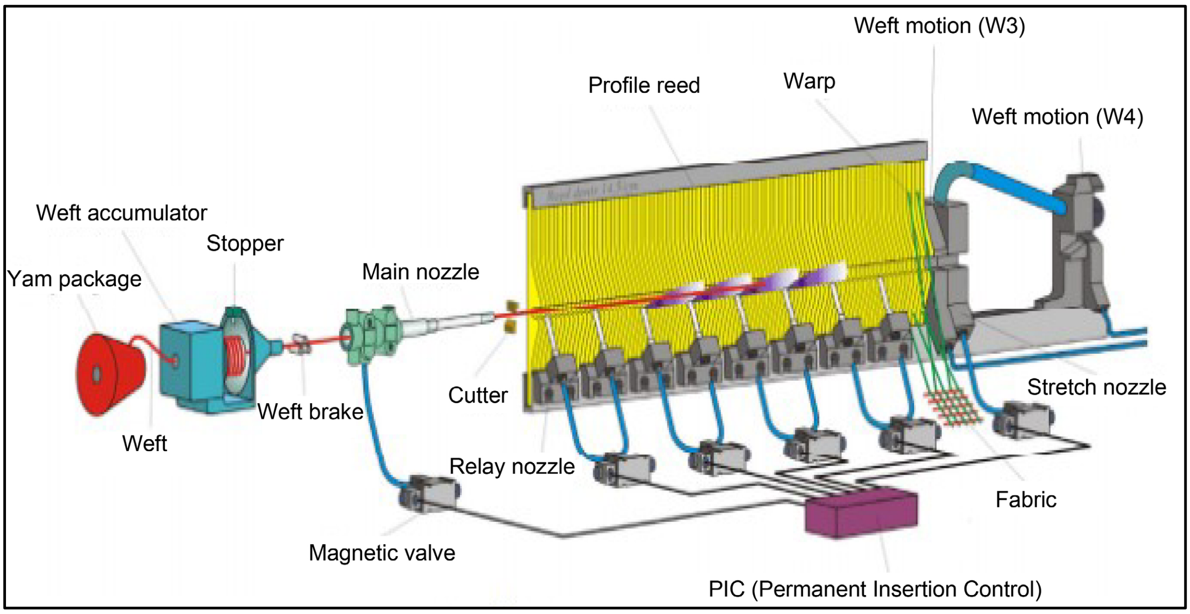


Figure 1. The weft insertion system of air-jet weaving machine.

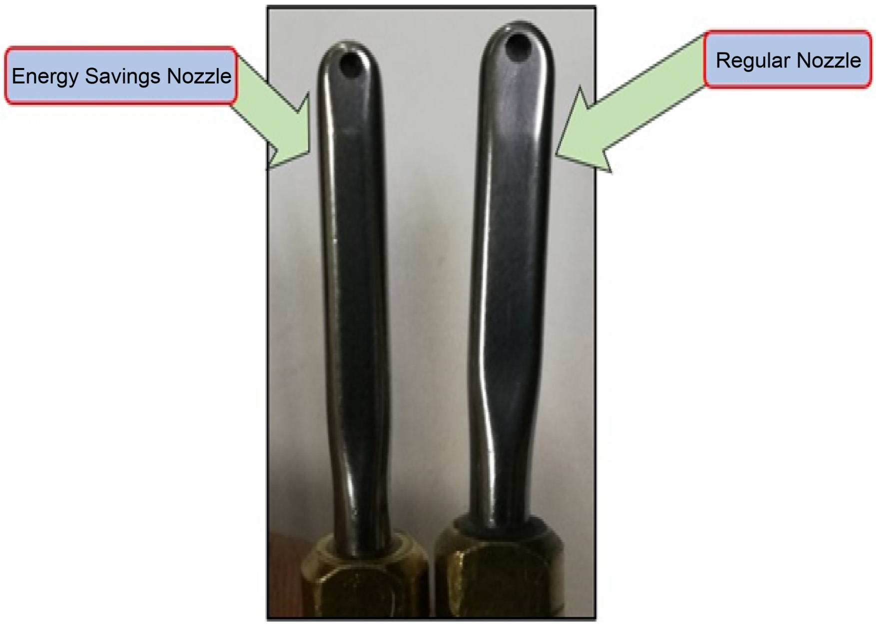


Figure 2. Regular nozzle & energy savings nozzle.

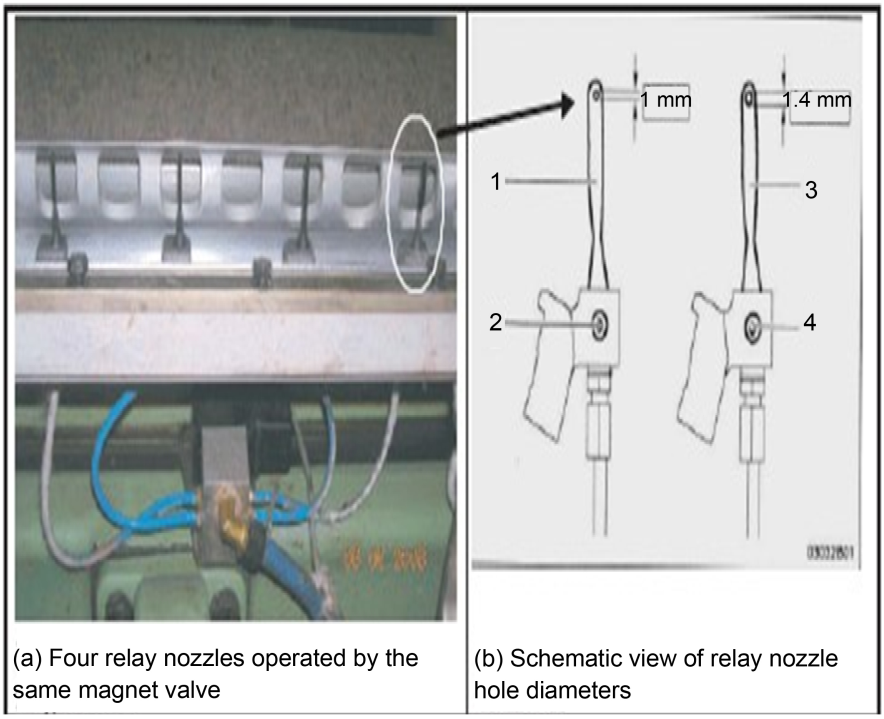


Figure 3. Detailed view of relay nozzles on loom.

in this section which is shown in Table 1. Here, we alternately employed these two different nozzles in the same machine while collecting data using a CFM (Cubic Feet per Minute) meter.

5.1.4. Experimental Data

For this experimental work, we have taken five different fabric construction and

Table 1. Machine & fabric parameter for various relay nozzle.

Parameters	Regular Nozzle	Energy Saving Nozzle
Machine Brand	TSUDAKOMA ZAX9100	TSUDAKOMA ZAX9100
Machine Speed (RPM)	750	750
Machine width (cm)	190	190
Reed Count (Dent/Inch)	23.5	23.5
Fabric Weave	3/1 RHT	3/1 RHT
Fabric Construction	8RSL + 9RSL × 10L70D/63 × 48	8RSL + 9RSL × 10L70D/63 × 48
	7OE × 9OE/66 × 38	7OE × 9OE/66 × 38
	20Ry × 150L40D/110 × 64	20Ry × 150L40D/110 × 64
	7OE × 10OE/63 × 35	7OE × 10OE/63 × 35
	7OE × 8L40D/55 × 43	7OE × 8L40D/55 × 43
Total number of Loom Used	20	20
Total Nozzle used per Loom	30	30
Relay Nozzle Diameter (mm)	1.4	1
Cost of Relay Nozzle Set	1500	1000

mounted them on 20 machines. In **Table 2**, we have organized our data which got from machine. Firstly, we checked the machine thoroughly and run this with a regular nozzle. In the meantime, we measured the airflow with a CFM meter and have taken the exact data. Secondly, we have replaced these regular nozzles with energy savings nozzles for the same machine of the same fabric construction. Then we have taken data from the energy savings nozzle and compared it with the regular nozzle. We have adopted data on air consumption more than five times and recorded the average data in the datasheet. During this work, the electrical and mechanical setting of these machines was the same.

CFM—The most popular unit of measurement for airflow is CFM or cubic feet per minute. Square units are used to measure areas (like square feet). Cubic units are used to measure volumes (such as the volume of air in a room), and CFM measures how many cubic feet may be exchanged or transported every minute shown in **Figure 4** [7]. [1 CFM is 1.699 m^3/h] [8].

From the experimental data, we see that the utilization of compressed has reduced due to using of energy savings nozzle for every construction of the fabric and also show that the reduction percentage is higher. No significant effect on machine efficiency was observed due to the relay nozzle hole diameter change.

Table 2. Machine efficiency & CFM data from running machine.

Machine No	Fabric Construction	Machine Efficiency (%)		Total CFM		CFM Reduction	Reduction (%)
		Regular Nozzle	Energy Saving Nozzle	Regular Nozzle	Energy Saving Nozzle		
1040	8RSL + 9RSL × 10L70D/63×48	95.1	96.21	61.38	45.35	16.03	26.12
1043	8RSL + 9RSL × 10L70D/63 × 48	95.31	95.81	62.79	47.21	15.58	24.81
1062	8RSL + 9RSL × 10L70D/63 × 48	94.25	93.31	61.14	44.31	16.83	27.53
1068	8RSL + 9RSL × 10L70D/63 × 48	96.98	96.21	62.29	43.94	18.35	29.46
1113	7OE × 9OE/66 × 38	97.32	95.65	63.63	54.35	9.28	14.58
1115	7OE × 9OE/66 × 38	95.13	95.81	64.98	55.81	9.17	14.11
1117	7OE × 9OE/66 × 38	93.64	94.78	63.17	53.81	9.36	14.82
1122	7OE × 9OE/66 × 38	95.87	96.5	62.24	52.12	10.12	16.26
1042	20Ry × 150L40D/110 × 64	98.25	100	77.28	68.19	9.09	11.76
1045	20Ry × 150L40D/110 × 64	99.15	98.15	78.94	67.25	11.69	14.81
1092	20Ry × 150L40D/110 × 64	99	98.35	77.63	69.31	8.32	10.72
1093	20Ry × 150L40D/110 × 64	100	100	77.13	70.21	6.92	8.97
1041	7OE × 10OE/63 × 35	96.75	96.1	66.74	60.98	5.76	8.63
1046	7OE × 10OE/63 × 35	95.55	95.25	67.45	59.39	8.06	11.95
1057	7OE × 10OE/63 × 35	92.21	95.36	66.38	59.87	6.51	9.81
1077	7OE × 10OE/63 × 35	95.89	96.45	67.41	59.97	7.44	11.04
1105	7OE × 8L40D/55 × 43	90.25	93.65	64.94	56.81	8.13	12.52
1125	7OE × 8L40D/55 × 43	98.15	97.85	63.21	54.18	9.03	14.29
1126	7OE × 8L40D/55 × 43	97.65	96.35	64.36	55.47	8.89	13.81
1130	7OE × 8L40D/55 × 43	95.35	95.15	64.29	56.91	7.38	11.48

CFM = Cubic feet per minute.

Figure 4. CFM meter for air consumption measurement.

5.1.5. Cost Calculation

From Table 2, we see that the average CFM for a regular nozzle is 66.87 and the energy savings nozzle is 56.78. So, the average air consumption reduction is 10.097 CFM. We can calculate it as a percentage and that value is 15.09%.

We can also show it as fabric construction-wise and get our desired savings value from Table 3.

For Regular Nozzle:

Here, the Average CFM is 66.87 & Efficiency is 96.08%.

So, We can calculate it to hours, days, and finally for one year.

Now, CFH (Cubic Feet per Hour) = CFM × 60 = 66.87 × 60 = 4012.20.

So, for 24 hours (1 day) = 4012.20 × 24 × 0.96 = 92441.08.

∴ Compressed air consumption per day for 1 machine is 92441.08 cubic feet.

Now, let the approximate value of compressed air generate cost including investment and maintenance cost which is $0.30 per 1000 cubic feet [9].

So, total cost of compressed air for 1 machine per day is = $(92441.08 × 0.30)/1000 ≅ $27.73.

Now, we can perform a calculation for 100 machines over a year.

So, total compressed air cost for 100 machines over a year is = $27.73 × 100 × 365 = $1,012,145.

∴ Compressed air cost (regular nozzle) for 100 machines over a year is $1,012,145.

For Energy Savings Nozzle:

Here, the Average CFM is 56.78 & Efficiency is 96.34%.

Now, CFH (Cubic Feet per Hour) = CFM × 60 = 56.78 × 60 = 3406.80.

So, for 24 hours (1 day) = 3406.80 × 24 × 0.96 = 78492.67.

∴ Compressed air consumption per day for 1 machine is 78492.67 cubic feet.

So, total cost of compressed air for 1 machine per day is = $(78492.67 × 0.30)/1000 ≅ $23.54.

So, total Compressed air cost for 100 machines over a year is = $23.54 × 100 × 365 = $859,210.

∴ Compressed air cost (Energy Saving Nozzle) for 100 machines over a year is $859,210.

Table 3. Fabric construction-wise machine efficiency & CFM data.

Fabric Construction	Machine Efficiency (%)		Total CFM		CFM Reduction	Reduction (%)
	Regular Nozzle	Energy Saving Nozzle	Regular Nozzle	Energy Saving Nozzle		
8RSL + 9RSL × 10L70D/63 × 48	95.41	95.38	61.90	45.20	16.70	26.98
7OE × 9OE/66 × 38	95.45	95.68	63.5	54.02	9.48	14.93
20Ry × 150L40D/110 × 64	99.10	99.12	77.74	68.74	9.00	11.58
7OE × 10OE/63 × 35	95.10	95.79	66.99	60.05	6.94	10.36
7OE × 8L40D/55 × 43	95.35	95.75	64.20	55.84	8.36	13.02
Average Data	**96.08**	**96.34**	**66.87**	**56.78**	**10.09**	**15.09**

5.1.6. Summary

Finally, we can show that our potential savings due to energy savings nozzle for 100 air-jet machines over the year is $152,935 & Individual machine savings per year is $1529.35.

5.2. Waste Reduction—Auxiliary Selvedge Waste

5.2.1. Experimental Details

Auxiliary selvedge is a dummy or false selvedge used to hold the weft yarn during the beat-up period. The eight warp threads that make up the auxiliary selvedge are often spaced apart from the final warp ends of the main fabric. Individual packets of warp yarns are supplied from a specific creel configuration positioned on the loom. Using a pair of scissors, the auxiliary selvedge is cut away from the main fabric as depicted in **Figure 5**. All shuttle-less looms employ the auxiliary selvedge on the left or finishing (of the weft insertion) side. The weft yarn is held by the auxiliary selvedge during beat-up. After beat-up, some fabric is woven, and the auxiliary selvedge, which includes both polyester ply yarn and weft fringe, is separated from the main fabric by being cut with a pair of scissors and accumulated in the appropriate waste box.

In this part, we used 7 warp yarns (**Figure 6**) as auxiliary selvedge waste instead of 8 warp yarns (**Figure 7**) to hold the weft yarn. For this experiment, we need to change some machine settings because the machine company provides the instruction to use 8 warp yarns to complete the weave perfectly. So, we can reduce waste by using 7 warp yarns and also savings an amount for this purpose.

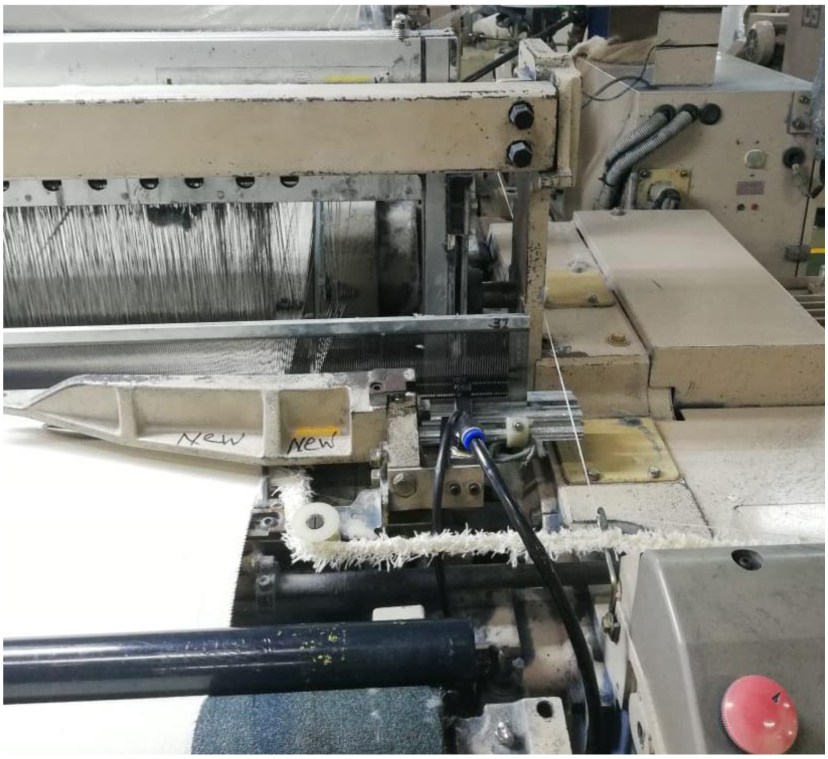


Figure 5. Auxiliary selvedge waste.

Figure 6. Warp waste-7 yarn.

Figure 7. Warp waste-8.

5.2.2. Experimental Data

We used two alternative fabric constructions with cotton and polyester cloth for this project. We mounted them in two machines and repeatedly ran them with eight warp waste yarn and seven warp waste yarn. We finally learned what we wanted. Machine Parameter is shown in **Table 4**.

Table 4. Machine parameters & waste reduction data.

Parameters	8 Warp Waste Yarn	7 Warp Waste Yarn
Machine Brand	TSUDAKOMA ZAX9100	TSUDAKOMA ZAX9100
Machine Speed (RPM)	850	850
Machine width (cm)	190	190
Reed Count (Dent/Inch)	23.5	23.5
Fabric Weave	3/1 RHT	3/1 RHT
Fabric Construction	20Ry × 150L40D/110 × 64 7OE × 9OE/66 × 38	20Ry × 150L40D/110 × 64 7OE × 9OE/66 × 38
Total number of Loom Used	2	2
Warp Beam Length (Yds)	860	860
Waste Yarn Count	32/2	32/2
Total Package Used	8	7
Machine Setting	WBS—28 Shed Angle—30°	WBS—32 Shed Angle—32°
Machine Efficiency (%)	96.34	96.47
Fabric Quality	No Defect Visible	No Defect Visible
Fabric Inspection Point	12.14 per 100 Square yards	13.54 per 100 Square yards

5.2.3. Cost Calculation

8 Warp Waste Yarn:

Consider the reference data table which is Table 4.

Length of each warp waste yarn in auxiliary selvedge = Total beam length = 860 yds (for 1 machine/day).

No. of warp waste yarn used in auxiliary selvedge = 8

Total weight of warp waste yarn in auxiliary selvedge

$$= \frac{8 \times 860 \text{ yds}}{840 \times \text{Yarn Count}(\text{Ne})}(\text{lbs}) = \frac{8 \times 860 \text{ yds}}{840 \times 32/2}\text{lbs}$$

$= 0.52$ lbs per day for 1 machine

So, total warp waste used in auxiliary selvedge for 8 yarn during the production of 1 machine/day is 0.52 lbs.

Now, we can perform a calculation for 100 machines over a year.

∴ Total warp waste generates for 100 machines over a year is,

$= 0.52 \times 100 \times 365$ lbs

= 18,980 lbs or 8610 KG

Finally, total warp waste used in auxiliary selvedge for 8 yarn per year for 100 machine is 8610 KG.

7 Warp Waste Yarn:

Consider the reference data table which is Table 4.

Length of each warp waste yarn in auxiliary selvedge = Total beam length =

860 yds (for 1 machine/day).

No. of warp waste yarn used in auxiliary selvedge = 7.

Total weight of warp waste yarn in auxiliary selvedge

$$= \frac{7 \times 860 \text{ yds}}{840 \times \text{Yarn Count}(\text{Ne})}(\text{lbs}) = \frac{7 \times 860 \text{ yds}}{840 \times 32/2} \text{lbs} = 0.45 \text{ lbs}$$

So, Total warp waste used in auxiliary selvedge for 7 yarn during the production of 1 machine/day is 0.45 lbs.

Now, we can perform a calculation for 100 machines over a year.

∴ Total warp waste generates for 100 machines over a year is

= 0.45 × 100 × 365 lbs

= 16,425 lbs or 7450 KG

Finally, total warp waste used in auxiliary selvedge for 7 yarn per Year for 100 machine is 7450 KG.

5.2.4. Summary

So, yearly waste reduction quantity due to decreasing one yarn is

= (8610 − 7450) KG

= 1160 KG

Yarn cost per KG is $3.85.

So, Total Potential Savings per Year for 100 machine is (1160 × $3.85) or $47. We also say that warp waste reduction percentage due to decreasing one yarn is 13.47%.

6. Results

So, the summary of our work is that the potential savings per year for 100 machines for air consumption reduction is $152,935 and for auxiliary selvedge waste reduction is $4745. From Table 5, we found the summary of this project work.

Table 5. Result of the project work.

Result of the Project Work							
Project Parameters	**Project Materials**	**Quantity/ Machine (1 Day)**	**Avg. Eff (%)**	**Cost/Machine (1 Day)**	**Reduction/ Machine (1 Day)**	**Savings/100 Machine (1 Day)**	**Savings/Year (For 100 Machines)**
Air Consumption Reduction	Regular Nozzle	66.87 CFM	96.08	$27.73	10.09 CFM	$419	**$152,935**
	Energy Savings Nozzle	56.78 CFM	96.34	$23.54			
Waste Reduction-Auxiliary	8 Warp Waste (Regular)	0.52 lbs	96.34	$0.91	0.07 lbs	$13	**$4745**

Selvedge Waste	7 Warp Waste (Experimental)	0.45 lbs	96.47	$0.78

7. Recommendation

According to my above observation, I can recommend some action for the betterment of cost minimization.

- At first, we need to create consciousness among the top management about the effectiveness & profitability of cost reduction initiatives. In this report, I have presented only two factors. We need to do this analysis for all possible parameters of our company to minimize the process cost. When the owners' body will realize the profitability, they will agree to take corrective action.
- Therefore, it is recommended that the minimum possible relay nozzle diameter that is suitable for the filling yarn linear density used is determined and we can save more than $0.15 M per year in air-jet weaving machine.
- Another thing is that we can save more compressed air by maintaining preventive maintenance of machines where all types of leakage will be recovered and also, we should use air-gun during cleaning.
- We should check every air-jet machine properly during running to avoid any type of air leakage.
- We can use the Automatic Relay Valve Drive (ARVD) function in machines for the cotton fabric to save a lot of compressed air.
- In the second part of the work, we can strongly recommend that by decreasing one warp waste yarn we can save a lot of amounts per year from this project.
- Waste also can be reduced by maintaining the standards of machine running check list.

8. Conclusions

The air consumption and waste reduction on air-jet looms in a weaving mill were reduced through an experimental study. Firstly, on looms with single-holed nozzles, relay nozzles with 1.4 mm-diameter holes were switched out for 1.0 mm-diameter ones, resulting in a 15% decrease in air usage. Secondly, auxiliary selvedge waste reduction of more than 13% in a year by applying a weft insertion setting and decreasing one warp waste yarn. Thus, the weaving mill was able to save approximately a total saving of ($152,935 + $4745) or a Total of $157,680 per year from energy costs and waste reduction with almost no expense.

In conclusion, our study demonstrated that using single-holed relay nozzles with smaller hole diameters and making the shortest machine modifications on air-jet looms might significantly cut energy costs and reduce waste for weaving mills without sacrificing loom performance or efficiency.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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