

Influence of draw frame passages on fibre orientation in sliver and air vortex spun yarn quality

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This study examines the impact of the Integrated Draw Frame (IDF) process, a method gaining popularity in recent years, on fibre orientation and yarn quality of air vortex spun yarns compared to the conventional Non-Integrated Draw Frame (Non-IDF) process. The effects of IDF and Non-IDF passages on sliver orientation parameters, such as cutting ratio, combing ratio and extended fibre percentage, are evaluated in both carding and finisher draw frame slivers. Yarns produced through the Non-IDF route exhibit higher yarn strength and elongation, complemented by better fibre alignment, lower unevenness percentages and fewer imperfections compared to those produced via the IDF process. Similarly, slivers from the Non-IDF process demonstrate superior cutting ratio, combing ratio and extended fibre percentage compared to slivers from the IDF route. This improvement is attributed to the additional doubling and drafting processes employed in the Non-IDF method, which result in more parallelised, straightened and oriented fibres. Although the yarn quality in the IDF process is slightly lower than that of the Non-IDF process, the manufacturing cost is reduced by Rs. 1.17/Kg in the IDF process.

Keywords: Air Vortex, Combing ratio, Cutting ratio, Extended fibre percentage, IDF process, Non-IDF process

1 Introduction

The structure of air-vortex spun yarns is a key determinant of their quality and performance¹. The properties of air-jet spun yarns are influenced by the number of draw frame passages, type of card (Non-IDF or IDF card), main draft, inter-jet distance, injector and twisting jet pressures and production speed¹⁻². Among these, draw frame passages play a crucial role in determining the characteristics of the final yarn product³⁻⁷.

Understanding the intricate dynamics between the draw frame passages and the quality of air vortex spun yarn is pivotal for the textile industry⁸⁻¹⁰. Yarn quality is influenced by various factors, such as tensile strength, evenness, and structural integrity. Moreover, meeting the demands of modern consumers requires yarn that is not only of high quality but also sustainable and cost-effective¹¹⁻¹⁴.

The influence of draw frame passages and other preparatory processes on the quality and structure of air-vortex spun yarn remains a relatively understudied area¹⁵⁻¹⁸. However, some studies have shown that increasing the draw frame speed can lead to a decrease in sliver orientation, which in turn results in a decrease in yarn tenacity and modulus, but an

increase in yarn bulk and elongation¹⁹⁻²⁰. Additionally, the preparatory process, such as carding and drawing, can significantly impact the orientation of slivers and the properties of air-vortex spun yarns²¹⁻²⁵.

While the air vortex spinning method has gained popularity, a noticeable gap remains in research regarding the impact of draw frame passages on yarn quality and the structure of the yarn produced. There are no proper recommendations on the optimal number of draw frame passages required for air vortex spinning. Furthermore, the effect of draw frame passages on the fibre orientation of vortex yarn has not been extensively studied.

There is insufficient research on the effect of draw frame passage on key air-vortex yarn parameters like fibre extent, hook extent, direction of hook and fibre migration. Understanding the relationship between draw frame settings, fibre types, and yarn characteristics is essential for optimising the production process²⁶⁻²⁸.

The findings of this study are expected to contribute to the field of textile engineering by bridging the existing knowledge gap. Yarn spinners will benefit from optimised production processes, leading to higher-quality yarn, reduced production costs and increased competitiveness in the market^{29,30}. This study aims to unravel the complexities of the relationship between draw frame passages and the quality of air-vortex spun yarn, providing new insights into the field.

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2 Materials and Methods

2.1 Materials

Viscose, polyester and cotton fibres were sourced from Sri Cheran Synthetics (Pallava group), Tamil Nadu, India. Their key properties are presented in Table 1. Air-vortex yarns were produced in two

Table 1— Fibre properties

Parameter	Viscose	Polyester	Cotton
Fibre fineness	1.2 d	1.4 d	4 μ g/inch (1.42 d)
Fibre length, mm	38 (cut)	38 (cut)	30 (2.5% span)
Elongation, %	17	23	8
Strength, g/d	2.6	6	2.4
Crimps/cm	1.5	5	-
Trash, %	-	-	3

counts, 30 Ne and 40 Ne, using three fibre types: 100% viscose, 100% polyester, and a 65/35 polyester/cotton (P/C) blend.

2.2 Methods

2.2.1 Production of Air Vortex Yarn

Air-vortex yarns were produced using two preparatory routes: First process flow involved an IDF (Integrated Draw Frame) card, a finisher draw frame and a vortex machine. The second process flow included a Non-IDF card, breaker draw frame 1, breaker draw frame 2, finisher draw frame and vortex machine (Murata Vortex MVS870EX Model). The process parameters used in the production of air vortex yarn are listed in Table 2.

Table 2 — Machinery and process parameters used in yarn production

Parameter	Viscose		Polyester		P/C blend	
	Carding					
Delivery hank, Ne	0.10		0.10		0.10	
IDF draft in IDF process	1.50		1.50		1.50	
Cylinder speed, rpm	450		450		400	
Delivery speed, m/min	180		180		180	
	Breaker DF passage 1: Non-IDF process					
Delivery speed, m/min	500		500		500	
No. of doublings	6		6		6	
Bottom roller (front zone, mm)	40		40		40	
Bottom roller (back zone, mm)	44		44		44	
Break draft	1.7		1.7		1.7	
Total draft	6.35		6.35		6.35	
Delivery hank, Ne	0.1		0.1		0.1	
	Breaker DF passage 2: Non-IDF process					
Delivery speed, m/min	500		500		500	
No. of doublings	6		6		6	
Bottom roller (front zone, mm)	40		40		40	
Bottom roller (back zone, mm)	44		44		41	
Break draft	1.7		1.7		1.7	
Total draft	6.35		6.35		6.35	
Delivery hank, Ne	0.1		0.1		0.1	
	Finisher draw frame					
Delivery speed, m/min	500		500		500	
No. of doublings	6		6		6	
Bottom roller (front zone, mm)	40		42		40	
Bottom roller (back zone, mm)	44		52		44	
Break draft	1.7		1.7		1.7	
Total draft	8		8		8	
Delivery hank, Ne	0.14		0.14		0.14	
	Vortex					
Yarn count, Ne	30	40	30	40	30	40
Delivery speed, m/min	400	380	400	380	400	380
Air pressure, MPa	0.57		0.57		0.57	
Spindle	M1		M1		M1	
Top setting, mm	39		39		39	
Bottom setting, mm	41		41		41	
Break draft	3.8	3.8	2.6	2.6	3.8	3.8
Condenser, mm	3	2	3	2	3	2



Fig. 1 — Schematic diagram of the apparatus used to determine fibre orientation

2.3 Evaluation of Sliver and Yarn Characteristics

Card sliver, finisher sliver and yarn were tested for structural and performance parameters, as discussed below.

2.3.1 Measurement of Fibre Orientation

Fibre orientation in slivers was measured following the method of Lindsley^{15,28}. The apparatus used is shown schematically in Fig. 1. The procedure comprised the following steps:

Step 1: A sliver of adequate length was taken, and the delivery direction was marked by lightly twisting one end from which it was delivered from the machine, designating the leading end as forward and the trailing end as backward. The top three plates (P, Q and R) were removed, and the sliver was placed onto the bottom plate D and secured by repositioning the top plates using clamping screws.

Step 2: The sliver was combed gently in the forward direction to remove all loose fibres that were not clamped by the plates Q and D. The combed-out fibres were discarded. Then the fibres were cut using a sharp razor blade at the right edge of the plate Q. The cut portion was weighed (W_f).

Step 3: The top plate Q was removed, and the fibres held beneath it were combed. The combed-out fibre portion was retained and weighed (C_f).

Step 4: The top plate Q back was repositioned to its original position. The extended fibre ends beyond plate Q were cut and weighed (E_f).

Step 5: Plate Q was removed, fibres were cut at the edge of plate R, and the portion was weighed (N_f).

Step 6: Steps 1–5 were repeated in the backward direction to obtain the corresponding fibre portion weights (W_b , C_b , E_b , and N_b , respectively).

Step 7: Measurements were repeated on several samples, and average values were used for calculation.

The various sliver orientation parameters were determined using the formulas below in both the forward and backward directions of slivers.

$$\text{Combing ratio (CO.R)} = \frac{C}{(E+N)} \quad \dots (1)$$

$$\text{Orientation index (OI)} = \left(1 - \frac{E}{N}\right) \times 100 \quad \dots (2)$$

$$\text{Cutting ratio (CR)} = E/N \quad \dots (3)$$

$$\text{Proportion of curved fibre ends } (\rho) = \frac{E}{(E+C+N)} \times 100 \quad \dots (4)$$

$$\text{Coefficient of relative fibre parallelisation } (K_{rp}) = \left[1 - \frac{(C)}{(C+N+E)}\right] \times 100 \quad \dots (5)$$

where C is the weight of the combed-out portion; E, weight of the extended portion after combing; and N, weight of the material after combing and cutting under the side plates.

Further, fibre hooks % and LCT length (mean length) in the sliver were tested using the LCT (Length Control Fibre Length Tester).

2.3.2 Testing of Yarn Parameters

The various yarn parameters tested, the standards used, and the number of tests conducted are presented in Table 3.

3 Results and Discussion

The fibre orientation parameters of carding slivers and finisher draw frame slivers are presented in Table 4.

3.1 Influence of Draw Frame Passages on Fibre Hooks %

Figure 2 shows that, in card slivers, the Non-IDF card sliver produces a higher proportion of fibre hooks than the IDF card sliver. The draft, associated with the IDF card sliver, reduces the percentage of hooks by effectively removing most

of the trailing hooks coming out from the card. As a result, the fibre hook percentage is lower in IDF card sliver.

In the finisher draw frame slivers, the overall hook percentage decreases due to the drafting and

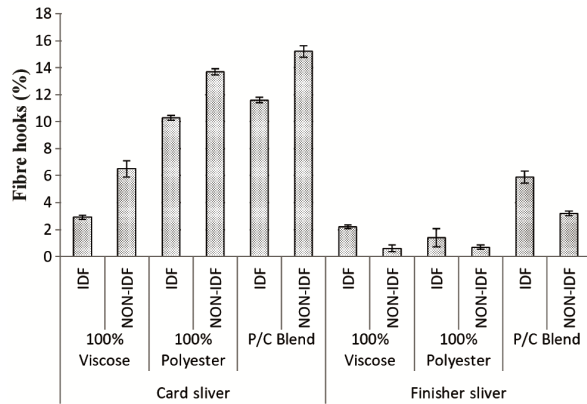


Fig. 2 — Fibre hooks in card and finisher draw frame sliver

doubling actions during drawing. The Non-IDF route undergoes three draw frame passages—two breaker draw frames and one finisher draw frame—before spinning, whereas the IDF route has only one finisher passage. Due to the additional draw frame passages, the Non-IDF finisher draw frame sliver has fewer hooks compared to the IDF finisher draw frame sliver. Consequently, Non-IDF finisher slivers exhibit fewer hooks than IDF finisher slivers.

Fibre type also influences the proportion of hooks. As shown in Table 4, 100 % viscose sliver has the lowest hook percentage, while the 100 % polyester and P/C blend slivers exhibit higher hook percentages. This can be attributed to differences in fibre length and variations in fibre parameters (Table 1), resulting in variations in the drafting processes of IDF and Non-IDF systems.

Table 3 — Details of yarn characteristics tested

Parameter	Instrument used	Test method	Number of tests
Yarn count	Wrap reel	ASTM D1907-07	3 tests/cone = 18 test
Single yarn strength & breaking elongation	Uster tensojet 4	ASTM D 2256-02 (500 mm test length at 5000 mm/min extension rate)	20 tests/cone = 120 test
Yarn evenness, imperfection and hairiness index - H (cm/cm)	Uster – UT5	ASTM D 1425-09 (at 400 m/min for 1 min)	1 test/cone = 6 test
Yarn classimat faults	Uster classimat tester - quantum 2	ASTM D 6197-99 (2005)	1 test/cone = 6 test

Table 4 — Card and finisher sliver fibre orientation characteristics

Parameter	100% Viscose				100% Polyester				P/C Blend				
	Card sliver		Finisher D/F sliver		Card sliver		Finisher D/F sliver		Card sliver		Finisher D/F sliver		
	IDF	Non-IDF	IDF	Non-IDF	IDF	Non-IDF	IDF	Non-IDF	IDF	Non-IDF	IDF	Non-IDF	
Fibre hooks %	2.2	6.5	2.9	0.6	10.3	13.7	1.4	0.7	11.6	15.2	5.9	3.2	
LCT length, mm	35.69	33.59	36.07	36.03	30.99	29.4	34.67	35.04	27.11	25.23	26.67	31.61	
Cutting ratio	Forward	0.3	0.34	0.30	0.28	0.33	0.51	0.21	0.18	0.64	0.71	0.35	0.22
	Backward	0.32	0.4	0.28	0.22	0.36	0.58	0.21	0.16	0.70	0.73	0.31	0.20
	Average	0.31	0.37	0.29	0.25	0.35	0.55	0.21	0.17	0.67	0.72	0.33	0.21
Combing ratio	Forward	0.14	0.17	0.12	0.11	0.12	0.16	0.14	0.12	0.15	0.19	0.12	0.10
	Backward	0.16	0.21	0.11	0.09	0.18	0.19	0.13	0.09	0.24	0.28	0.10	0.07
	Average	0.15	0.19	0.12	0.10	0.15	0.18	0.14	0.11	0.20	0.24	0.11	0.09
Orientation index	Forward	85.5	85.03	86.76	87.95	87.69	83.77	89.91	91.95	80.84	78.59	87.67	91.67
	Backward	84.5	82.93	88.43	90.84	81.84	81.5	90.6	92.03	78.86	74.16	90.00	92.80
	Average	85.00	83.98	87.60	89.40	84.77	82.64	90.26	91.99	79.85	76.38	88.84	92.24
Proportion of curved fibre ends (ρ)	Forward	10.6	13.5	11.6	7.8	10.95	13.9	9.3	8.3	10.9	12.9	10.1	7.6
	Backward	11.1	14.8	10.3	8.2	14.3	15.6	11.7	8.2	12.0	14.7	12.1	7.3
	Average	10.85	14.15	10.95	8.00	12.63	14.75	10.5	8.25	11.45	13.80	11.10	7.45
Coefficient of relative fibre parallelisation (K _{rp})	Forward	75.83	71.82	76.5	80.2	81.7	63.5	82.9	86.2	61.0	58.3	74.1	82.3
	Backward	74.67	67.45	77.1	81.6	81.1	63.0	82.6	85.5	60.4	54.7	76.4	83.1
	Average	75.25	69.64	76.80	80.90	81.40	63.25	82.75	85.85	60.70	56.50	75.25	82.70

3.2 Influence of Draw Frame Passages on Fibre Orientation Parameters

Table 4 and Figure 3 illustrate the effect of draw frame passages on the fibre orientation parameters.

3.2.1 Effect on Cutting Ratio, Combing Ratio and Orientation Index

Lower cutting and combing ratios, alongside a higher orientation index, indicate better fibre alignment in sliver²⁴⁻²⁶.

Figure 3 (a) illustrates that the IDF card sliver in the forward direction shows improved fibre orientation and lower trailing hooks due to its drafting system, unlike Non-IDF card sliver. Trailing hooks increase in the backward direction, leading to higher cutting and combing ratios and lower orientation index^{31,32}. Non-IDF card slivers exhibit greater variation between forward and backward directions due to more trailing hooks.

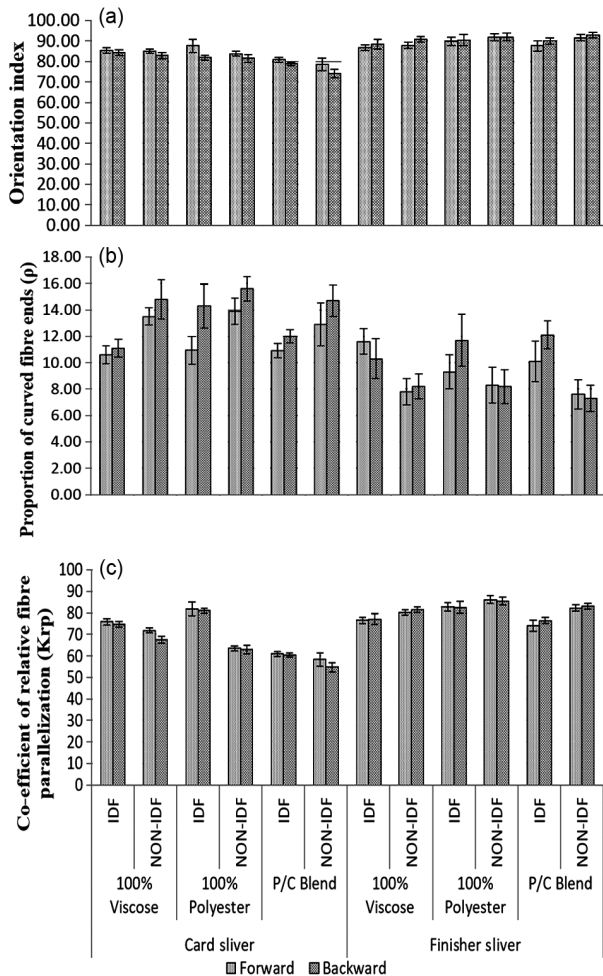


Fig. 3 — Parameters evaluated in the card and finisher draw-frame slivers included: (a) orientation index, (b) proportion of curved fibre ends, and (c) coefficient of relative fibre parallelisation

In the finisher draw frame sliver, the backward direction again exhibits slightly higher cutting and combing ratios. However, Non-IDF finisher slivers perform better than IDF finisher slivers because the additional draw frame passages substantially reduce trailing hooks. P/C blend slivers show relatively poorer orientation due to greater fibre-to-fibre friction and differences in fibre behaviour during drafting.

3.2.2 Effect on Proportion of Curved Fibre Ends and Coefficient of Relative Fibre Parallelisation

Figures 3 (b) and (c) show changes in curved fibre ends and fibre parallelisation with draw frame passages. Better fibre orientation reduces curved fibre ends (ρ) and increases fibre parallelisation (K_{rp})³²⁻³⁶. Card slivers show higher ρ than finisher slivers, with Non-IDF card slivers having higher ρ than IDF card slivers due to trailing hooks. Finisher slivers reduce ρ through increased doubling and drafting. Non-IDF finisher slivers (three passages) show lower ρ than IDF finisher slivers (one passage). ρ decreases 7 %-15 % in IDF slivers and 31 %-42 % in Non-IDF slivers due to better drafting, with minimal directional variation in Non-IDF finisher slivers.

K_{rp} is consistently higher in finisher slivers than card slivers. Among card slivers, IDF shows better K_{rp} than Non-IDF due to enhanced parallelisation and hook removal^{37,38}. In the backward direction, K_{rp} decreases slightly due to the presence of more trailing hooks. In finisher slivers, Non-IDF shows higher K_{rp} than IDF, due to increased doubling and drafting. Minimal variation in K_{rp} between forward and backward directions highlights the effective removal of hooks in finisher slivers.

It is noted that K_{rp} increases by 2-10 % between IDF card and finisher slivers, and by 10-29 % between Non-IDF card and finisher slivers, highlighting the enhanced doubling and drafting efficiency in the Non-IDF finisher process.

3.3 Influence of Draw Frame Passages on Vortex Yarn Characteristics

The effects of draw frame passages on 30 Ne and 40 Ne air-vortex yarn characteristics are given in Table 5.

3.3.1 Air-Vortex Yarn (RKM) Strength

Figure 4 (a) shows that the single yarn strength is higher in Non-IDF slivers than in IDF sliver. This improvement is attributed to better fibre alignment and lower hook content. Polyester yarn exhibit the highest RKM, followed by P/C blend and viscose yarns, owing

Table 5 — Air-vortex yarn characteristics

Parameter	100% Viscose				100% Polyester				P/C Blend			
	30 Ne		40 Ne		30 Ne		40 Ne		30 Ne		40 Ne	
	IDF	Non-IDF	IDF	Non-IDF	IDF	Non-IDF	IDF	Non-IDF	IDF	Non-IDF	IDF	Non-IDF
RKM, g/tex	14.68	15.44	15.24	16.18	28.09	30.43	24.58	28.04	19.07	21.09	19.37	22.01
Elongation, %	8.19	7.84	8.14	9.6	8.83	9.5	8.05	9.17	7.7	8.87	7.1	8.49
U, %	10.44	9.47	11.68	10.95	10.9	10.2	13.51	11.92	13.38	11.57	14.63	12.59
Thin, -50%	8	2	33	17	16	8	81	64	92	76	108	101
Thick, +50%	13	15	59	36	17	8	50	35	64	51	85	71
Neps, +200%	7	14	26	43	4	0	7	3	17	13	72	66
Total Faults, IPI	28	31	118	96	37	16	138	102	173	140	265	238
Hairiness index	4.62	4.72	3.05	3.03	3.48	3.5	3.15	3.19	3.35	3.31	3.18	3.28

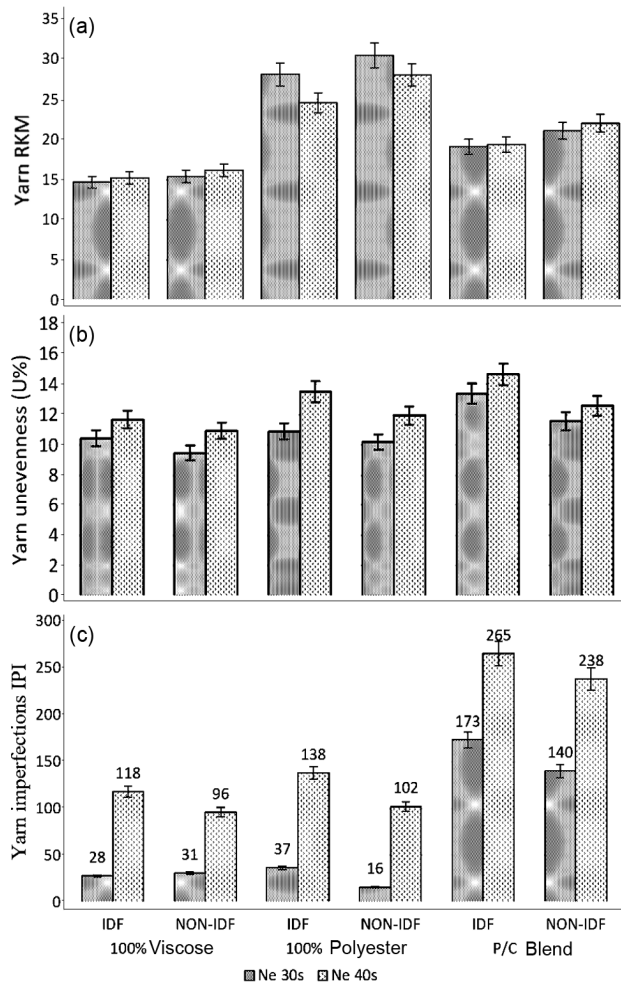


Fig. 4 — Influence of draw-frame passages on air-vortex yarn quality: (a) yarn strength, (b) yarn evenness and (c) yarn imperfections

to polyester's superior fibre strength. Although the IDF process shows lower RKM due to inferior fibre orientation, the elongation values for IDF and Non-IDF yarns do not differ significantly.

3.3.2 Yarn Evenness (U%)

Yarn unevenness (U%) is higher in the IDF process than in the Non-IDF route [Fig. 4 (b)], due to less effective fibre dedusting, parallelisation, and orientation. The Non-IDF process, with two breaker draw frames and one finisher draw frame, achieves a lower U% compared to the single finisher draw frame in the IDF process.

3.3.3 Yarn imperfections (IPI)

Figure 4 (c) displays that the yarn imperfections are higher in the IDF process due to more fibre hooks and lower evenness. Non-IDF slivers, with additional doublings, show improved evenness and fewer imperfections. Higher drafting forces in air-vortex spinning increase imperfections in finer yarn counts.

3.3.4 Yarn Hairiness (H)

Table 5 indicates that there is no significant difference in yarn hairiness between IDF and Non-IDF processes, suggesting that hairiness is less sensitive to changes in draw frame passages than other parameters.

3.4 Economic Considerations of IDF and Non-IDF Process Routes

The economic aspects for both IDF and Non-IDF process routes are tabulated in Table 6.

Table 6 compares the draw frame manufacturing costs for both routes. The IDF process incurs a lower production cost (Rs. 0.91 per kg) compared to the Non-IDF route (Rs. 2.08 per kg). The higher labour, energy and maintenance costs in the Non-IDF route are due to the use of three draw frame machines, whereas the IDF route requires only a single machine. Thus, the IDF route reduces draw frame manufacturing cost by Rs. 1.17 per kg of sliver.

Table 6 — Draw Frame Manufacturing cost of IDF and Non-IDF process

Particulars	Manufacturing cost in Rs./ kg of sliver production		Remarks
	IDF process	Non-IDF process	
Labour cost	0.65	1.29	Labour cost Rs.660 / Operator / Shift of 8 hours.
Energy cost	0.2	0.6	Power cost @Rs.9 per unit.
Maintenance cost	0.06	0.19	10-year average maintenance cost = Rs.70000 / year / draw frame delivery.
Total manufacturing cost in Rs./kg	0.91	2.08	Manufacturing costs less by Rs. 1.17/kg in the IDF process.

4 Conclusion

This study demonstrates that draw frame passages play a decisive role in determining fibre orientation, sliver structure and air-vortex yarn quality. The additional drawing in the Non-IDF route effectively reduces fibre hooks, improves fibre alignment, and enhances parameters such as cutting ratio, combing ratio, orientation index, curved fibre ends, and fibre parallelisation. These improvements result in stronger yarns with reduced unevenness and fewer imperfections, regardless of fibre type or yarn count. Although the Non-IDF system produces better sliver and yarn quality, it incurs higher manufacturing costs due to increased labour, energy consumption and machine maintenance. Conversely, the IDF route offers lower production cost with moderate yarn quality. Thus, the Non-IDF route may be preferred for producing better-quality yarns.

References

- Kumar A, Ishtiaque S M, Salhotra K R & Senthil K M S, *Indian J Fibre Text Res*, 33 (2008) 451.
- Kumar A, *Indian J Fibre Text Res*, 22 (2004) 321.
- Perel J, *Text Res J*, 52 (1982) 376.
- Deluca L B, *Text Res J*, 35(1965)858.
- Garde A R, Wakandar V A & Bhaduri S N, *Text Res J*, 31 (1961) 1026.
- Ghosh G C & Bhaduri S N, *Text Res J*, 38 (1968) 535.
- Simpson J, Sands J E & Flori L A, *Text Res J*, 40 (1970) 42.
- Alam K, Rahman M, Li M, Rahman A M D, Ahmed M A, & Islam T, *SPE Polymers*, 6 (2025) 1.
- Karakan G & Çeven E K, *J Eng Fiber Fabr*, 18 (2023) 1
- Wang M, Wang P & Gao W, *Text Res J*, 116 (2025) 2277.
- Simegnaw A, *Int J Text EngProc*, 5 (2019) 22.
- Tyagi G K & Shaw S, *Indian J Fibre Text Res*, 37 (2012) 27.
- Ramasamy K M, Duraisamy R & Mammo H, *Int J Eng Trends Tech*, 67 (2019) 157.
- Kumar P, *Int J Eng Res Tech*, 5 (2016) 814.
- Barella A & Vigo J P, *J Text Inst*, 68 (1977) 263.
- Sankara Kuthalam E & Senthil Kumar P, *J Text Inst*, 108 (2016) 449.
- Chattopadhyay R & Sarkar R, *Indian J Fibre Text Res*, 11 (1986) 19.
- Morton W E & Summers R J, *J Text Inst Proc*, 40 (1949) 106.
- Lindsay C H, *Text Res J*, 21 (1951) 39.
- Das D, Ishtiaque S M & Dixit P, *J Text Inst*, 103 (2012) 676.
- Ishtiaque S M, Mukhopadhyay A & Kumar A, *J Text Inst*, 98 (2007) 501.
- Simpson J & Patureau M A, *Text Res J*, 40 (1969) 956.
- Zou Z, *Indian J Fibre Text Res*, 39 (2014) 296.
- Basal G, *Text Res J*, 76 (2006) 492.
- Erdumlu N, Ozipek B & Oztuna A S, *Textile Res J*, 79 (2009) 585.
- Ortlek H G, Nair F, Kilik R & Guven K, *Fibre Text East Eur*, 16 (2008) 17.
- Ozedemir H & Ogulata R T, *Fibre Text East Eur*, 19 (2011) 37.
- Lindsay C H, *Text Res J*, 21 (1951) 39.
- Hearle J W S & Gupta B S, *Text Res J*, 35 (1965) 788.
- Audivert R, *Text Res J*, 41 (1971) 365.
- Balasubramaian N, Supanekar S D & Nerukar S K, *Text Res J*, 45 (1975)296.
- Punj S K, Debnath S & Chowdary A, *Indian J Fibre Text Res*, 26 (2001) 251.
- Balasubramanian N & Bhatnagar V K, *Text Res J*, 41 (1971) 750.
- Kumar A, Ishtiaque S M & Salhotra K R, *Indian J Fibre Text Res*, 33 (2008) 451.
- Salhotra K R, Ishtiaque S M & Kumar A, *J Text Inst*, 97 (2006) 271.
- Audivert R & Vidiella J E, *Text Res J*, 32 (1962) 652.
- Ishtiaque S M, *Indian J Text Res*, 11 (1986) 215.
- Nerukar S K, *Indian J Text Res*, 4 (1979) 63.