Journal of Engineering and Technology

of the Open University of Sri Lanka

Volume 03 No. 01 March 2015 ISSN 2279-2627

JET - OUSL

Faculty of Engineering Technology
The Open University of Sri Lanka

Journal of Engineering and Technology

Of the Open University of Sri Lanka

Volume 03 **No. 01** **March 2015** | **ISSN 2279-2627**

Content page

All corresponds should be addressed to:

Editor in Chief - Journal of Engineering and Technology
Faculty of Engineering Technology
The Open University of Sri Lanka
Nawala
Nugegoda
Sri Lanka

Telephone: +94112881314, email: nssen@ou.ac.lk

The ***Journal of Engineering and Technology*** of the Open University of Sri Lanka is a peer – reviewed journal published bi-annually by the Faculty of Engineering Technology of the Open University of Sri Lanka. The Journal accepts original articles based on theoretical and applied research in the area of Engineering and Technology in all specializations.

Statements and opinions expressed in all the articles of this Journal are those of the individual contributors and the Editorial Board or the Faculty of Engineering Technology of the Open University of Sri Lanka do not hold the responsibility of such statements and opinions.

Journal of Engineering and Technology
of the Open University of Sri Lanka (JET-OUSL), Vol. 3, No.1, 2015, ISSN 2279-2627

Facing the Future Challenges of the Sri Lankan Apparel Industry: An Approach based on Porter's Diamond Model for the Competitive Advantage of Nations

Nishika Samarasinghe[1], S. A. Ariadurai[2*] and M. E. R. Perera[2]

[1]Lanka Institute of Fashion Technology, Colombo 7, Sri Lanka
[2]Department of Textile and Apparel Technology, Open University of Sri Lanka

*Corresponding Author - email: saari@ou.ac.lk, Tele: +94112881228

Abstract – *Gaining competitiveness in the quota free trade has become a driving force for the apparel companies to adopt changes in technology and organizations to enhance productivity. While global expansion of the apparel industry historically has been driven by trade policy, by 2005, the Agreement on Textiles and Clothing (ATC) by the World Trade Organization had phased out many of the quotas that had previously regulated the world apparel industry. This caused a tremendous change in the global geography of apparel manufacturing and trade, and a restructuring of company strategies seeking to realign their manufacturing and sourcing networks to accommodate new economic and political realities. This change has brought other key factors for country competitiveness to the forefront, including labour costs, productivity, and competencies. Countries where the cost of labour is low are emerging as leaders in the lower-value assembly segments of the value chain, while countries with higher labour cost are being forced to upgrade into higher-value segments, such as branding and design that rely on high-quality human capital to maintain their competitiveness. As a result, skills of the work force in the apparel industry will become increasingly important element for developing economies to maintain and upgrade their positions in the global apparel value chain. The purpose of this study is to investigate the history of Sri Lankan apparel industry and challenges it faced in different eras and based on the experience gained propose recommendations to face the futuristic challenges of the world apparel trade based on the diamond model for competitive advantage of nations as proposed by Michael Porter.*

Key words: *Sri Lanka, Apparel Industry, Competitiveness, Diamond Model, Future Challenges*

1 INTRODUCTION

Sri Lanka's apparel industry is the most significant and dynamic contributor for Sri Lanka's economy. The industry has grown over the last three decades and has become the number one foreign exchange earner and the largest single employer in the manufacturing industry. The industry provides direct employment opportunities to over 300,000 and indirect to 600,000 (Wijendra, 2014). It is also the country's prime net foreign exchange generator since 1992. Apparel industry, recorded a historic level of US dollar 4.3 billion in 2013, and in the year 2014, year on year January to November apparel exports surged by a strong 10.35 percent to US dollar 4.458 billion, which is 94 percent of the annual apparel exports target set for the year (Hewage, 2015). Further, apparel accounts for nearly 70 percent industrial exports from Sri Lanka (Abeysinghe, 2014).

Based on these statistics, one can easily conclude that the apparel is the only success story of the country's export oriented industrialization policy adopted in 1977. In the last decade, starting from 2005, Sri Lankan apparel industry has received much credit for successfully weathering competition from exporters of developing countries and for transforming itself from a low value exporter to a high value exporter. However, a deeper analysis of the available statistics depicts a different scenario which if not arrested early may lead to Sri Lanka losing out in the world apparel trade market.

The world market share of apparel exports from Sri Lanka has declined from 1.4 percent in 2000 to about 1.0 percent by 2012. During this period, the apparel market share of Bangladesh in the world has increased from 2 percent to 5 percent, Vietnam from 1 percent to 3 percent and China from 18 percent to 38 percent. Further, during the period starting from 2005 to 2011 apparel imports from China to the USA grew by 17 percent, Vietnam by 14 percent, and Bangladesh by 12 percent while imports from Sri Lanka declined by 3 percent (Abeysinghe, 2014).

In this backdrop, the pertaining question is how did the Sri Lankan apparel industry cope with the dynamic changes that had taken place in the global textile and apparel market during the different eras and how would the apparel industry continue to face the challenges of quota free era effectively in the future?

Therefore the objective of this paper is to study the past and current situations of the Sri Lankan apparel industry and identify the future challenges that are expected to be faced by the Sri Lankan apparel industry with reference to the competitive world scenario and propose effective strategies for the industry to gain competitive advantage in the global market in order to improve its effectiveness and thus address the identified challenges.

This study is undertaken by reviewing the history of the Sri Lankan apparel industry through various published records and research articles. The current situation of the Sri Lankan apparel industry is analyzed by undertaking a SWOT analysis, based on literature review, interviews with number of industry personnel and the insights the authors have gained through the various engagements they have had in the Sri Lankan textile and apparel industry over the years.

The recommendations for the Sri Lankan apparel industry to face the future challenges and compete and improve its world market share in the apparel trade are arrived at using the Diamond Model of Michael Porter for the Competitive Advantage of Nations (Porter, 1990).

2 WORLD APPAREL INDUSTRY

Textile and apparel is one of the oldest and largest export industries in the world. It is also one of the most globalized industries. Apparel manufacturing is a springboard for national development, and often is the typical starter industry for countries engaged in export-oriented industrialization due to its low fixed costs and emphasis on labour-intensive manufacturing (Adhikari and Weeratunge, 2006; Gereffi, 1999).

In the world trade, in 2013, the textiles and apparel sector contributed nearly 4.3 percent to world merchandise exports (World Trade Organization, 2014). The main impediment to trade in the past has been the quantitative restrictions that have been in force for several decades. The restrictions on the textile and apparel industry have a long history tracing back to the 1930s, when the USA and the UK took action to limit textile imports from Japan. The emergence of some less developed countries as manufacturers of apparel together with excess capacity in many developed countries resulted in the UK and the USA negotiating Voluntary Export Restraints (VERs) with emerging economies. A series of short term and long term trading arrangements were then followed by Multi Fibre Arrangement (MFA).

While global expansion of the apparel industry historically has been driven by trade policy, by 2005, the Agreement on Textiles and Clothing (ATC) by the World Trade Organization had phased out many of the quotas that previously regulated the industry. This caused a tremendous flux in the global geography of apparel manufacturing and trade and a restructuring of company strategies seeking to realign their manufacturing and sourcing networks to accommodate new economic and political realities (Gereffi and Frederick, 2010). This change brought other key factors in country competitiveness to the forefront, including labour costs, productivity, and managerial and institutional competencies. As a result of these changes, low-cost countries such as Bangladesh, China, and India are emerging as leaders in the lower value assembly segments of the value chain, while countries such as Sri Lanka and Turkey, are upgrading into higher-value segments which rely on higher-quality human capital to maintain their competitiveness. As a result, workforce skills of the apparel industry are becoming increasingly important elements for developing countries to maintain and upgrade their positions in the global apparel value chain (Gereffi and Frederick, 2010).

The apparel industry is the ideal example of a buyer-driven commodity chain marked by power asymmetries between the suppliers and global buyers of final apparel products (Gereffi and Memedovic, 2003). Global buyers determine what is to be produced, where, by whom, and at what price. In most cases, these buyers outsource manufacturing to a global network of contract manufacturers in developing countries that offer the most competitive rates. These buyers include retailers and brand owners and are typically headquartered in the leading markets in Europe, Japan, and the United States. These companies tend to perform the most valuable activities in the apparel value chain—design, branding, and marketing of products— and in most cases, they outsource the manufacturing process to a global network of suppliers. Like all global industries, the apparel value chain relies on international standards to coordinate the activities of suppliers. By the turn of the century, most leading companies had implemented private standards and codes of conduct based on cost, quality, timeliness, and corporate responsibility in terms of labour and environmental standards (Bartley, 2005; Gereffi et al., 2001). Further, performance of the manufacturing company is measured regularly, and delivery, quality, and price are tracked over time.

While quotas were eliminated, tariffs still play a central role in global apparel trade. Average Most Favoured Nation (MFN) tariffs on apparel imports are on average around

11 percent for the EU and the US with considerable variations for product categories, in particular in the US where tariffs vary between 0 and 32 percent. In this context preferential market access has a substantial impact on global apparel trade patterns. Major preferential market access schemes can be divided into two types of agreements - regional and bilateral trade agreements and the Generalized System of Preferences (GSP) (Frederick and Staritz, 2012)

Developed countries, in particular the EU, Japan, and the US, have negotiated regional trade agreements to advance regional manufacturing networks. Developing countries have also increasingly negotiated regional trade agreements. However, negotiations and implementation have been slow, and apparel and textile products are often excluded. In addition to regional agreements, countries have increasingly negotiated bilateral trade agreements, with the EU and the US being most active in this regard. Twenty seven developed countries have provided tariff preferences to over 100 beneficiary countries through the GSP. Within the GSP, some countries have negotiated preferential access for lower-income countries. Canada and Japan have also improved preferential market access for Least Developed Countries (LDCs) in their GSP in the early 2000s.

3 SRI LANKAN TEXTILE AND APPAREL INDUSTRY

Sri Lankan apparel industry from its modest beginnings in the 1970s has emerged as the country's leading foreign exchange earner accounting for approximately 60 percent of the total industry exports from Sri Lanka for year 2000, generating direct and indirect employment to almost 1,000,000 people (The Island, 2002). The export-oriented manufacturing of clothing or the readymade apparel industry in Sri Lanka has begun in the 1970s and expanded rapidly after the introduction of trade liberalization of economy in 1977 (The Island, 2002). Direct foreign investment occupied a vital role in the early era of industry's establishment and growth, while lately domestic capital became similarly important. The MFA set up a quota system granted an assured market in EU, USA, and Canada for countries such as Sri Lanka, India, China, Hong Kong, Taiwan and Korea (Kelegama and Epaarachchi, 2003).

According to Tilakaratne (2006) during late 1990s, the apparel industry grew at 18.5 percent per annum and the export-led expansion of the industry led to the replacement of tea by apparel as the nation's largest foreign exchange earner. The growth of Sri Lankan apparel industry has been remarkable in terms of its contribution to GDP, exports, foreign exchange earnings and employment generation. Tilakaratne (2006) further discussed that a great proportion of the apparel companies in Sri Lanka are small and medium scale. Nevertheless, the small and medium scale companies export merely about 15 percent of the total exports and the apparel industry is dominated by a few large companies, which claim to about 85 percent of the total value of exports (Dheerasinghe, 2003).

The apparel industry currently has a very large installed capacity. The high level of technical and managerial skills available in the apparel industry, low cost land and the skilled and literate workforce provide the apparel industry with a comparative advantage in the region. English language proficiency is very high among the managerial levels and moderate to fair among the lower grades which is a great advantage to foreign investors.

The apparel industry's core strength lies in its ability to produce high quality goods at competitive prices, combined with an industry structure which is flexible and capable of servicing leading international brands. The Sri Lankan apparel industry is also recognized for its laudable standards of social compliance (The Island, 2002).

A wide range of reputed international branded clothing such as Victoria's Secret, Liz Claiborne, Pierre Cardin, Abercrombie and Fitch, Ralph Lauren, Tommy Hilfiger etc. are manufactured in Sri Lanka. Major global importers and retailers from the USA, EU, Australia and Japan are represented in Sri Lanka, some of whom have been carrying out operations in Sri Lanka for several years. These companies are locally owned companies and joint ventures or totally foreign owned (The Island, 2002).

Sri Lanka offers a wide range of incentives for investors. These incentives are available to both foreign and domestic investors, without preference, provided the investment is undertaken through a company incorporated in Sri Lanka (Sahoo et. al, 2003). Sites are available for investors in well-developed and fully serviced industrial estates at competitive costs within 30-50 km distance from the Colombo Port and the International Airport. The Katunayake Export Processing Zone in particular, has served as a model zone in the Asian region. Additionally investors have the option of locating their companies outside export processing zones or industrial parks and are able to lease the site or purchase land outright (The Island, 2002).

Both foreign and local companies have setup textile mills/finishing plants and many accessory manufacturing industries to support the thriving apparel industry. Raw material and accessories currently being manufactured are knitted fabric, woven fabric, buttons, zippers, hangers, yarn, thread, interlining, elastic, padding quilting and packaging (The Island, 2002). The, services offered include dyeing and finishing, screen-printing, embroidery and washing. With the introduction of high tech machinery and capital infusion, many existing companies have been automated and upgraded (The Island, 2002). One of the most important factors which have contributed to the rapid development of the apparel industry in Sri Lanka has been the highly trainable, skilled and literate workforce (The Island, 2002). Sri Lanka has a proud record in human resource development and is among the leading developing nations that have made significant headway in this area. While many companies carry out in-house training for their workforce, the state training institutions and private sector training institutions provide specialized training courses to cater to the specific needs of the apparel industry (The Island, 2002).

The technology levels of companies vary considerably with the large companies having a higher standard than the small and medium companies. Foreign owned companies and joint venture partnerships with foreign collaborators have helped in the process of technology transfer and training, the main source for technical information have been the suppliers of machinery and equipment and local research organizations. Research and development activities in the companies are low. While most of the companies concentrate on manufacturing from sketches and designs received from the customer very few companies have design and design development capabilities (The Island, 2002). The comparative safety of an assured market on account of the quota regime has encouraged the Sri Lankan apparel industry to develop a strong manufacturing culture. Accordingly the apparel industry has over the years geared itself to selling capacity to the buyers, and regrettably has neglected the need to strengthen the marketing capabilities and product design and development skills which are essential to prepare it to compete and sustain in a quota free era.

In the recent past, the global apparel industry has been subject to significant changes in terms of changes in consumer demands, changes in technology, and fierce competition. These changes have also filtered down to the Sri Lankan apparel industry and there is now considerable pressure on the industry to each higher standard of manufacturing and service. As the apparel industry is a relatively low skilled and labour intensive operation, over time there has been a shifting of manufacturing from countries such as Hong Kong, South Korea and Taiwan to low wage countries such as Bangladesh, India and Sri Lanka. As this process of shifting (or shifting comparative advantage) has continued, Sri Lanka has gradually lost its low labour cost comparative advantage (Essays UK, 2013).

It is been broadly recognized in modern times that, without innovation, companies would quickly lose their competitive edge. Thus an innovation strategy is a fundamental tool for continued growth even in difficult times (Cooper and Edgett, 2000). According to Goffin and Mitchell (2005) there are four key dimensions of innovations in the manufacturing sector. Among these four factors, new product innovation is the most important element to companies in the manufacturing sector. Nevertheless, if a company focuses only on product innovation opportunities for sustainable competiveness could be fail to see. Companies in the manufacturing sector could also generate services to assist differentiate their products; service innovation is the second dimension. Improvements could also make to the manufacturing along with delivery process, which referred to the next innovation dimension; process innovation. Finally, companies in the manufacturing sector can use business process innovation to make it easier for customers to do business with the company or to cut costs (Goffin and Mitchell, 2005).

4 SWOT ANALYSIS ON THE STATUS OF THE SRI LANKAN APPAREL INDUSTRY

For the purpose of this study a SWOT analysis on the Sri Lankan apparel industry was done and the important strengths, weaknesses, opportunities and threats are discussed below.

Strengths

One of the biggest strength of the Sri Lankan apparel industry is its higher product quality level for the current market segments. In fact among the apparel manufacturing countries, Sri Lanka is considered as one of the main countries supplying products for niche market with specialized products, especially intimate apparel (lingerie) and casual wear (Staritz, 2012).

The Sri Lankan apparel industry has also built a strong image of corporate social responsibility, in particular relating to compliance with internationally agreed employment practices, and improved social and environmental standards. As a result of this, Sri Lanka has a reputation as a country which follows labour laws and maintains good working conditions.

Improvement in the human capital base and design capabilities of the industry has facilitated the industry to promptly respond to buyers' quest for variety. These initiatives have resulted in good on time delivery with further efforts towards reducing lead-times. These non-price factors seems to have played a fundamental role in securing export orders, even though Sri Lanka is no longer a low-cost manufacturing base compared to many other apparel manufacturing countries in the region.

Another important strength of the Sri Lankan apparel industry, over its competitors, is the availability of skilled labour, educated and trainable work force coupled with management of manufacturing capacity and ability to handle high volume orders. Universities, technical colleges and other government and non-government organizations are now offering training facilities at various levels to develop various skills relating to the textiles and apparel industry. As a result of this Sri Lankan apparel industry possesses a better skilled workforce compared to the countries that are in the same market segment.

Sri Lanka being a small country with very good road network facilitates easy movement within the country to various companies spread throughout the nation.

Weaknesses

Sri Lankan apparel industry has over the years geared itself to selling capacity to the buyers, and regrettably has neglected the need to strengthen the marketing capabilities and product design and development skills which are essential to prepare it to compete and sustain in a quota free era. Thus there is a lack of marketing skills with over dependence on buying officers, and allocation of quotas resulting in low levels of marketing information, and knowledge about export marketing with hardly any marketing activities.

The country's small textile industry does not possess the capacity to supply quality fabric inputs to the Ready Made Apparels (RMA) sector. Another distinct weakness is the lack of accessory industries to RMAs, such as hand embroidery, beading, printing and washing, particularly in the intimate wear sector. Thus, Sri Lanka's RMA industry is heavily dependent on imports of textiles and accessories: an estimated 80-90 percent of fabrics and 70-90 percent of accessories are imported (Kelegama and Wijayasiri, 2004). Workers skilled in pattern-making, brassier technology, fabric technology and moulding are scarce in number. The RMA industry is increasingly moving towards low replenishment sourcing and just-in-time sourcing. This desire by retailers to order small batches of different products with increasingly short lead time requires manufacturers and distributors to be able to quickly process, fill and ship new orders. The removal of the quota system will enable buyers to procure requirements from the most efficient manufacturers posing at threat to those manufactures competing solely on price.

Lack of a strong work ethic along with high absenteeism and labour turnover is another main impediment in the apparel industry. It is estimated that average labour turnover worked out per factory is about 60 percent per annum. Taking the labour migration within the apparel industry into account, the net number of persons leaving the industry each year is estimated as 25 percent (Liyanage and Galhena, 2012).

Available studies on the Sri Lankan Apparel sector show that whilst overall factor productivity in the sector has improved since launching liberalization reforms in 1977, productivity in comparison to competitor nations has declined (Research Intelligence Unit, 2012).

Sri Lanka can no longer compete with the rest of the world as a low labour cost destination as increasing cost of labour and availability of employment in other industries and foreign employment opportunities resulting in estimated 15,000 vacancies in the apparel industry which has traditionally employed women who get a minimum wage around Rs. 20,000 (Daily Mirror, 2014).

Sri Lankan apparel industry is mainly dependent on a limited number of clients in the USA and EU markets. These two markets contribute to about 93 percent of the industries total exports. Furthermore, manufacturers have limited direct contact with leading global buyers, around 65 percent of the Ready Made Apparel (RMA) are exported via intermediary buying offices based in Sri Lanka, the disadvantage of this being that many foreign buyers and investors are simply unaware of Sri Lanka's potential to be a supplier of choice to many of them (Kelegama and Wijayasiri, 2004).

Other weakness faced by the Sri Lankan apparel industry includes inadequate focus on upstream linkage resulting in longer lead-time, limited knowledge about international environments and recent global industry developments, lack of product design and development, and low level of productivity based on international standards.

Opportunities

Sri Lankan apparel industry has the opportunity to establish a strong relationship with distributors and buyers and developing an expansion strategy for the markets with good potential. Further, there exists an opportunity to gain a higher market share by implementing an aggressive marketing strategy in the markets.

EU and USA are the leading importers of apparel in the world. The EU accounts for 34 percent and the USA for 20 percent of the imports. The three leading export destinations of Sri Lanka in the EU – the UK, Italy and France – just by themselves account for 14 percent of total apparel imports in the world. While Sri Lanka has been successful in penetrating the EU market its share in the EU market is less than 3 percent (Ceylon Today, 2014), thus there exists an opportunity to capture a bigger market share in the EU.

Further, opportunities exists in capturing the South Asian, East Asian, and other massive markets such as China, Japan, Russia, and Brazil, especially the 'high priced' apparel with designer wear and intimate apparel, a market where Sri Lankan manufacturers are now experts in manufacturing and marketing.

Another opportunity the Sri Lankan apparel industry has is the existence of free trade agreements between India and Pakistan which could be exploited to export finished apparel and to import fabrics and accessories.

As Sri Lanka is already known in the world market as a manufacturer of very high quality apparels, this reputation could be successfully exploited to increase the market share, especially in the high end market segments.

Threats

One of the bigger threats faced by the Sri Lankan apparel industry is the intensification of the competition, especially from the sub Asian member countries, before and after the phasing out of the MFA. Especially the arrival of new competitors in the Asian sub-continent such as Vietnam, Cambodia, Myanmar and Laos and increased the competition in the apparel product ranges in which Sri Lanka is involved.

Further, improvement of the former socialist economies, which have a good textile industry and a large domestic market which are highly potential and geared to meet the quality and delivery requirements especially from EU poses a threats to the Sri Lankan apparel industry.

The increase in Sri Lanka's labour costs at a faster pace than productivity is another threat faced by the Sri Lankan apparel industry. For the apparel industry to be globally competitive, they need to achieve higher productivity and on-time delivery while maintaining higher quality of finished products and competitive pricing.

The structural changes in the western retail markets have resulted in buyers changing the methods and time of sourcing. Traditional pre-season orders are being replaced by speed sourcing (last minute ordering), and more replenishment of orders (within season ordering). Change in the sourcing patterns will pose immense challenges to the Sri Lankan apparel industry in terms of shorter lead times, and improved supply chain management. Thus the necessity to reduce lead time from the manufacturers to the shop, and the distant suppliers' inability to deliver the value added apparel on time may become a greater threat to the industry.

Geographical location of the country is another disadvantage to the industry. This is because Sri Lanka is located at the furthest end of the Indian Ocean, when compared with other competitive apparel exporting countries, which export to the USA, EU and other wealthy nations.

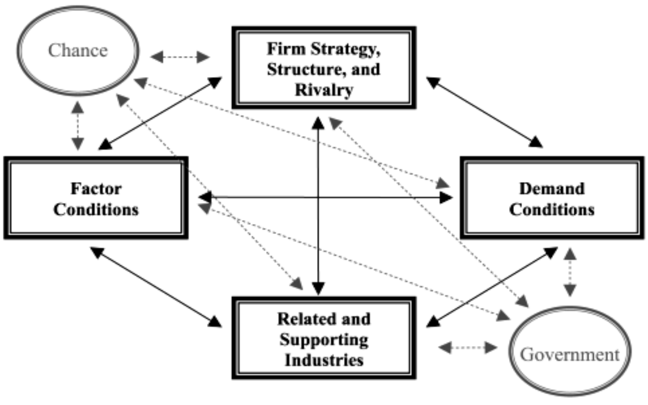
Another issue for the industry is the requirement to tighten the environmental and labour regulations in the importer's country and thus the obligation to conform to these standards.

5 RECOMMENDATIONS TO FACE FUTURE CHALLENGES

Despite the various challenges, for the period 2010-2016, Sri Lanka is ambitiously targeting a revenue of US dollar five billion from the apparel sector. According to the Sri Lanka Export Development Board's (EDB) five year strategic plan, Sri Lanka is to develop textile manufacturing and processing sector to reach a target of 30 million metres (10 million kg) and to bring in new areas such as technical textiles. Through these initiatives, the government and the EDB plan to facilitate the textile industry to play a significant role in supplying raw materials to the apparel industry and to cater to the demand (Hewage, 2014).

The future of Sri Lanka's apparel industry depends, to a large extent, on maintaining the momentum built up over the last twenty years while increasing the competitive advantage that Sri Lanka has in the international environment. A firm foundation has been laid, on which the future of this sector could be strengthened and safeguarded. Yet there is much to be done to meet the challenges of intense competition in the future.

Thus in order to arrive at the recommendations for the Sri Lankan apparel industry to face the future challenges and continue to compete and improve its world market share in the apparel trade, Porter's national competitive advantage model (Porter, 1990) has been used as the basic tool, into which the findings of the SWOT analysis done have been incorporated. Porter's national competitive advantage model constitutes four factors. He calls those factors the "diamond of national advantage". The Porters diamond model includes: factor conditions, demand conditions, related and supporting industries and firm strategy, structure and rivalry. Besides the above four factors, Porter gives weightage to a couple of factors, such as governmental policy and the role of chance of events. Governmental policy influences all the four factors through various regulatory / deregulatory measures. It can control the availability of various resources of change the pattern of demand through taxes and so on. It can encourage / discourage supportive industries through various incentives / disincentives. Similarly, chance of events, such as war or some unforeseen events like inventions / innovations; discontinuities in the supply of inputs; and so forth can eliminate the advantages possessed by competitors. This is illustrated in Figure 1.



Source: Porter (1990)

Figure 1 Porter's diamond model

Based on Porter's model, the recommendations for the Sri Lankan apparel industry to face the future challenges are given under six headings.

Factor Conditions

In the Porter's model, factor conditions show how far the factor of manufacturing in a country can be utilized successfully in a particular industry. According to this concept, for competitive advantage, contribution of the factors of manufacturing is crucial for the creation and upgrading of product. In the apparel industry the main competitive advantage factors are raw materials, labour, and production and process technologies (Mataraarachchi, 2008). Following are the recommendations that are given to improve the factor conditions of the Sri Lankan apparel industry to improve its competitiveness in future.

Raw Materials: For the industry to continue to be competitive in its existing markets it needs to make efforts to strengthen the raw material base of the apparel industry. This would help the apparel industry to reduce the lead time which is increasingly becoming a threat in losing the existing markets. If delays involved in obtaining raw material could be eliminated by attracting world class fabric manufacturers, accessory manufacturers etc., the present long lead times could be reduced.

Therefore, there is an opportunity to develop the textile industry to provide raw materials and accessories for the apparel industry in the region.

Labour: In the Sri Lankan apparel industry there is an acute weakness in management skills especially in the medium and the smaller sized level companies and these have to be developed. More skilled staff and continuous training for them can help enhance manufacturing level but its importance is generally overlooked by many companies. In this respect as a long term strategy, human resources development should be go hand in hand with educational reforms with more investments being diverted to develop designer capabilities and the marketing and management skills of the employees of the Sri Lankan apparel industry.

Increasing productivity and efficiency of labour is associated with technology enhancements as well. This should be associated with work plans and targets set according to international standards. Proper time management, maintaining accurate work measurements, proper tools to collect information pertaining to manufacturing and close monitoring with efficient methods to detect errors and inefficiencies associated with manufacturing are essential to minimize losses. Quick responses to correct errors and to avoid inefficiencies and use the most appropriate method to correct them are key elements in efficiency improvement.

Production and Process Technologies: The apparel sector is one of the most globalised industries, with market characteristics of low predictability, short product- lifecycles, high volatility and a high level of impulse purchase (Bruce et al., 2004). In this phase product development occupy a major role in revenue generation. In the current dynamic and changing environment one way to remain competitive and sustain performance is through innovation. Rapidly rising international competition in the post MFA era is forcing apparel manufacturing companies in Sri Lanka to seek ways to become more innovative. Research proves that focusing on innovation management is an ideal strategic direction to uplift current industry performances. It can be noticed that most of the apparel manufactures have implemented various innovation practices as a competitive tool. However, at the same time they are facing several issues and challenges in those practices (Ranaweera, 2014). Research and development is one of the means by which business can experience future growth by developing new products or processes to improve and expand their operations. Investigative activities that a business chooses to conduct with the intention of making a discovery that can either lead to the development of new products or procedures, or to improvement of existing products or procedures. In this respect one of the main interventions that need to be done is to increase investment for research and development by the private sector.

Demand Conditions

With reference to demand, Porter is of the view that it is not merely the size of the market that is important, but it is the intensity and sophistication of the demand that is significant for competitive advantage. If consumers are sophisticated, they will make demands for sophisticated products and that, in turn, will help the manufacturing of sophisticated products. Thus Sri Lanka needs to look at and venture into new markets within the current market areas and outside the existing market areas. Thus the opportunities that are available in the new market segments in Europe, and North America should be probed into. This segmental market penetration will increase the opportunities in different markets and will open up new business opportunities, ensuring long term sustainability in the future. As the lead time from Sri Lanka is quite high compared to the western competitors such as Mexico and Turkey who are geographically much closer to the current main markets of Sri Lanka, the Sri Lankan apparel industry should focus on new markets that are closer to the country and by usage of air freight for faster delivery. The industry also needs to look at new potential markets such as China, Japan, India, Russia, and Brazil. The Government of Sri Lanka should look into the possibility of obtaining preferential access to these massive markets.

With the intention of penetrating into new markets the apparel industry should adopt strategies to overcome the existing weaknesses. In respect of this the following course of actions are recommended.

- As Sri Lanka is no more a low cost labour country the industry needs to adopt strategies that would reduce the cost of manufacturing in other areas of the manufacturing process. This would include initiatives in lean manufacturing which leads to reduction of waste.
- The apparel industry should undertake initiatives to improve the productivity, especially to the levels of the competitor nations. Productivity can be improved by increasing the outputs keeping the inputs constant or by giving the same quantity of outputs with reduced inputs or by increasing outputs and at the same time reducing inputs. This can be done by several methods such as: improving systems and methods of operations, including automation and investment in new technology; improving planning and scheduling of operations; improving control; improving motivation of people.
- Increase the skill of the labour force, especially in specialized operations. This should be done by training and developing the workforce on the necessary skills
- Enhance and encourage local and foreign investment to enlarge the industrial base
- Develop more product focused strategies. That is the apparel industry should identify the need/s of a particular market and the obsessively deliver a solution to

the consumer who has that need. This way the apparel industry will be able to capture new markets which are in need of new products.

With respect to products following are some of the recommendations that are being made.

- Change from simple products to more complex products
- Upgrade cotton based products into more value added products.
- Sri Lankan apparel companies should gradually increase higher value products in the countries' portfolio by providing niche market products to the end customer.
- Sri Lanka's product base is highly concentrated on casual ware. Future trends in European and American markets are for casual ware rather than designer attire. Therefore the apparel industry needs to have further shift towards casual and comfortable clothes.

Venturing into new markets outside the traditional markets should be coupled with measures to reduce costs of manufacturing, increase productivity, specialize and be product focused, to train and develop manpower skills, enhance investments and adopt new and efficient technology.

Quality improvement is a precedence area, with which Sri Lanka can maximize opportunities in the developed markets. An integrated approach in quality assurance in the process from fabric to apparel can be a powerful tool in using quality as a differentiation strategy for competitive advantage.

Firm Strategy, Structure, and Rivalry

According to Porter a company operating along with its competitors as well as its complementary companies gathers benefit through a close working relationship in form of competition or backward and forward linkages. If competition is acute, every company will like to produce better quality goods at a lower cost in order to survive in the market. In this respect following are some of the recommendations for the Sri Lankan apparel industry to remain competitive in respect of strategies and structural changes.

The Sri Lankan apparel industry needs to establish a provision of physical and legal infrastructure and human resources for a futuristic business centre. This need to be complemented with extensive network client connections with business advantages such as access to larger market in neighbouring or an international shipping or aviation route which demand frequent services together with competitive incentives.

Another main strategy that the industry needs to engage is to come up with exclusive brand names from leading manufacturers. In the local market a few niche brands such as Odel, Emerald, and Envoy have emerged, while in the export apparel sector, the country has introduced home grown brands such as Amante, Arugambay, Avirate and Adithi which have already gained recognition and acceptance in regional markets. However, Sri Lankan apparel industry need to be further develop these initiatives to target and capitalize on the world top markets so as to compete with the overseas brands and establish a name for itself just like 'Ceylon Tea' has established its name in the world tea market.

As a strategy the Sri Lankan apparel manufacturers will have to target middle and upper level market (higher value apparel) and enhance the unit value realizations considerably to develop competitive advantage for the industry as whole. The leading apparel manufacturers will have to move from the "export marketing mode" to "international marketing mode". For this to take place the apparel industry needs to recognize the importance of innovations in the manufacturing sector.

Further, export alliance would be a strong means to capture the market. Small and medium sized companies with not so unique products and only limited funds available for export market development can form export alliances. This way they can exploit the market much more professionally than individual companies. In addition they can benefit by sharing the very heavy marketing expenses and the orders received from buyers.

Sri Lankan apparel industry needs to build a strategy to forge strong partner relationships by offering on-time delivery and quality performance throughout the supply chain. They need to further actively build sustainable client and supply bases by supporting the growth of customers and suppliers, through continuous value additions to products and services.

Within the apparel industry, there needs to be structural changes done to improve the efficiency of operations. Key elements of efficiency improvement are proper time management, collection of information and manufacturing, reduction of defects and wastages, work measurements, etc. These could be improved with the advanced technological compliance, improving health and safety, and building environmental friendly work practices, which would move the local apparel industry ahead of most of the other neighboring competitors. There is need for planning and programming of lead-times from the stage of raw materials sourcing to dispatching of finished apparels, which offers considerable opportunity for developing competitive advantage.

A long term plan to build professionalism and stable work force is necessary for further growth in the apparel industry. Introduction of modern machines will speed up the sewing process and assist the operator to use other advanced facilities of machines thus decreasing the needle down time. Improving the level of information availability is an important factor in building competitive advantage; timely fashion and market information is vital. Further, there is also need for continuous information follow on tracking of purchase orders.

Related and Supporting Industries

The fourth factor deals with related and supporting industries. For the apparel industry in Sri Lanka to grow it is necessary that resources must be invested to improve infrastructure facilities such as transportation, power and energy, telecommunications and waste disposal system etc. Sri Lanka would have to attract fabric mills, accessory manufacturers, marketing and training institutions, designing centres etc. Incentives and encouragement should be diverted to foster areas such as fabric design capabilities and information technology to build up a full service industry. Rising energy prices in the country is a big concern. Some of the initiatives that can be adopted to overcome this issue are:

- Investments on multi-fuel boilers that meet the requirements of steam requirements for manufacturing.
- Investment on new machinery to facilitate new manufacturing processes that consume lesser energy and are more efficient
- Relook at the traditional dyeing processes that are practiced in the textile / apparel industry with the objective to reduce dyeing time, energy costs, and margin of error.
- Development of infrastructure to provide training facilities as well as a change in attitudes to match the new challenges in the textile / apparel industry is essential to provide sufficient manpower as well as to improve quality and productivity.
- Need to have a high caliber telecommunications infrastructure along with state-of-the-art information technology system to facilitate modern trading, exchange and transfer platforms.

Government Policies

As discussed earlier as the cheap labor factor is not in existence anymore when compared to the markets such as of China, and Bangladesh, it is much advisable to concentrate on the labour cost per product than the labor cost per hour to thrive in the future.

In this respect an important area where the Sri Lanka needs to improve is governance and marketing environments. Some of the issues in this area are already discussed under the SWOT analysis. Following are some of the interventions that are required to improve the governance and marketing environments in the country.

- Environment for apparel industry growth in future
- Less political intervention in labour matters
- Improved and consistent macroeconomic environment
- International policy negotiations
- Better coordination with the industry manufacturers would be encouraging to develop a more conductive environment for apparel industry growth in future
- Need to build a conductive business environment and follow international practices.
- The apparel industry should adhere and comply with certifications such as eco-labeling, ISO 9000 and ISO 14000 to enter the new markets which would enable to build better brand image.
- The Government must improve infrastructure facilities; ensure minimum disruptions in the working environment to support the industry.

Chance of Events

These are disruptive developments outside the control of companies and governments that allow in new players who exploit opportunities arising from a reshaped industry structure. For example, radical innovations, unexpected oil price rises, revolutions, wars, etc. some of the events that cannot be controlled by the Sri Lankan government or the industry. As these are unexpected events which are beyond the control of the industry and the government nobody can have strategies to counter them. However, the industry and the governments should have the capacity built in for quick responses for such unexpected eventualities.

6 CONCLUSIONS

The Sri Lankan apparel industry is expecting to achieve US dollars 8.5 billion apparel exports by 2020. In order to achieve this target, the apparel industry needs to record year on year 12 percent growth rate (Hewage, 2015). Considering the fact that year on year growth in 2013 was 13 percent and in 2014 it was nearly 10.3 percent, on the surface, the target of 12 percent annual growth per annum may not look that difficult. However, these targets were achieved through notable increments in few specific market segments. For example, in 2013 a growth rate of 20.2 percent in knit apparel export contributed towards the overall double digit growth. Sri Lanka's exports to Japan, China, Russia and Brazil increased to 12 percent of total exports in 2014 thus contributing to the overall growth.

Thus, in order to sustain the targeted 12 percent growth per year in the next six years the apparel industry needs to be continuously bullish and continue to improve on its buyer solutions by providing them with the total solution. The Government also needs to constructively engage with the country's trade partners to obtain more concessions, especially from the emerging markets, to sustain the planned levels of growth. Further, there is a need to formulate new policy frameworks, creating new avenues to penetrate into emerging markets, particularly China. It is paramount that the Sri Lankan apparel industry implements brand promotion activities, especially in the niche market where its reputation of providing quality products to top global brands is unquestionably one of the best in the world. In this regard, the bold initiative taken by the Sri Lankan apparel industry to mark its signature in the global apparel arena by building the competitive edge over the 'Value' as opposed to the 'Volume' is highly commendable.

In conclusion, with proper strategies and focused initiatives from all the stakeholders of the Sri Lankan apparel industry, the goal of the Sri Lankan apparel industry, as stated by the Joint Apparel Association Forum, to be the premier fashion and apparel outsourcing hub and elevating Sri Lanka to "Fashionably to its Mastery" is indeed an achievable mission.

REFERENCES

1. Abeysingha, Subhashini (2014), The Time Has Come For Sri Lanka To Look Beyond Apparel Exports, Daily Financial Times, March 21, 2014, Colombo, Sri Lanka
2. Adhikari and Weeratunga (2007), Textiles and Clothing Sector in South Asia: Coping with Post-quota Challenges, in BS Chimni, BL Das, S Kelegama and M. Rahman (eds), Multilateralism at Cross-roads: Reaffirming Development Priorities, South Asian Yearbook of Trade and Development 2006, pp. 109–45. Centre for Trade and Development and Wiley India: Delhi, India
3. Bartley, T. (2005). Corporate Accountability and the Privatization of Labour Standards: Struggles over Codes of Conduct in the Apparel Industry. In H Prechel (Ed.), Politics and the Corporation (Vol. 14, pp. 211–244). Emerald: Bingley, UK
4. Bruce, M., & Daly, L., and Towers, N. (2004). Lean or Agile: A Solution for Supply Chain Management in the Textiles and Clothing Industry?. International Journal of Operations & Production Management, 24 (2), 151– 170.
5. Ceylon Today (2014), Solving the Dilemma of Export Diversification, March 24, 2014, Colombo, Sri Lanka
6. Cooper, RG, and Edgett, SJ. (2000). Developing a Product Innovation and Technology Strategy for Your Business. Journal of Research Technology Management, 53(3), 33-40. Industrial Research Institute: Arlington, USA
7. Daily Mirror (2014)., Apparel Industry in Sri Lanka Mulls Automation To Overcome Labour Woes, Mirror Business, November 21, 2014., Colombo, Sri Lanka
8. Dheerasinghe, R. (2003). Garment Industry in Sri Lanka Challenges, Prospects and Strategies. Staff Studies, 33(1 and 2), 33-72, Central Bank of Sri Lanka: Colombo, Sri Lanka
9. Essays, UK. (November 2013). Can Sri Lanka Face Financial Challenges Economics Essay. Retrieved from http://www.ukessays.com/essays/economics/can-sri-lanka-face-financial-challenges-economics-essay.php?cref=1
10. Frederick, S. and Staritz, C., (2012)., Apparel Industry Developments after the MFA Phase-out. In: Sewing Success? Employment and Wage Effects of the end of the Multi-fibre Arrangement (MFA). Volume I, The World Bank: Washington DC, USA.
11. Gereffi, G., (1999)., International trade and industrial upgrading in the apparel commodity chain. Journal of International Economics (48), 37-70. Elsevier: Amsterdam, Netherlands
12. Gereffi, G. and Frederick, S. (2010): The global apparel value chain, trade and the crisis: challenges and opportunities for developing countries. In: Cattaneo, O., Gereffi, G., Staritz, C. (eds.): Global Value Chains in a Post-crisis World., 157-208. The World Bank: Washington DC.
13. Gereffi, G. and Memedovic. O. (2003): The global apparel value chain: what prospects for upgrading for developing countries, Sectoral Studies Series, UNIDO: Vienna, Austria.
14. Gereffi, Gary, Ronie Garcia-Johnson and Erika Sasser. (2001). The NGO-industrial complex. Foreign Policy (125): 56-65. Slate Group: Washington DC, USA
15. Goffin, K., and Mitchell, R. (2005). Innovation Management (1st ed.). Palgrave Macmillan Publications: New York, USA.
16. Hewage, Indunil (2014), Lankan Apparel Exports Sees Double Digit Growth, Daily News, July 14, 2014, Colombo, Sri Lanka
17. Hewage, Indunil (2015), Apparel exports top US dollar 4.3bn up to Nov 2014, Daily News, January 19, 2015, Colombo, Sri Lanka
18. Kelegama, S., and Epaarachchi, R. (2003). Garment industry in Sri Lanka. In G. Joshi (Ed.) ApparelIndustry in South Asia: Rags or riches? Competitiveness, productivity and job quality in post-MFA environment (197-226). United Nations Publications: Delhi
19. Kelegama, S and Wijayasiri, J., (2004). Overview of the garment industry in Sri Lanka. In Saman Kelegama (ed), Readymade Garment Industry in Sri Lanka: Facing the Global Challenge, pp 13-45, Institute of Policy Studies: Cololmbo, Sri Lanka
20. Liyanage, D M., and Galhena, B L., (2012)., Determinants of Turnover Intention of Sewing Machine Operators: Case from leading Apparel Company, Kelaniya Journal of Management, Vol. 1. No. 2, pp 107-123, University of Kelaniya: Kelaniya, Sri Lanka

21. Mataraarachchi, R (2008)., An Analysis of Apparel Exports from Sri Lanka, MSc Thesis, University of Moaratuwa: Moratuwa, Sri Lanka
22. Porter, ME., (1990)., The competitive advantage of nations. Free Press: New York, USA
23. Ranaweera, HRAT., Uplifting Sri Lankan Apparel Industry Through Innovation Management to Face the Challenges in the Post MFA Era, Reshaping Management and Economic Thinking through Integrating Eco-Friendly and Ethical Practices, Proceedings of the 3rd International Conference on Management and Economics, 26-27 February 2014, Faculty of Management and Finance, University of Ruhuna, Sri Lanka
24. Research Intelligence Unit, Foot-loose: Garment sector realities, found at http://www.riunit.com/news_det.php?NewsID=17, Accessed on January 5, 2015
25. Sahoo, Pravakar., Nataraj, Geethanjali. and Dash, Ranjan Kumar., (2013)., Foreign Direct Investment in South Asia: Policy, Impact, Determinants and Challenges., Springer Science & Business Media, 383 pages
26. Staritz, Cornelia (2012)., Apparel Exports – Still a Path for Industrial Development?, Dynamics in Apparel Global Value Chains and Implications for Low-income Countries., Austrian Research Foundation for International Development: Vienna, Austria
27. The Island (2002)., Overview of the Sri Lanka Apparel Export Industry, The Island Business, April 01, 2002, Colombo, Sri Lanka
28. Tilakaratne, WM., (2006). Phasing out MFA and the emerging trend in the readymade apparelindustry in Sri Lanka. In M. Murayama (Ed.), Employment in readymade garment industry in post MFA era: The case of India, Bangladesh and Sri Lanka., Joint Research Programme Series: 140, pp 1-30, Institute of Developing Economies – Japan External Trade Organization: Tokyo, Japan
29. Wijendra, Harshani, (2014), Sri Lankan Apparel Export Position in Global Market, Textile Learner, found at http://textilelearner.blogspot.com/2014/01/sri-lankan-apparel-export-position-in.html, Accessed on January 31, 2015
30. World Trade Organization (2014), International Trade Statistics – 2014, WTO Secretariat, Geneva, Switzerland

Journal of Engineering and Technology
of the Open University of Sri Lanka (JET-OUSL), Vol. 3, No.1, 2015, ISSN 2279-2627

Sensitivity of the ICTAD Price Fluctuation Formula Procedure for the True Material Price Fluctuations in Construction Industry

S. A. Y. B. Jayasinghe*, C. S. Alahakoon, L. S. S. Wijewardena

Department of Civil Engineering, The Open University of Sri Lanka, Nawala, Nugegoda, Sri Lanka.

*Corresponding Author - email: ybhathiya@gmail.com, Tele: +94714425013

Abstract–*Some clients and contractors of long term construction projects experience that the Price Adjustment (PA) technique for price fluctuations introduced by the Institute of Construction Training and Development (ICTAD) known as the "ICTAD formula method for adjustment to contract price due to fluctuation in prices" has some uncertainty when used to calculate the contract price fluctuations. This issue arises basically due to the non-conformity of the price indices (PI) and uncertainty of the fundamental assumptions on which the ICTAD formula derivation is based on. Therefore, this paper would study on the degree of sensitivity of the ICTAD price fluctuation formula method with the true material price fluctuation. The analyses pointed that the ICTAD price adjustment seriously depended on valuation assessed, input percentage, PI and fixed coefficient (FC) - 0.966. The latter directly depends on the cost adjustment factor (CAF) and rest adjustment factor (RAF). The combined effect of all these factors are statistically analyzed using the gathered data to propose a modified FC which can address the shortcomings of the current ICTAD formula FC - 0.966. At the end of this study, a modified FC of 0.757 which allows CAF up to 51.2% and RAF up to 12.6% is proposed using the linear regression and the weighted average basis, which can be used in the ICTAD formula. This coefficient models the true price fluctuation more closely than when calculated using the current 0.966.*

Keywords: *Cost Adjustment Factor, Fixed Coefficient, ICTAD Price Adjustment, Input Percentage, Rest Adjustment Factor*

NOMENCLATURE

F - price adjustment for the period (Rs.)
V - valuation of work done during the period concerned (Rs.)
V_{na} - value of non-adjustable elements (Rs.)
P - percentage cost contribution (%)
I - index published by ICTAD
X - fixed coefficient
K – cost adjustment factor
R - rest adjustment factor

Subscripts
x – *input* X
c - current
b – base
C – conventional
F - formula

1 INTRODUCTION

Fluctuations of material prices present a range of challenges and consequences for the construction industry such as high contractor bids that include a cushion that can render the bids uncompetitive. Consequences also include dramatic contract losses and defaults, severely impacted and delayed projects and litigation resulting from efforts to mitigate, shift or recover unanticipated losses.

Application of the price fluctuations to the contract amount largely depends on the category of contract that the construction project follows. Therefore, there is a necessity of a simple mechanism to compute the price fluctuation as closely as possible to the true fluctuation so that the client as well as the contractor is both satisfied. The Institute for Construction Training and Development (ICTAD), which is the regulatory authority for the construction works related activities in Sri Lanka, has developed a general formula for adjustments to contract price due to fluctuation in prices.

This formula should model the actual price fluctuations as closely as possible and at the same time should be simple enough to be used repetitively and frequently since calculation of actual price fluctuations is a tedious task. Also, it should be applicable to any type of construction work, be it building construction, road works, irrigation works, heavy construction etc. ICTAD price fluctuation formula introduced for this purpose has been in use for quite some time but very little has been done to study the sensitivity of the formula to actual price fluctuations.

Since price fluctuations are unavoidable in long term construction projects, ICTAD price fluctuation clauses are generally included under contract conditions and a substantial amount of money is paid to the contractor to compensate for price fluctuations due to the general inflationary nature of prices. This necessitates a thorough study of sensitivity of the ICTAD formula and based on the current highly competitive nature of the construction industry any modifications required needs to be done not to disadvantage both the client and the contractor.

1.1 Aim and Objectives

The aim of this study is to evaluate on the sensitivity of the ICTAD price fluctuation formula method for the successful construction projects. Three objectives were set to achieve this aim namely; to find the relationship between ICTAD price adjustments & true price adjustments through the data analysis, to estimate the accuracy of the ICTAD formula method for the Price Adjustments (PAs) through the sensitivity analysis and to propose a modification to increase the accuracy of ICTAD formula through the statistical analysis.

1.2 Focus and Purpose of the Study

This paper will critically discuss the nexus between currently used price fluctuation computation method formulated by ICTAD and the true price fluctuation determined by the first principles i.e. the conventional method. Also, this study seeks to identify some critical causes leading to the uncertainty of the PAs due to the application of general ICTAD fluctuation formula. Required data will be collected basically from the selected construction projects, private sector organizations, experienced persons in civil engineering field etc. Thus, this paper would compare & contrast the critical causes for non-conformity of the PAs arising from ICTAD formula method and true fluctuation calculation.

2 LITERATURE SURVEY

PA clauses for a particular contract allow the contractor to submit a more realistic bid without adding an arbitrary mark-up for escalation. Price escalation is the change in cost or price of specific goods or services in a given economy over a period. The escalation in price of units reflects the inflationary trends in the economy (Chaphalkaretal & Sandbhor, 2012). A brief overview of the practice of fluctuation adjustment in other countries, confirms that there is no single fluctuation formula that suits all jurisdictions, nor a single formula to satisfy all employers and contractors (Construction industry council, 2011).

In 1973, the National Economic Development Office in UK (NEDO) established systematic PAFs, namely Baxter Formula for civil engineering works, Osborne Formula for other building works and Bespoke formula used for the specialist engineering installations (Abeysekara, 1997). These formulas operate the all the BOQ items allocated for work categories and the balance of adjustable work such as preliminary and general items, water, insurance, adjustments on the tender summary, provisional sums and work or items excluded from formula adjustment. The PA for balance of adjustable work is calculated using another formula (JCT, 2011).

Present methods for PA calculation can be divided into two approaches. First approach is the FIDIC formula for PA calculation (FIDIC, 2005). Other Asian countries, e.g. India and Pakistan, are also practicing a PA formula similar to the FIDIC formula. The responsible authority for India is Central Public Works Department (CPWD, 2007). Also, in Pakistan, the Pakistan Engineering Council (PEC) is responsible for the PA formula for contract works (PEC, 2005). Second approach is developed by the Department of Public Works (DPW) of South Africa and the relevant indices published by the Department of Statistics South Africa (Association of South African quantity surveyors, 2013). With reference to this, generally, there are two types of fluctuation calculating methods, namely conventional method and price index based formulae (formula method).

3 METHODS FOR PRICE ADJUSTMENT

In conventional method, at the time of tender the contractor will be provided with a list of the principal materials, plant and labour to be used in the contract and is expected to insert the unit prices for those resources on which bill rates are based. Then, comparing these base prices with the current prices at the time of each interim payment, the price fluctuation of selected resources will be computed (Samaraweera, 2013). Conventional method is a fully reimbursement method.

Formula method adjusts the price fluctuation based upon price indices at tender month and date of measurement. PAs will be made in accordance with the change in the Price Index (PI) of relevant resources within the contract period published by the responsible authority in the country. The Price Fluctuation Formula (PFF) will be determined by comparing the difference between the PI in effect for the base month and current month. Formula method is a partially reimbursement method.

3.1 ICTAD Fluctuation Formula

The responsible authority for both formula and the PIs in Sri Lanka is the ICTAD (ICTAD, 2007). The PIs for materials, labour, machineries and fuel are published by the ICTAD every month. There are 46 categories of materials from M1 to M46, 3 categories of labour from L1 to L3, 2 categories of machineries of P1, P2 and fuel category of P3 published in the ICTAD PI bulletin (ICTAD, 2013). In the development of this formula, two assumptions have been made, namely inputs uniformly distributed throughout the contract (Mel, 2013) and 90% of contract value is major costs and 10% of contract value is minor costs, i.e. 90% cost recovered at 40% of BOQ items (ICTAD, 2008). Latter assumption is based on the 80-20 concept of the construction economics. The general formula (contract value more than 10 Million Rupees) for PA reference to the "ICTAD formula method for adjustments to contract price due to fluctuation in prices" is as follows (ICTAD, 2008).

$$F = \frac{0.966(V - V_{na})}{100} . \sum_{\text{all inputs}} P_x . \frac{(I_{xc} - I_{xb})}{I_{xb}} \qquad (1)$$

Where;

$\sum_{\text{all inputs}} P_x . \frac{(I_{xc} - I_{xb})}{I_{xb}}$ = Fluctuation Index (Input Value Factor)

4 METHODOLOGY

4.1 Methodology Adopted

The methodology used in this study is represented in the form of a flow chart diagram in Figure 1. The analysis of the research problem is basically divided into three separate analyses namely data analysis, sensitivity analysis and statistical analysis. Data analysis represents the evaluation of the four selected construction projects with the model project for the real fluctuation scenario. As shown in Figure 2 sensitivity analysis demonstrates the investigation of the four selected construction projects for the six hypothetical fluctuation scenarios. The analyzed data gathered from both data and sensitivity analyses, finally, is evaluated under the statistical analysis to find the suitable modification for the ICTAD price adjustment formula. The short summary of the step by step approach for the methodology used in this study is as follows.

a) Collection of master BOQs, master programmes (bar charts), work norms for BOQ items and interim payments (monthly bills).

b) Preparation of resource schedules for materials, labour and plant.

c) Calculation of PA for each interim payment according to the conventional method and according to the ICTAD formula method separately.

d) Assessment of the effect of price indices used in the ICTAD formula with the true changes of prices throughout the span of the project subjecting different time frames in the master programme.

e) Determination of the closeness of ICTAD formula to the true fluctuation amount obtained by conventional method.

f) Investigation of relationship between FC with CAF and RAF considering selected projects for real and hypothetical price fluctuation conditions.

g) Development of mathematical relationship between FC and CAF with relevant to graphical form using computed data from earlier sensitivity analysis.

h) Determination of modified FC for the current ICTAD formula with the help of the statistical analysis and the weighting averages to increase the closeness of the ICTAD price adjustment to the true price adjustment.

4.2 Data, Sensitivity and Regression Analysis

Analysis of data is a process of inspecting, cleaning, transforming, and modelling data with the goal of discovering useful information, suggesting conclusions, and supporting decision-making (Bhatnagar, 2014). In this study data analysis will be carried out by using linear regression which is one of the most common methods categorized under the statistical analysis.

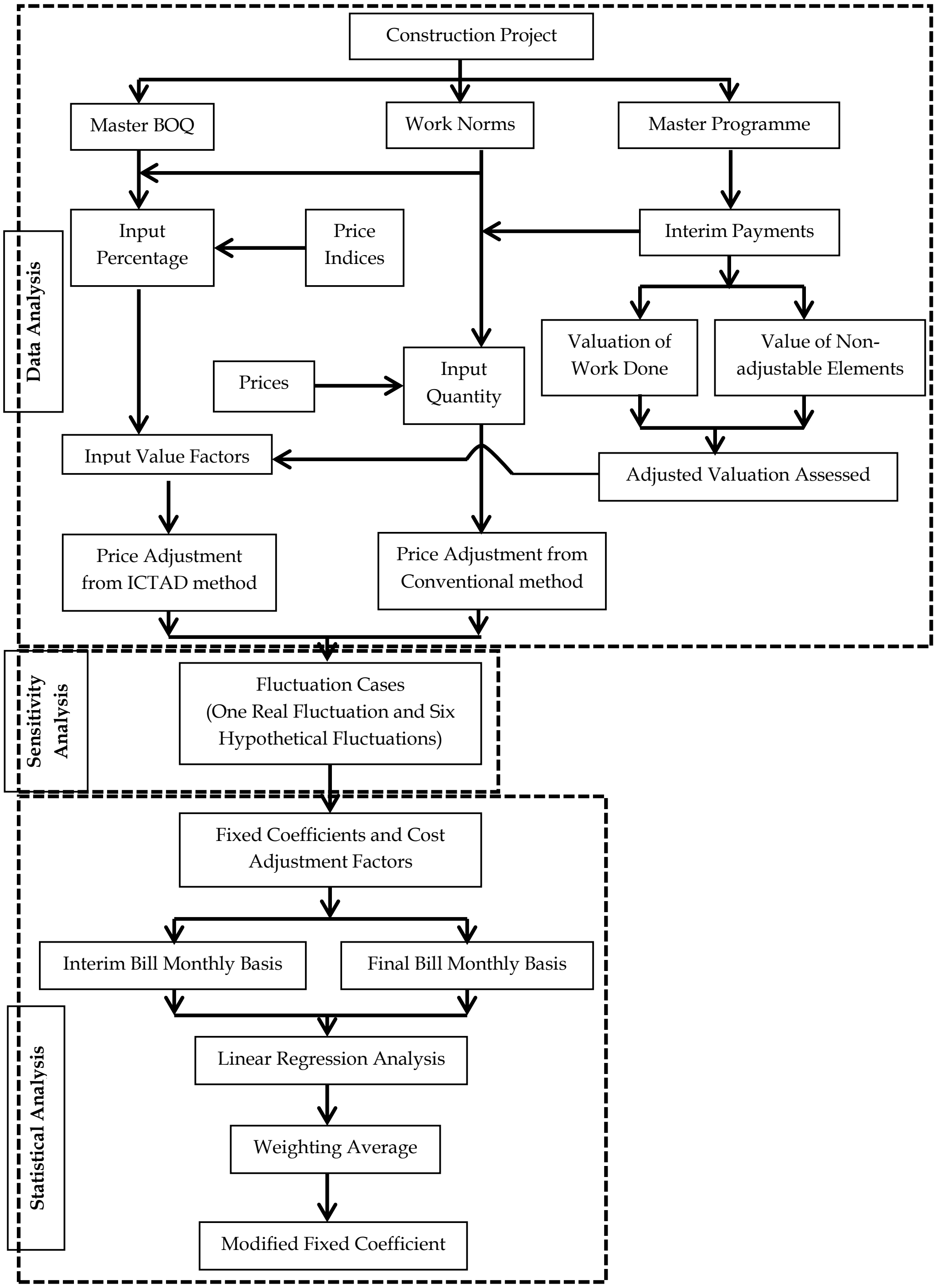


Figure1 Flow chart for research problem analysis

Sensitivity analysis of the ICTAD price fluctuation formula is the study of how the uncertainty in the output of a mathematical formula, i.e. ICTAD formula, can be apportioned to different sources of uncertainty in its inputs, i.e. input percentages, price indices, valuation assessed etc., with reference to the true PA (Dimov et. al., 2015).

Simple linear regression aims to find a linear relationship between a response variable and a possible predictor variable by the method of least squares (Montgomery et. al., 2012). The predictable variable is known as the criterion variable and is referred to as Y. The base variable is called the predictor variable and is referred to as X. In simple linear regression, the predictions of Y when plotted as a function of X form a straight line (Lawrence, 2009).

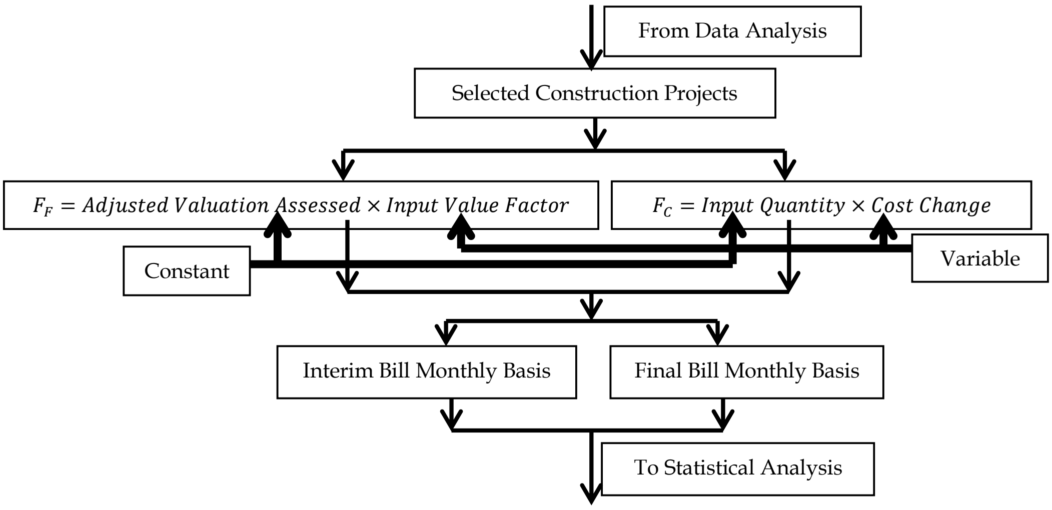


Figure 2 Flow chart for sensitivity analysis of selected projects

5 RESULTS AND DISCUSSION

5.1 Data Analysis

Data analysis is carried out to find the relationship between ICTAD price adjustments & true PAs. This section consists of several activities namely collection of master BOQs, collection of master programmes (bar charts), preparation of work norms, collection of interim payments, determination of input percentages, calculation of price indices and input value factors, computation of valuation of work done and value of non-adjustable elements, determination of PA using ICTAD method, calculation of input quantities, computation of change of costs and determination of PA using conventional method.

5.2 Results and Discussion of Data Analysis

The analysis of four numbers of long term construction projects gave the following results as indicated in Table 1 and Figure 3.

Table 1 Comparison of ICTAD formula and conventional methods

BILL NO	PRICE ADJUSTMENT							
	PROJECT NO. 1		PROJECT NO. 2		PROJECT NO. 3		PROJECT NO. 4	
	ICTAD FORMULA METHOD	TRADITIONAL METHOD	ICTAD FORMULA METHOD	TRADITIONAL METHOD	ICTAD FORMULA METHOD	TRADITIONAL METHOD	ICTAD FORMULA METHOD	TRADITIONAL METHOD
1	48,720.10	19,090.30	1,490.56	0.00	4,257.68	0.00	9,005.79	6,464.88
2	138,470.84	112,759.32	8,582.77	0.00	5,219.77	5,931.00	12,419.86	10,029.25
3	150,933.03	83,214.94	10,770.71	6,702.50	2,387.64	255.00	39,026.44	35,545.20
4	108,906.25	104,494.50	5,863.48	735.80	4,565.30	3,251.30	52,068.46	76,381.31
5	210,402.71	148,342.00	17,697.56	14,451.25	21,913.48	17,873.24	37,729.07	36,616.24
6	173,982.80	85,118.44	17,938.51	17,816.07	3,854.89	700.88	64,458.33	45,422.40
7	133,222.69	128,715.20	7,676.48	2,867.85	23,855.93	17,832.78	75,270.18	54,914.24
8	41,747.44	44,288.50	26,914.70	14,170.61	29,175.63	20,596.31	92,911.12	38,634.98
9	131,094.38	54,199.00	15,868.78	25,947.01	21,309.96	27,625.69	45,997.20	15,290.37
10	77,455.01	22,576.73	10,879.61	5,671.89	13,128.44	6,803.20	193,020.89	127,570.94
11	158,028.94	162,276.84	15,948.41	28,327.26	41,571.97	23,203.90	41,294.82	23,680.13
12	126,254.77	127,184.50	13,549.58	16,440.19	26,271.92	14,998.91	103,608.19	36,067.08
13	133,952.31	139,202.40	17,629.11	6,162.56	35,364.51	10,565.09	309,947.83	117,342.24
14	131,102.24	135,512.63	6,024.80	650.08	4,198.09	0.00	247,718.54	118,982.47
15	194,387.14	206,310.33	6,412.01	4,712.42	16,930.68	0.00	43,574.23	22,839.50
16	201,945.42	116,158.70	PROJECTS COMPLETED IN 15 MONTHS				103,410.82	53,653.95
17	141,967.69	86,663.55					49,108.80	37,096.83
18	16,269.82	21,065.10					18,021.86	0.00
TOTAL	**2,318,843.57**	**1,797,172.98**	**183,247.07**	**144,655.49**	**254,005.89**	**149,637.29**	**1,538,592.43**	**856,531.99**
DIFFERENCE	**521,670.60**		**38,591.58**		**104,368.60**		**682,060.44**	
% OF OVER-ESTIMATE	**29.03**		**26.68**		**69.75**		**79.63**	

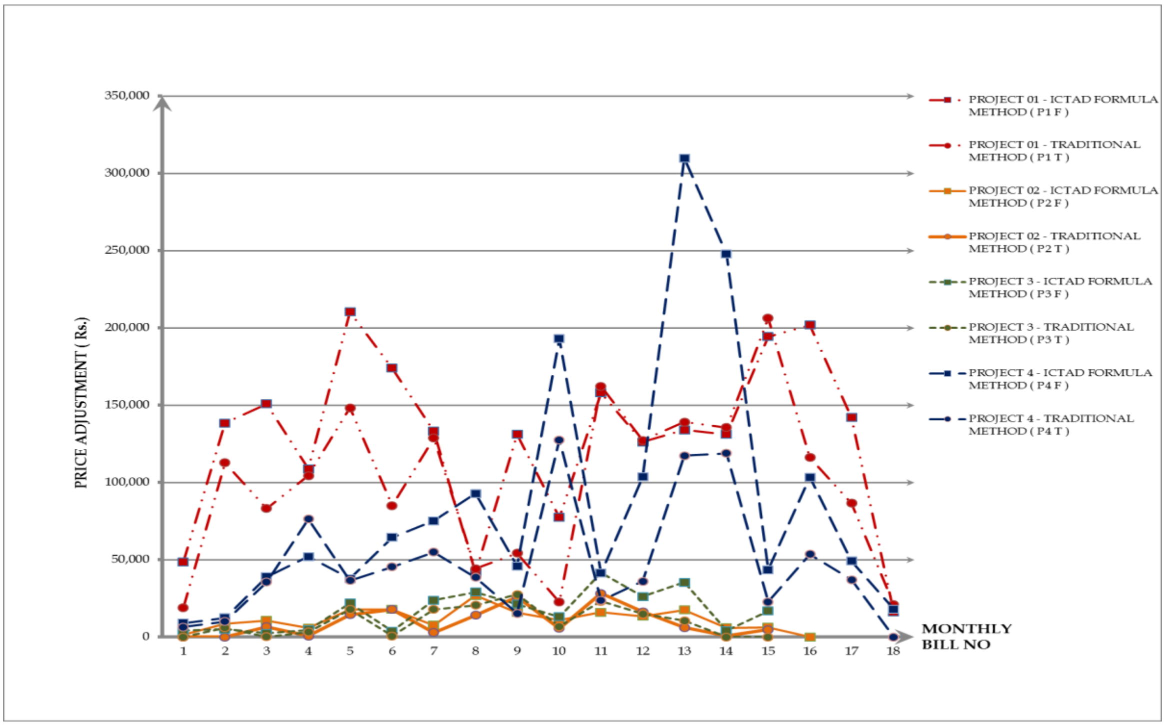


Figure 3 Price fluctuation with time in selected projects

Only the final summary of the selected project nos. 1, 2, 3 and 4 is represented here as a form of table without indicating other information and tabulations such as master BOQs, programmes, interim payments, input percentage tables etc. These results were also observed in the model project analysis and hence these selected projects further justified the pre-founded important points which are the base for this research problem analysis.

According to the data analysis adopted for selected projects as well as the model project a considerable difference is observed between the PA amount calculated by means of ICTAD method and conventional method. This fluctuation occurs due to the several contradictions between the formulae with relevant to the true situation. Analysis of model and selected projects revealed the following key points.

a) Assumption of uniformly distributed input percentages for a particular project throughout the project duration is not valid.

b) Assumption of 90% of cost recovered at 40% BOQ items for a particular contract is not valid for every project.

c) Cost adjustment factor (K) used in the derivation has a fixed value of 15% which allows for the profit (P) & overheads (OH) of the contractor. But this margin ranges generally from 15% to 35% and cannot be fixed for every project. The analyzed two projects consist of 22% of P & OH and therefore ICTAD formula need to be adjusted according to that.

d) Rest adjustment factor (R) facilitate the PA indirectly for the minor inputs and in the derivation it is assumed as 10%. However, depending on the type of the construction this factor varies accordingly and therefore it is not fair to fix it for every contract.

One of the major parameters that affect the ICTAD price adjustment is the input percentage and this value depends on an assumption that 90% of cost is recovered by 40% of BOQ items. This is based on the 80-20 concept of construction materials, i.e. each individual project, 80% of the total cost is found in 20% of the major items of materials (Bent, 1996). Basically, this assumption is not valid for every project and this can be clearly understood reference to Table 2 and Figure 4.

Table 2 Actual variation of cost of BOQ items in selected projects

PROJECT NO. 1		PROJECT NO. 2		PROJECT NO. 3		PROJECT NO. 4	
CUMULATIVE GROUP (%)	% OF CUMULATIVE AMOUNT	CUMULATIVE GROUP (%)	% OF CUMULATIVE AMOUNT	CUMULATIVE GROUP (%)	% OF CUMULATIVE AMOUNT	CUMULATIVE GROUP (%)	% OF CUMULATIVE AMOUNT
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
4.55	30.72	4.76	27.29	6.67	27.60	4.76	26.51
9.09	50.06	9.52	46.56	13.33	54.02	9.52	38.56
13.64	63.31	14.29	57.64	20.00	67.58	14.29	49.75
18.18	72.54	19.05	67.08	26.67	74.85	19.05	60.89
22.73	77.98	23.81	74.30	33.33	80.59	23.81	71.67
27.27	80.91	28.57	78.40	40.00	85.77	28.57	78.98
31.82	83.23	33.33	81.58	46.67	88.58	33.33	83.26
36.36	85.48	38.10	84.33	53.33	90.87	38.10	86.40
40.91	87.67	42.86	86.80	60.00	93.13	42.86	88.75
45.45	89.71	47.62	89.04	66.67	95.18	47.62	91.09
50.00	91.63	52.38	90.77	73.33	96.81	52.38	93.36
54.55	93.34	57.14	92.45	80.00	98.34	57.14	95.24
59.09	94.68	61.90	94.07	86.67	99.35	61.90	96.16
63.64	95.93	66.67	95.50	93.33	99.70	66.67	96.97
68.18	97.04	71.43	96.91	100.00	100.00	71.43	97.78
72.73	97.90	76.19	98.11			76.19	98.39
77.27	98.64	80.95	98.85			80.95	98.87
81.82	99.22	85.71	99.25			85.71	99.28
86.36	99.60	90.48	99.59	ONLY 15 COST GROUPS		90.48	99.57
90.91	99.78	95.24	99.87			95.24	99.85
95.45	99.91	100.00	100.00			100.00	100.00
100.00	100.00	ONLY 21 COST GROUPS				ONLY 21 COST GROUPS	

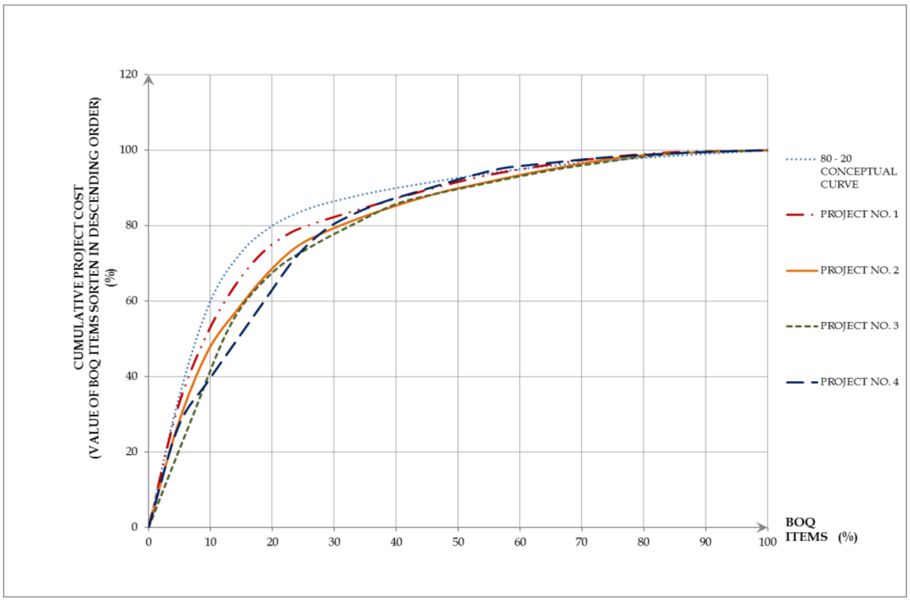


Figure 4 80-20 Concept with actual variation in selected projects

The fluctuation calculated using the formula of all selected construction projects including the model project demonstrated a considerable deviation from the true fluctuation due to the unbalance of computed input percentages. Also, the assumption i.e. input percentages are uniformly distributed throughout the project duration, is also misleading the PA amounts since this assumption is based on the period of use of particular input with corresponding input quantities. As an example, project no. 4 gave 79.6% of over-estimate due to the non-uniformly distributed input percentages. Following are some inputs in this project no. 4 which are subjected to additional payment under the ICTAD price adjustment.

Bricks – Only used in 6th, 7th and 8th months (duration 3 months), but the price index varies since the start of 1st month to the end of 18th month. When the price indices are changed the input value factor corresponding to this input gets activated producing extra cost on the total PA amount. Therefore, client must pay some additional amount to the contractor which the contractor is not actually entitled. This additional amount is Rs. 19,004.87. However, the true PA amount corresponding to the 3 month duration is Rs. 3,049.71.

3/4" Metal – Only used during 1st to 8th months (duration 8 months), but the price index varies since the start of 1st month to the end of 18th month. Therefore, the client must pay an additional amount of Rs. 12,398.33 to the contractor instead of the true reimbursement of Rs. 4,034.66.

Steel Reinforcements - Only used during 1st to 6th months (duration 6 months), but the price index varies since the start of 1st month to the end of 18th month. The true reimbursement must be Rs. 72,517.79, but additionally the client need to pay an amount of Rs. 572,811.46 to the contractor.

The total additional payment which is paid under the ICTAD price adjustment method due to the non-uniformly distributed input percentages is Rs. 654,954.57. This amount has a value of 76.5% of over-estimate and from this it is clear that the non-uniformly distributed input percentages seriously affect the ICTAD price adjustment.

The CAF and the RAF which are used in the derivation of ICTAD formula have some shortcomings due to its non-adjustability of the value. These two factors are assumed as constant for every project taking their values as 15% for CAF and 10% for RAF. These two factors are directly related to the FC, i.e. 0.966, in the current ICTAD formula and when these two factors are changed, the ICTAD price adjustment amount can be over-estimated in most cases and under-estimated in very few cases. The ICTAD publications define the CAF, i.e. K, as the factor which denotes the profit of the contractor included in the BOQ items, but practically this factor cannot be fixed for each and every construction project due to the following reasons investigated in this data analysis.

a) The selected construction projects consist of various overall profit margins depending on the type of the construction project. This margin varies from 15% to 35% and therefore the use of current ICTAD fixed coefficient of 0.966 which is based on K=15% is not reliable.

b) The contractor tends to use front loaded BOQ items and/or back loaded BOQ items when bidding and this will also make variable K values throughout the contract period. However, when calculating PA amount due to fluctuation by current ICTAD formula, for all interim payments the valuation assessed multiplied by same FC, i.e. 0.966. But the valuation assessed contributed by different CAFs and therefore an average value must be used to address this issue.

Also the RAF, i.e. R, is defined by the ICTAD as the factor which represents the PA corresponding to the minor inputs reimbursed indirectly with the major input PA amount. This factor is fixed in the current ICTAD formula and taken as 10% for all projects. On the other hand major inputs are considered to be 90%. But in the data analysis it is found that the observation of the exact 90% boundary to separate major and minor inputs in the computation of input percentages is impossible. As an example, for project no. 1 this value is taken as 91.63% and for project no. 2 this value is considered as 90.77%. Sometimes this boundary is slightly higher than 90% and sometimes it is slightly lower than 90%. Therefore, the constant RAF in the computation of input percentages reduces the sensitivity of the ICTAD price adjustment formula.

5.3 Sensitivity Analysis

Sensitivity analysis is carried out to estimate the accuracy of the ICTAD formula method for the PAs. As mentioned earlier, under the sensitivity analysis above selected four numbers of construction projects were further analyzed with respect to the periods which the price fluctuations may occur. As shown in Figure 5, six hypothetical fluctuation scenarios are used to assess the sensitivity of the ICTAD price adjustment formula and these scenarios.

As an example, scenario 1 demonstrates the first phase has no price fluctuation relative to the base month, second phase and third phase have equal price fluctuations; therefore it is named as constant; rise; rise. Similarly, scenario 2 demonstrates the first and second phases have no fluctuation, but third phase has a price fluctuation. For all selected projects one phase means a 1/3 of project duration and therefore for project no. 1, 4 one phase equals to 6 months since total project duration is 18 months and for project no. 2, 3 that is equal to 5 months since project duration is 15 months. The calculations relevant to the sensitivity analysis are similar to the calculations of the data analysis.

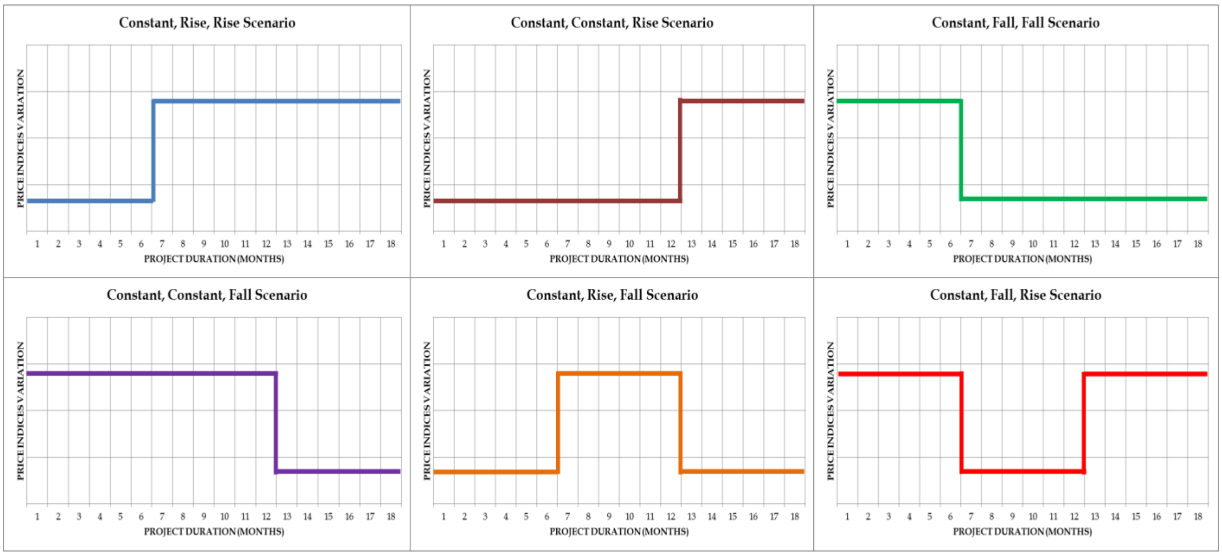


Figure 5 Six hypothetical fluctuation scenarios

5.4 Results and Discussion of Sensitivity Analysis

Table 3 and Figure 6 only represent the price fluctuation in different fluctuation scenarios for four numbers of selected projects in final bill monthly basis, i.e. fluctuation at the end of project duration. In Table 3 and Figure 6, case – 0 represent the real fluctuation observed throughout the project duration. The observed total PAs in some cases got negative and in some cases got positive. The latter represent the most common case i.e. client needs to pay corresponding PA to the contractor. But the negative fluctuation (as an example project no. 1, case 3 and 4) represents the necessity of payment of PA to the client by the contractor. This sensitivity analysis reveals the following results.

1) When the amount of PA is increased, the difference between the formula adjustment and the true adjustment also increased. This can be observed in project no. 1-fluctuation cases 0, 1, 2, project no. 2-fluctuation cases 0, 1, 2 and project no. 3-fluctuation cases 1, 2.
2) When the prices or price indices increased relative to their bases then the total fluctuation gets positive value resulting cost reimbursement to the contractor from the client. This can be observed for 0, 1 and 2 fluctuation cases for all four projects.
3) When the prices or price indices decreased relative to their bases then the total fluctuation gets negative value resulting cost reimbursement to the client from the contractor. This can be seen in all four projects for fluctuation cases 3 and 4.
4) In most cases either positive or negative PA, the ICTAD price adjustment over-estimates the true price adjustment. This is demonstrated in all four projects in fluctuation cases 0, 1, 2, 3 and 4.

Table 3 Price adjustment in different fluctuation scenarios

CASE	PRICE ADJUSTMENT							
	PROJECT NO. 1				PROJECT NO. 2			
	ICTAD FORMULA METHOD	TRADITIONAL METHOD	DIFFERENCE	% OF OVER-ESTIMATE	ICTAD FORMULA METHOD	TRADITIONAL METHOD	DIFFERENCE	% OF OVER-ESTIMATE
0	2,318,843.57	1,797,172.98	521,670.60	29.03	183,247.07	144,655.49	38,591.58	26.68
1	1,532,243.26	1,294,083.19	238,160.07	18.40	417,016.22	262,277.94	154,738.28	59.00
2	801,870.86	699,578.82	102,292.04	14.62	218,842.39	145,486.63	73,355.76	50.42
3	(491,061.74)	(458,673.85)	(32,387.89)	7.06	(393,442.52)	(247,909.90)	(145,532.62)	58.70
4	(432,976.63)	(273,855.44)	(159,121.19)	58.10	(250,352.90)	(177,052.51)	(73,300.39)	41.40
5	687,256.63	486,875.93	200,380.69	41.16	21,745.46	(4,172.84)	25,918.30	(621.12)
6	212,252.83	314,587.99	102,335.16	32.53	(37,874.40)	(17,456.16)	(20,418.24)	116.97

CASE	PRICE ADJUSTMENT							
	PROJECT NO. 3				PROJECT NO. 4			
	ICTAD FORMULA METHOD	TRADITIONAL METHOD	DIFFERENCE	% OF OVER-ESTIMATE	ICTAD FORMULA METHOD	TRADITIONAL METHOD	DIFFERENCE	% OF OVER-ESTIMATE
0	254,005.89	149,637.29	104,368.60	69.75	1,538,592.43	856,531.99	682,060.44	79.63
1	701,096.83	559,696.26	141,400.57	25.26	720,223.87	477,313.86	242,910.01	50.89
2	285,984.37	150,649.00	135,335.37	89.83	861,926.79	383,054.22	478,872.57	125.01
3	(714,942.95)	(598,385.38)	(116,557.57)	19.48	(408,098.17)	(280,655.07)	(127,443.10)	45.41
4	(331,563.71)	(127,408.50)	(204,155.21)	160.24	(415,322.05)	(244,480.29)	(170,841.76)	69.88
5	225,964.35	365,592.96	139,628.61	38.19	(32,693.14)	17,475.35	(50,168.49)	(287.08)
6	(282,554.44)	(385,296.18)	(102,741.74)	26.67	645,118.99	207,491.11	437,627.88	210.91

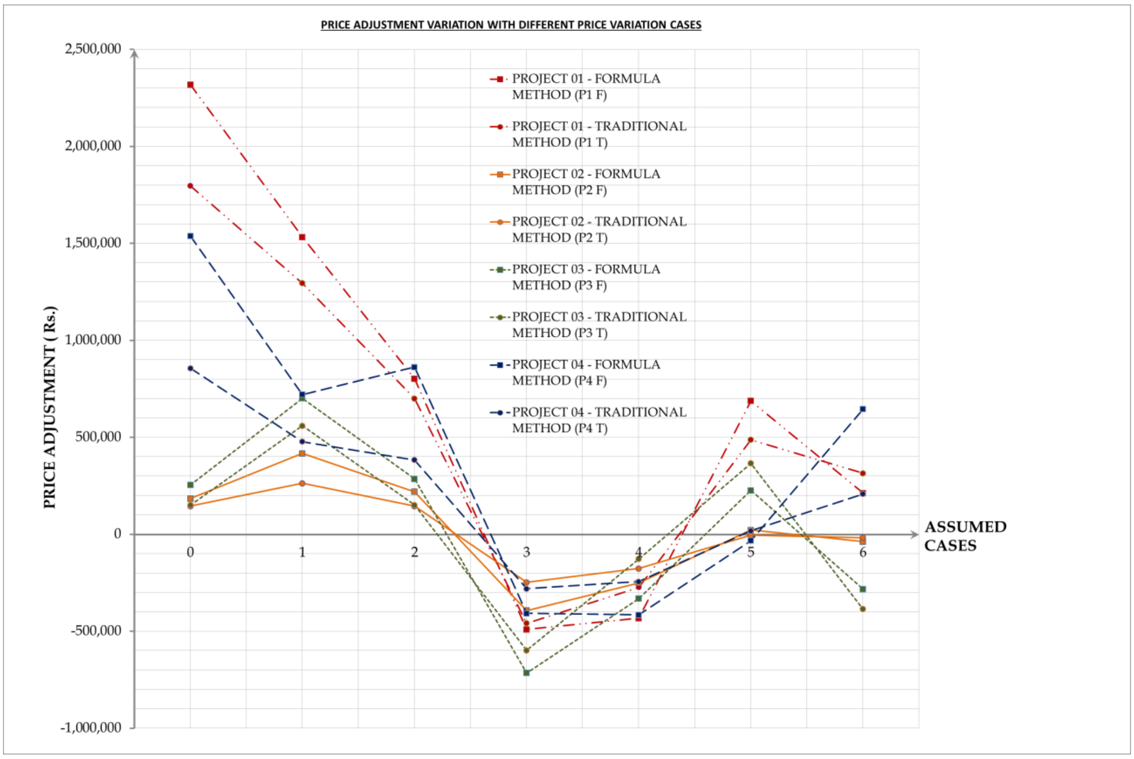


Figure 6 Price adjustment in different fluctuation scenarios

5) However, when there is rise and fall of the prices and price indices throughout the project duration, there is a tendency to become ICTAD price adjustment smaller than the true price adjustment due to the lack of sensitivity of the formula

to the true fluctuation. Out of the 28 observations only 4 observations represented this issue which can be negligible.

6) Valuation assessed is another governing factor which affects the ICTAD price adjustment and the non-realistic amounts may result over-estimates or under-estimates of the PA computed using ICTAD formula. This observation can be experienced when comparing the monthly bill PA values for different fluctuation scenarios. This can happen in the ICTAD price adjustment in any of the following two ways.
   a) If there is a particular month on which the valuation of work done contributing a very few amount of items liable to the PA, but the majority contributed by the items not liable to the PA, then the contractor would receive an extra amount of payment even with the small input value factors. This results the over-estimate.
   b) If there is a particular month with the large amount of non-adjustable elements, then the valuation assessed gets small even with the considerable amount of valuation of work done. This results a reimbursement of less PA to the contractor or client even with the large value of input factors. This results the under-estimate.

   Therefore, there should be a proper consideration when evaluating the valuation assessed in the ICTAD price adjustment formula.

7) In some fluctuation scenarios, PA computed by ICTAD formula shows a positive PA while true PA is negative. This reveals again that the cost to be reimbursed from contractor to the client, but due to the less sensitivity of the ICTAD formula client need to suffer by paying an additional amount to the contractor. This can be seen in project no. 2-fluctuation case 5. Also the vice versa situation of this issue can be observed in project no. 4-fluctuation case 5.

5.5 Statistical Analysis

Statistical analysis is carried out to propose a modification to increase the accuracy of ICTAD formula. It was justified from both data analysis and sensitivity analysis; there is a large over-estimation of the amount of PA calculated by the ICTAD formula. Therefore, the results which are collected from the sensitivity analysis including results gathered in the data analysis can be addressed by changing the FC of the current ICTAD formula to suit the selected fluctuation scenarios with different profit margins. Also, this modified FC may have some flexibility to the non-uniformly distributed input percentages. The calculation of x and K values for six different price fluctuation scenarios with corresponding real price fluctuation case for four numbers of selected construction projects provide series of observations.

The x and K values are computed considering two situations namely interim bill basis, i.e. at the end of every bill month FC and CAF will be calculated, and final bill basis, i.e. at the end of project FC and CAF will be calculated. In interim bill basis, FC is computed for each bill using the following relationship.

$$x = \frac{\frac{100.F_C}{(V - V_{na})}}{\sum_{all\ inputs} P_x . \left(\frac{I_{xc} - I_{xb}}{I_{xb}}\right)} \quad (2)$$

In final bill basis computation FC can be determined by using following relationship.

$$x = \frac{0.966.F_C}{F_F} \quad (3)$$

After calculating these x values for all interim bill basis and final bill basis for each scenario in all selected projects, following relationship is used to compute the corresponding K values where R can be taken as 10%.

$$K = \frac{100}{\frac{x}{100}.(100 - R)} - 100 \quad (4)$$

At the end of x and K computations it can be seen that the numbers of observations for four numbers of projects varied due to the zero fluctuations of the conventional method and the total numbers of observations of 286 reduces to 262. Also, practically it is not possible to have negative K value and/or a K value which is greater than 100% in the price fluctuation calculations.

Therefore, observations of K values which are negative and/or greater than 100%, were considered as outliers and hence rejected and remaining observations are taken for the statistical analysis (Taylor & Sihon, 2004). Hence, following numbers of observations are used to carry out the statistical analysis in terms of interim bill basis.

a) Project no. 1 – 50 nos.
b) Project no. 2 – 25 nos.
c) Project no. 3 – 29 nos.
d) Project no. 4 – 35 nos.

Therefore, the total numbers of observations of 262 was further reduced to 139 rejecting 123 numbers of observations due to the above mentioned reason. Also, the total numbers of observations for final bill basis analysis is 28. However, these observations reduced to 17 after the rejection of the unsuitable K values. Therefore, in this calculation only 17 observations can be evaluated since the computation of FC based on the weightages of both total conventional PA and total formula PA at the end of the project duration.

From the data analysis and the sensitivity analysis, seven different fluctuation scenarios were obtained and these scenarios yield 139 numbers of x and K values for all projects on the basis of monthly fluctuation. Also, for all selected projects 17 numbers of x and K values obtained on the basis of total fluctuation. Therefore, to conduct a regression analysis, the following two data sets can be used.

Data Set no. 1 – Interim bill basis FC and CAF values having 139 observations

Data Set no. 2 – Final bill basis FC and CAF values having 17 observations

The two data sets mentioned above provide two trend lines which are the most suitably fixed to the observed fluctuation between the FC and CAF may yield two simultaneous mathematical relationships. Solving these equations in weighted average basis, the proposed fixed coefficient can be computed. The summary of the statistical analysis based on the interim bill basis and final bill basis for selected projects are represented in Table 4.

Table 4 Summary of regression statistics for selected projects

Interim Bill Basis – For Selected Projects		Final Bill Basis – For Selected Projects	
Regression Statistics		Regression Statistics	
Multiple R	0.9851	Multiple R	0.9895
R Square	0.9704	R Square	0.9791
Adjusted R Square	0.9702	Adjusted R Square	0.9777
Standard Error	0.0278	Standard Error	0.0180
Observations	139	Observations	17

This analysis demonstrated the calculated multiple R, R squared and adjusted R squared for both models are very closer to 1. Therefore, it is justified that the linear dependency between x and K and the goodness of fit of the two regression models to observed fluctuation (Gwet, 2010).

Figure 7 and Figure 8 show the graphs in between the K variable and x based on interim bill month and final bill month respectively. The general fluctuation in both graphs is non-linear but this non-linear fluctuation can be fitted to the linear fluctuation as indicated in the same figures. These new two sets of new trend lines provide two simultaneous mathematical relationships as shown in the same figures.

The proposed modified fixed coefficient can be computed by using the weighted averages and this value is equal to the 0.757. Also, according to the modified x value, the corresponding K value can be calculated based on weighted averages and this value is equal to 51.2%. The allowable limit of RAF corresponding to both new x and K values can be calculated as 12.6%.

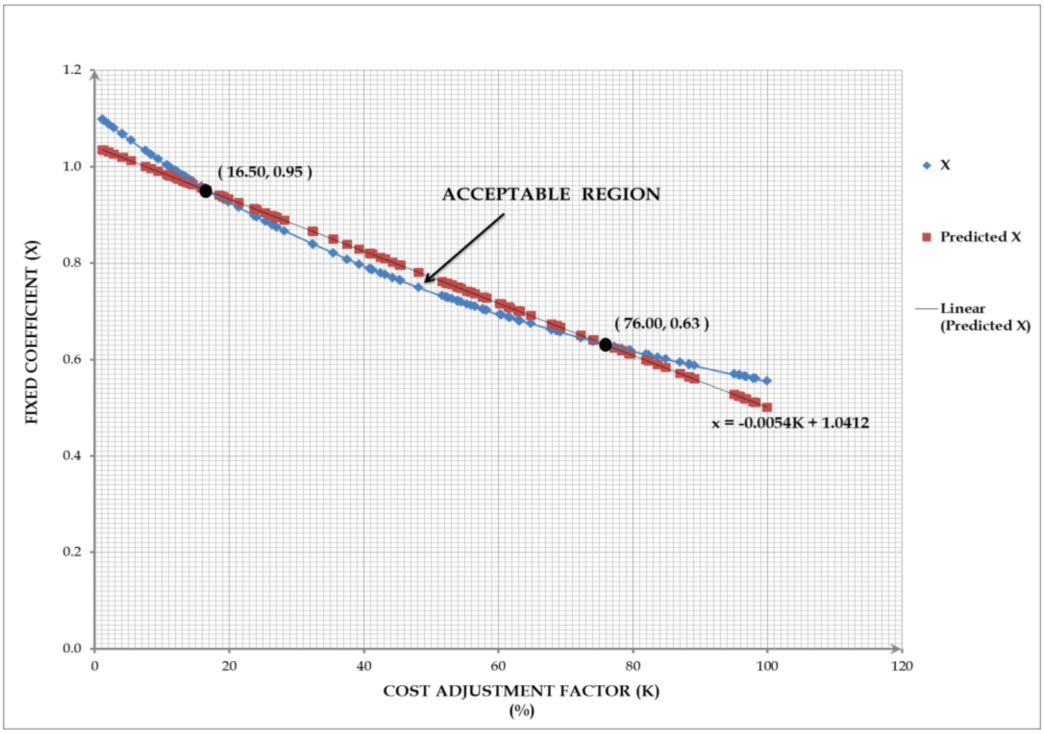


Figure 7 Variable K-line fit plot for interim bill basis – for selected projects

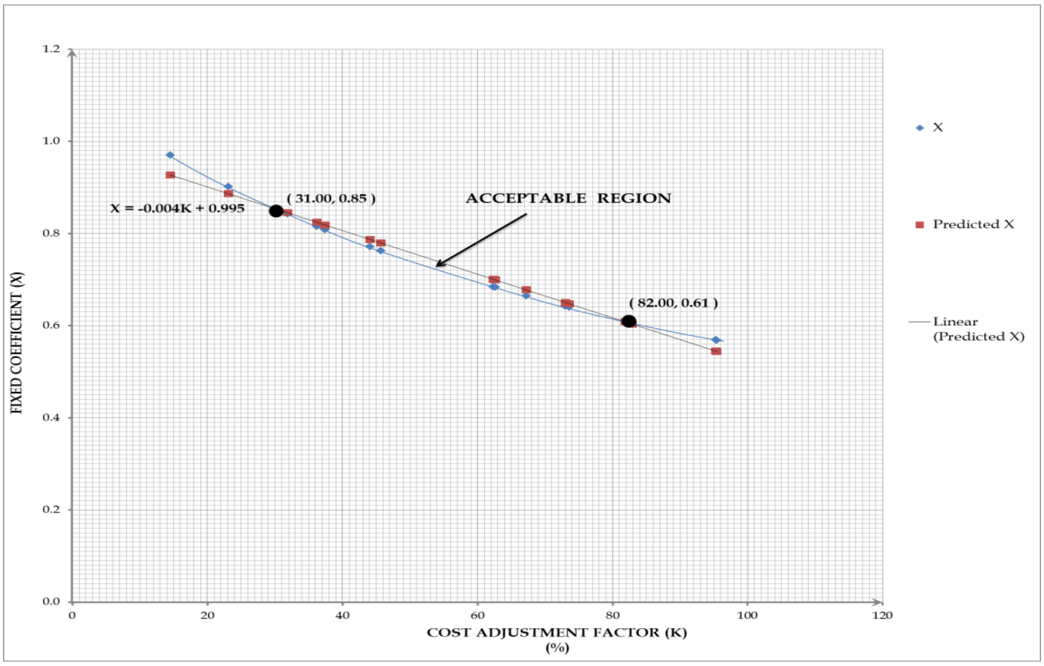


Figure 8 Variable K-line fit plot for final bill basis – for selected projects

5.6 Results and Discussion of Statistical Analysis

The statistical analysis lead to a new fixed coefficient to replace the current ICTAD fixed coefficient and the use of this modified fixed coefficient improves the sensitivity of the ICTAD price fluctuation formula while reducing the large over-estimate comparatively. Hence the modified ICTAD price adjustment formula is as follows.

$$\boldsymbol{F} = \frac{\mathbf{0.757}(\boldsymbol{V} - \boldsymbol{V_{na}})}{\mathbf{100}} . \sum_{all\ inputs} \boldsymbol{P_x} . \frac{(\boldsymbol{I_{xc}} - \boldsymbol{I_{xb}})}{\boldsymbol{I_{xb}}} \qquad (5)$$

Also, it is clear that this modified FC allows a 51.2% of contractors' average profit margin (K = 51.2%) throughout the project duration instead of the constant 15% in current FC. Furthermore, this modified FC allows a 12.6% of minor inputs (R = 12.6%) to pay in the ICTAD price adjustment indirectly. But in the current FC, only 10% is considered.

According to the ICTAD price adjustment formula, the $\mathrm{F_F} \propto \mathrm{x}, (\mathrm{V} - \mathrm{V_{na}}), (\mathrm{I_{xc}} - \mathrm{I_{xb}}), \mathrm{P_x}$ and $\mathrm{x} \propto \mathrm{R}, (1/\mathrm{K})$. Therefore, modification of x in the formula may address the R and K directly. Also, the analysis of several projects in different fluctuation scenarios with different levels of input usage i.e. construction materials usage and price indices changes addressed the valuation assessed and the price indices. The combined effect of all these factors analyzed logically through a statistical analysis gave the following result.

Modified FC	=	0.757
Allowable CAF	=	51.2%
Allowable RAF	=1	2.6%

In the current ICTAD formula above values are 0.966, 15% and 10% respectively. Since the current ICTAD price adjustment formula always over-estimated the PA, the modified FC reduced up to 0.757. But 15% of CAF increases up to 51.2% to allow the effect of front end and back end loading of the BOQ items. The 10% of RAF is also increased by a small value up to 12.6% to allow the minor inputs issue. The effect of this modified FC is represented in Table 5 and Figure 9.

Table 5 Comparison of modified FC with current FC on sensitivity of ICTAD formula

PROJECT	When X = 0.966		When X = 0.757	
	Difference	% of Over Estimate	Difference	% of Over Estimate
Model	Rs. 30,752.55	20.62 %	-Rs. 8,172.60	-5.48 %
1	Rs. 521,671.60	29.03 %	Rs. 19,974.63	1.11 %
2	Rs. 38,591.58	26.68 %	-Rs. 1,055.05	-0.73 %
3	Rs. 104,368.60	69.75 %	Rs. 49,412.87	33.02 %
4	Rs. 682,060.44	79.63 %	Rs. 349,176.57	40.77 %

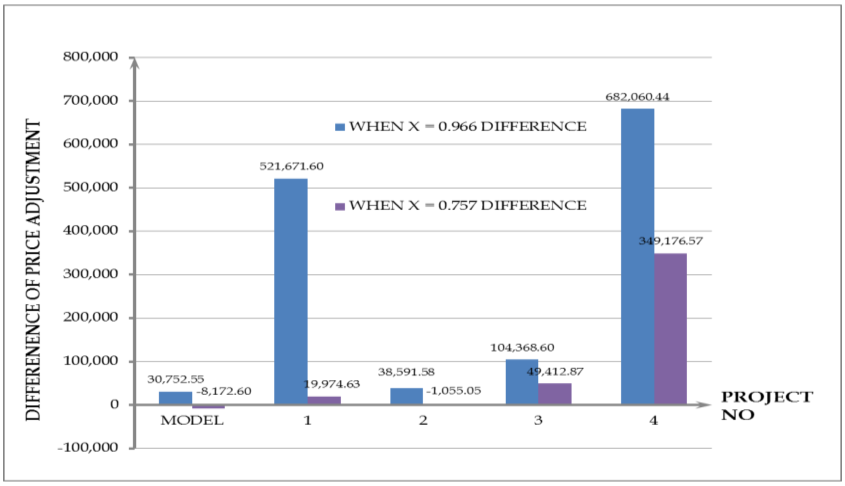


Figure 9 Comparison of modified FC with current FC on sensitivity of ICTAD formula

Comparing over-estimates resulted from the current ICTAD FC and the modified FC, it is clear that in all selected projects including model project, the over-estimates of PA drastically reduced due to the application of modified FC. Therefore, the use of this modified FC instead of the current FC may increase the sensitivity of the ICTAD price adjustment formula reducing the large over-estimations leading to more client/contractor satisfaction in the construction industry.

6 CONCLUSION

The aim of this paper is to evaluate on the sensitivity of the ICTAD price fluctuation formula method for the successful construction projects. To achieve this aim, three objectives are set as to find the relationship between ICTAD price adjustments & true PAs, to estimate the accuracy of the ICTAD formula method for the PAs and to propose a modification to increase the accuracy of ICTAD formula through the statistical analysis. Following three chapters explain the conclusion on the findings of this study with relevant to the three objectives.

(a) The data analysis on both model project and selected projects indicated that the ICTAD price adjustment formula depends on five parameters namely input percentage(P_x), price indices(I_x), cost adjustment factor(K), rest adjustment factor (R) and valuation assessed($V - V_{na}$). Also, the two basic assumptions of ICTAD formula, i.e. uniformly distributed P_x and 80-20 concept are found to be inaccurate. Furthermore, the fixed values of CAF and RAF cannot be used for every project due to its variability. Therefore, the data analysis revealed that these parameters have some shortcomings and combined effect of these issues result in a large over-estimation on the PA computed using current ICTAD formula compared to the true price fluctuation. The shortcomings which can be observed in the ICTAD fluctuation calculations cannot be seen in the conventional price fluctuation calculations due to the straightforwardness of the concept based on it. This can be explained as follows.

(i) The true PA based on the quantity of inputs which are used in the particular month and therefore if an input not used in that bill month, then the PA due to that input gets zero even with a positive or negative change of cost. Hence, in this method the over-estimates resulted due to the non-uniformly distributed input percentages are prevented.
(ii) There are no factors used for this method and PA for inputs can be directly calculated.
(iii) The true PA is based on the change of cost, but not the valuation assessed. Therefore, there are no effects from items which are not liable to the PA.

(b) The sensitivity analysis on selected projects with seven numbers of different price fluctuation scenarios indicated that in majority of cases ICTAD price adjustment was greater than the true PA. Also, when the amount of PA increases, the difference between formula adjustment and true adjustment increases. Therefore, in this analysis, the accuracy of ICTAD formula is challenged under the different fluctuation scenarios. The accuracy of the formula decreases due to the effect of valuation assessed. The valuation assessed consists of the total work done within the valuation period and this work done is contributed by inputs liable and un-liable to price fluctuation. This will lead to a large value of ICTAD price adjustment with a small input value factors. Therefore, the sensitivity analysis justified that the use of valuation assessed to compute the PA in the ICTAD formula is not sensitive to the true price fluctuation.
(c) The statistical analysis on the selected projects with their fluctuation scenarios proved that the factors related to the ICTAD price adjustment must be modified to increase the sensitivity of the ICTAD price adjustment relative to the true PA. However, individual modifications for input percentages, price indices and valuation assessed are impractical since the relationships of those factors with the PA considerably varied from project to project and fluctuation scenario to fluctuation scenario. Therefore, the combined effect of these factors is considered and from the data and sensitivity analysis it is found that the modification of FC in the current ICTAD formula can address above mentioned issues. The FC directly depends on the K and R, but it is reasonable to take R as 10% since the statistical analysis considered only the building construction projects. The variation of FC with different K values takes a form of simple parabola, but this variation can be fitted to the linear variation. The computed new FC according to the linear regression analysis and the weighted average basis has the flexibility to close the ICTAD price adjustment to the true PA.

This study was only limited to building construction projects and the selected number of samples are also limited to four. In order to arrive at a general conclusion resulting in a close representation, it is advisable to analyze at least 30 projects of varying nature. These two points are the limitations of this study. However, selection of seven fluctuation scenarios for four numbers of projects gave approximately the equivalent effect of 30 projects. The modified FC for the ICTAD formula which is computed at the end of this study has considered the effect of variation of input percentages, price indices, CAF, RAF and valuation assessed with a more logical way.

REFERENCES

1. Abeysekara, WVKM 1997, Construction contracts and claims-Project Report, OUSL.
2. Association of South African quantity surveyors 2013, Contract price adjustment provisions, Midrand, ASAQS.
3. Bent, JA & Humphreys, KK 1996, Effective project management through applied cost and schedule control, CRC Press, Florida.
4. Bhatnagar, V 2014, Data mining and analysis in the engineering field, IGI global, Hershey.
5. CPWD 2007, CPWD works manual, New Delhi, CPWD.
6. Chaphalkar, NB & Sandbhor, SS 2012, Wholesale price index and its effect on price escalation of materials for Indian construction industry, Maharashtra, IJERT.
7. Costruction industry council 2011, Guidelines on contract price fluctuation system, Hong Kong, CIC.
8. Dimov, I, Fidanova, S & Lirkov I 2015, Numerical methods and applications, Springer, Heidelberg.
9. FIDIC 2005, Conditions of contract for construction: for building and engineering works designed by the employer, Geneva, FIDIC.
10. Gwet, KL 2010, The practical guide to statistics:basic concepts, methods and meaning application with MS excel, R and openoffice calc, Advanced analytics, Gaithersburg.
11. ICTAD 2008, ICTAD formula method for adjustments to contract price due to fluctuation in prices, Colombo, ICTAD.
12. ICTAD 2007, Standard bidding document: procurement of works, Colombo, ICTAD.
13. ICTAD 2013, ICTAD statistical bulletin, Colombo, ICTAD.
14. JCT 2011, Formula rules 2011, London, JCT.
15. Lawrence, KD, Klimberg, RK & Lawrence, SM 2009, Fundamentals of forecasting using excel, Industrial Press, New York.
16. Mel, JD 2013, Basic concepts and logical approach of ICTAD formula, Colombo, ICTAD.
17. Montgomery, DC, Peck, EA & Vining, GG 2012, Introduction to linear regression analysis, John Wiley & Sons, New Jersey.
18. PEC 2005, Standard guidelines and formula for price adjustment, Islamabad, PEC.
19. Samaraweera, D 2013, Application of the formula, Colombo, ICTAD.
20. Taylor, JK & Cihon, C 2004, Statistical techniques for data analysis, CRC Press, Florida.

Journal of Engineering and Technology
of The Open University of Sri Lanka (JET-OUSL), Vol. 3, No.1, 2015, ISSN 2279-2627

Effect of Structural Parameters on Dimensional Stability and Spirality of Core Spun Cotton/Spandex Single Jersey and 1x1 Rib Structures

C. N. Herath

Department of Textile and Apparel Technology, The Open University of Sri Lanka, Nawala, Nugegoda, Sri Lanka

Corresponding Author - email: chera@ou.ac.lk, Tele: +94 112881065

Abstract – *In this research, effect of structural parameters on dimensional stability and spirality variations of core spun CO-SP single jersey and 1x1 rib fabrics made with high, medium and low fabric tightness factors under various relaxation levels have studied and compared the results with the cotton fabrics.*

During relaxation treatments, structural spacing have reduced due to increase of wale and course densities and structural spacing were negatively correlates to fabric tightness factor and relaxation state. Lower structural spacing were reported by cotton-spandex weft knitted fabrics compared to cotton knitted fabrics. Higher stitch densities have given by cotton-spandex structures and it was positively correlated to fabric tightness and relaxation sate. Dimensional constants change with the relaxation level and higher values given by CO-SP structures than CO structures, even though they made with same stitch lengths. CO-SP single jersey and 1x1 rib structures could reach to a stable state faster than CO structures. Significantly lower spirality deformations have given by cotton-spandex fabrics compared to cotton fabrics and thus, 1x1 rib fabrics gave lower spirality angles than single jersey fabrics, even though they made with same fabric tightness. Spirality of deformations weft knitted fabrics were proportionate to TF^{-1} and relaxation level. Hence, mathematical models for spirality variations of cotton-spandex and cotton single jersey and 1x1 rib structures have developed.

Keywords*: Dimensional stability, Spirality, cotton/spandex, structural parameters,*

NOMENCLATURE

CO-SP Cotton-Spandex	*CO 100% Cotton*	*SKC Structural knit cell*
TF Fabric tightness factor	*CPC Courses/cm*	*WPC Wales/cm*

1 INTRODUCTION

Spirality of knitted fabric takes place when the wales are not perpendicular to the courses, which form an angle between wale direction and vertical direction during manufacturing as well as washing and finishing treatments. It is a very common problem arising with circular knitted fabrics and influences on apparel manufacturing process, aesthetic appearance and functional performances. Most of the problems related to apparel manufacturing occur due to mismatched patterns, sewing difficulties, displacement of side seam of T-shirt and panty hoses to the back and front of the body and garment distortion. Therefore Spirality has been investigated by many researchers from both fundamental and practical aspects.

2 LITERATURE REVIEW

Dimensional stability enables the garments to keep the shape of it during wash and wear and it depends on many factors such as structural parameters, yarn and fabric parameters, relaxation level etc. (Munden, 1960, Herath, 2008 and Marmarali, 2003). Thus, it was reported that tumble drying conditions significantly affected on dimensional stability of weft knitted garments (Higgns *et al.*, 2003). Previous research works clearly demonstrated that the fibre related factors, yarn parameters, fabric and yarn types, knitting machine parameters and knitted structural parameters are the effecting factors for fabric spirality (Araujo and Smith, 1989 and Tao J. *et al.*, 1997). Fabric spirality is significantly affected by the twist of the yarn, which develops torsional stresses due to bending and twisting of yarns. Therefore, stitches have a tendency to rotate inside the fabric to develop spirality (Ceken, 2004, Marmarali, 2003). Thus, it was found that rotor spun and air jet (air vortex) yarns, two plied yarns as well as coarser yarns have shown lesser fabric spirality and thus 50/50 cotton/polyester blends have given a lower tendency to produce spirality in fabrics than the 100% cotton yarns (Deshal, *et al.* 2008). Researchers have experimented the effect of knitting machine parameters such as no. of knitting system used (higher the feeders higher the course inclination), direction of machine rotation, gauge (lower the gauge , lower the spirality) (Ceken and kayacan, 2004 and Deshal, *et. al.* 2008).Knitted structural parameters such as stitch length(higher the stitch length higher the spirality), stitch density (higher the stitch density lower the spirality), fabric tightness factor (higher fabric tightness lower spirality) and relaxation treatments have shown significant influence on fabric spirality [Anad, *et al.* 2002 and Deshal, *et al.* 2008]. Thus, spirality of cotton rib structures have given much lower angles than that of made with single jersey structures [Anad, *et al.* 2002]. However, almost all the research works related to spirality were carried out with cotton and cotton blended fabrics.

3 OBJECTIVES

This research work was carried out to achieve the following objectives.

(a) To study the dimensional stability and spirality variations of core spun CO-SP single jersey and 1x1 rib fabrics made with high, medium and low fabric tightness factors under dry-, wet-, full - relaxation conditions and washing treatments up to 10th washing cycle.

(b) To study the dimensional stability and spirality variations of similar types of CO fabrics made with high, medium and low tightness factors subjected to the same relaxation treatments and laundering treatments and compare the results with the cotton/spandex fabrics.

(c) To analysis to effect of structural parameters on the spirality variations of core spun CO-SP and CO weft knitted fabrics subjected to relaxation and laundering treatments.

4 METHODOLOGY

4.1 Materials

CO-SP (93% cotton and 7% spandex) yarns were used to knit single jersey and 1x1 rib structures in a circular knitting machine. Ring spun 100% cotton (30Ne) and 40decitex "Creora®" spandex filaments (HSSX-40D) from Hyosung Company, South Korea, were used for core spun CO-SP spinning. Thus, for comparing purpose, same structures were knitted using ring spun CO yarns with the nominal count of 30Ne. In order to obtain three tightness factors (TF) of the three structures, three stitch lengths such as low, medium and high were selected. Table 1 shows the knitted yarn specifications. As per the table 1, tenacity of CO-SP yarns are lower, but extension at break and twist are higher than CO yarns. Table 2 shows the knitting specifications. Table 3 gives the machine set stitch lengths and machine off stitch lengths, which were measured under 95% significant level, are given in parenthesis . Machine off stitch lengths of 1x1 rib structures have been calculated according to the SCSL (Structural knit Cell Stitch Length - i.e. length of yarn required to knit one Structural Knit Cell (SKC) concept. Each fabric tightness factor for CO and CO-SP single jersey and 1x1 rib knitted structures were used the same machine set stitch lengths as given in table 3.

Table 1 Specifications of knitted yarns

Material	Nominal count [Ne]	Measured count [tex]	Tenacity [cN/tex]	Extension at break [%]	Yarn twist [tpi]
100%CO	30	20.14	18.217	5.04	19.7
CO/SP	30	20.40	15.245	8.94	27.4

Table 2 Knitting specifications for sample preparation

Structure and Material	Machine diameter [inches]	Gauge	Machine RPM	No. of positive feeders	No. of needles
Single jersey (CO-SP and CO)	30	28	22	72	2640
1x1 Rib (CO-SP and CO)	30	18	20	60	1680

Table 3 Machine set and machine off stitch lengths in cm.

Structure	Material	Low fabric tightness [L-TF] stitch length-cm	Medium fabric tightness [M-TF] stitch length-cm	High fabric tightness [H-TF] stitch length-cm
Single jersey	CO-SP	0.290 (0.268±0.020)	0.270 (0.255±0.012)	0.250 (0.240±0.010)
	CO	0.290 (0.284±0.021)	0.270 (0.262±0.032)	0.250 (0.242±0.041)
1x1 Rib	CO-SP*	0.290 (0.522±0.053)	0.270 (0.488±0.054)	0.250 (0.462±0.066)
	CO*	0.290 (0.586±0.083)	0.270 (0.542±0.051)	0.250 (0.502±0.054)

Note: (1) machine-off stitch lengths given in parenthesis
(2)* machine off stitch lengths measured per SCSL

4.2 Procedure

4.2.1 Sample preparation

Sample size of 30x30 cm^2 were cut from CO and CO-SP knitted fabrics. Six samples were cut from each tightness factor of each knitted structure. All samples were subjected to dry-, wet- and full-relaxation treatments according to the ASTM D 1284-76 standards and then followed by laundering treatments according to the ISO 6330 standards.

4.2.2 Relaxation treatments and laundering treatments

Dry Relaxation

Cut samples were kept for 48 hours on flat surface in a conditioning cabinet with tension free state. Standard atmospheric conditions such as 21°C ± 2 at a relative humidity of 65%±2 were maintained in a conditioning cabinet.

Wet Relaxation

Knitted samples were immersed in a stainless steel water bath containing 0.05g/l standard wetting agent with water temperature, maintaining at about 38 °C and allowed to relax with minimum agitation for 24 hours. Then, samples were hydro-extracted for 1 minute and laid on a flat surface for 48 hours. Then, samples were brought back to the standard condition of 21°C± 2 at a relative humidity of 65% ± 2 for 48 hours with free of tension.

Full Relaxation

Samples were washed thoroughly, briefly hydro extracted for 1 minute and tumble dried for 60 min. and 90 min. durations for single jersey and 1x1 rib knitted structures respectively, around 70 °C. Tumbler dry duration was decided base of on the trial experiments. Samples were then laid on a flat surface in a conditioning cabinet of 21°C±2 at a relative humidity of 65%±2 for 48 hours with free of tension.

Laundering treatments

Full relaxed samples were machine washed up to 10th cycles (washing cycle 1:W1 to washing cycle 10: W10) in a standard front loading machine under normal agitation with machine RPM of 56. Each washing cycle includes wash, rinse, spin and tumble drying steps. After each selected washing cycle, samples were tumble dried around 70°C for 60 minutes and 90 minutes for single jersey and 1x1 rib structures respectively. Washing temperature was set at 40 °C and rinsed with cold water. Thus, water intake for washing was 30 liters. 0.1 g/ *l* standard wetting agent was used. The mass of the load was maintained constant to 3 kg to keep the liquid-material ratio as 1:10.

4.2.3 Measurements

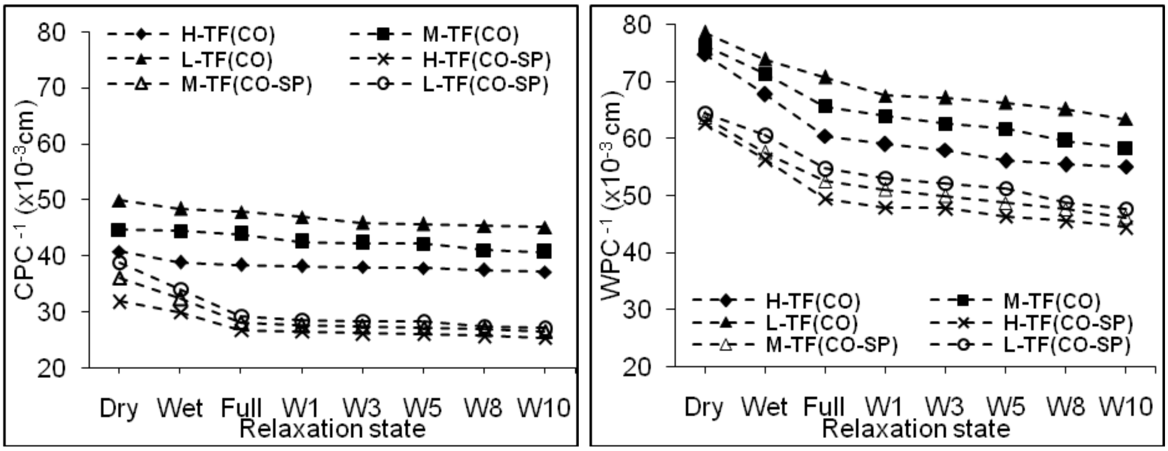
Following measurements have taken after finishing of each relaxation stage and at the end of selected washing treatments such as W1, W3, W5, W8 and W10. Course and wale spacing were calculated based on the measured courses per cm (CPC) and wales per cm(WPC) values as described in the literature (Marmarali, 2003, Araujo and Smith, 1989 and Anad, *et al.* 2002). All CPC and WPC were measured after unraveling the 100 wales or 50 ribs at five places of each sample. Ribs per cm (RPC) of 1x1 rib structures have been measured using SCSL concept. For comparing purposes of structural spacing variations, it was assumed a single rib covered two wales in the 1x1 rib structure. Based on WPC and CPC values, course spacing (CPC^{-1}) and wale spacing (WPC^{-1}) have determined. Spirality angle due to the displacement of wales relative to the courses were measured according to IWS TM 276 standard at the end of each relaxation treatment at five places per each knitted fabric sample.

5 RESULTS AND ANALYSIS

5.1 Structural spacing variations with relaxation

In manufacturing knitted fabrics, yarns are subjected to heavy stress and strains, which will be gradually releasing during relaxation with minimizing the internal energy of structure. This causes to change the stitch shape and therefore, the course density (CPC) and wale density (WPC) can be increased. This will lead to gradually changing the course spacing (CPC^{-1}) and wale (WPC^{-1}) spacing. These structural spacing changes may cause for dimensional instability and spirality in knitted fabrics. Figure 1 and 2 show the changing patterns of structural spacing ($CPC^{-1}$and WPC^{-1}) of CO-SP and CO single jersey structures made with low (L-TF), medium (M-TF) and high (H-TF) tightness factors, under various relaxation stages.

Figure 1 shows that the course and wale spacing have gradually decreased with progressing of relaxation and thus, spacing have drastically reduced from dry relaxation to full relaxation and further reduced with washing treatments. In wet relaxation, water can act as a lubricant to support to change the stitch shape by releasing strains to achieve minimum energy level. Thus, tumble dying in full relaxation further provides the heat energy to reach to the stable states of the stitch shape. In washing, water agitation provide both these facilities to knitted stitches to come to a stable state, meanwhile the course and wale densities increase with decreasing the structural spacing.



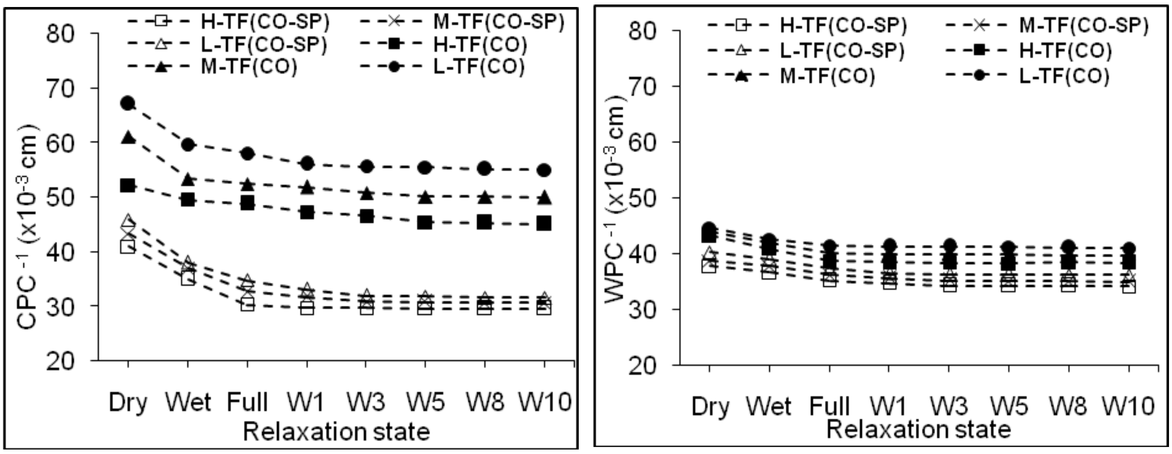
(a) Changes of course spacing (CPC^{-1}) **(b) Change of wale spacing (WPC^{-1})**

Figure 1 Changes of structure spacing of single jersey fabrics under relaxation

According to both figures, it can be observed that lower structural spacing reported by CO-SP structures than CO single jersey structures after all relaxation treatments. Reasons would be that CO-SP single jersey structures gave lower machine off stitch lengths than that of CO structures as shown in Table 3, due to - higher stretch and recovery properties of CO-SP, so CO-SP structures have lower stitch lengths than CO structures resulting higher CPC and WPC, in other wards lower course spacing and lower wale spacing.

In addition to that structural spacing are negatively correlated to the fabric tightness factors in all experimented cases. Reason would be that structural spacing cannot be increased during relaxation the higher fabric tightness structures (having higher stitch densities) due to restrictions imposed by inter yarn friction and compression forces (Higgns *et al.*, 2003, Tao J. *et al.*, 1997). Thus, deviations of course and wale spacing among three fabric tightness factors are higher in CO-SP single jersey structures than CO structures after each relaxation level. A feature observed in figure 1 was the higher wale spacing than course spacing. This is because the lower WPC than CPC in the CO-SP and CO single jersey structures.

Figure 2 shows the structural space changes given by 1x1 rib structures made with CO and CO-SP yarns. They show the same structural spacing changing patterns as single jersey structures such as lower structural spacing given by CO-SP rib structures, negatively correlated structural spacing with fabric tightness factors, drastically reduced structural spacing from dry relaxation to full relaxation, gradually continuing the spacing reduction till 10th washing cycle and clear deviations of course and wale spacing of CO-SP rib fabrics than CO rib fabrics. However, in 1x1 rib CO-SP and CO structures show higher CPC^{-1} than WPC^{-1} due to lower CPC than WPC. This is a conflicting characteristic compared to single jersey structures.



(a) Changes of course spacing (CPC-1) **(b) Change of wale spacing (WPC-1)**

Figure 2 Change of structure spacing of 1x1 rib fabrics under relaxation

5.2 Stitch density variations with relaxation

Due to the decreasing patterns of structural spacing of CO-SP and CO single jersey structures during relaxation, stitch densities of them are increasing. This causes for many structural deformations and spirality is an important one of them. Figure 3 and 4 show the stitch density variations of CO and CO-SP single jersey and 1x1 rib structures under relaxation treatments.

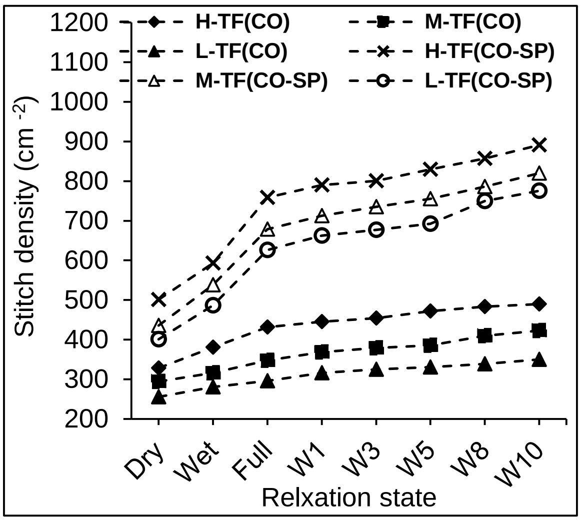


Figure 3 Stitch density variations of single jersey fabrics under relaxation

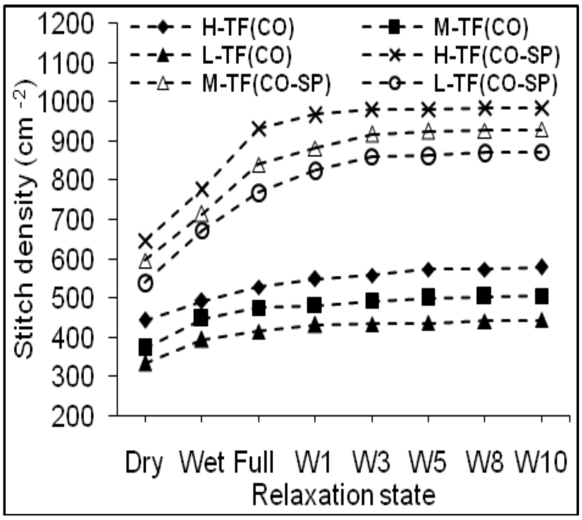


Figure 4 Stitch density variations of 1x1 rib fabrics under relaxation

According to figures 3 and 4, higher stitch densities reported with CO-SP single jersey and 1x1 rib fabrics. This is due to the lower structural spacing reported by CO-SP knitted fabrics due to its good resiliency than CO knitted fabrics at all relaxation levels. Further CO-SP and CO rib fabrics have shown higher stitch densities than the single jersey fabrics, even though their machine set stitch lengths are same for each fabric tightness factor (as given in Table 3). This may be due to the double layer (two planar) construction of rib structures resulting overlapping of wales and increasing the WPC, whereas single jersey is a single layer construction (single planar) and no overlapping of wales. Higher TF means that the particular structure has higher stitch densities. When the stitch densities are higher, wales cannot displace due to higher compression given by neighboring stitches of wales as well as higher inter yarn friction, which can cause to reduce the spirality of knitted fabrics with increasing fabric tightness. Thus, stitch densities have shown progressive increases with relaxation treatments. This is due to changing the shape of the stitch allowing accommodating more no. of stitches per unit fabric area.

5.3 Dimensional stability under relaxation

When the structural spacing and stitch density changes take place in a knitted structure, it effects on the dimensional parameters, which was determined using Munden's geometrical correlations-K values- (Munden,1960) as given below. Dimensional stability is normally expressed by these dimensional parameters. If the dimensional parameters becomes to a stable states, fabric will not have further dimensional deformations (i.e.: Dimensionally stable). Stitch shape factor (Kp) gives the states of changing the shape of the stitch, which is responsible for the dimensional deformations and spirality.

Kp = (courses.cm^{-1})/ (wales.cm $^{-1}$) = $\frac{K_C}{K_W}$ (K_C *and* K_W *dimensional constants)* (1)

Where

courses.cm^{-1} (CPC)= $\frac{K_C}{l}$ (2)

Wales.cm^{-1} (WPC) = $\frac{K_W}{l}$ *(l : stitch length)* (3)

Dimensional constant for stitch density variations (Ks) using following formula.

Stitch density (S) = (courses.cm^{-1} x wales.cm^{-1}) = $\frac{K_C \times K_W}{l^2} = \frac{K_S}{l^2}$ (4)

Table 4 and 5 give the dimensional constants for CO-SP and CO single jersey structures respectively. According to above table, Kp and Ks values have gradually increased with the relaxation level. That means the stitch densities and stitch shapes have changed through the treatments. Further, the cV% of Kp values have calculated to determine the completely relax state (i.e: minimum energy state) of knitted stitches, which can be decided, if the cV% (coefficient of variations) of Kp values are taken lower values. According to the cV% after W8 and W10, stitch shapes reach to a better stable state and therefore, lesser deformation in the structure can be expected. It means that CO-SP single jersey fabric became dimensionally stable and lower spirality deformations after W8 and W10. According to the table 5, all K values of CO fabrics are lower than that of CO-SP fabrics. It implies that tendency of changing the shape of CO-SP plain stitch is not very fast like in the case of CO-SP structures. Based on the cV% values of Kp, it can be said that the CO single jersey fabric have not reach to a stable state even after W10. Therefore, further dimensional and spirality deformations can be expected with CO knitted fabric structures. However, it was observed from table 4 that CO-SP structures reached to a comparatively better stable state after W8. This is because the higher resiliency characteristics of CO-SP knitted yarns. As a result, higher dimensional stability and lower spirality deformations can be expected from CO-SP single jersey structures.

Table 6 and 7 shows the variations of K-values CO-SP and CO 1x1 rib fabrics. According to them, K values related to CO-SP and CO 1x1 rib fabrics increased with progression of relaxation treatments. The K- values of 1x1 rib structures are higher than the values given by single jersey fabrics. Because, 1x1 rib structures have higher structural parameter values (as resiliency), higher stitch shape changes and higher stitch lengths.

Table 4 Dimensional constants (K-values) for CO-SP single jersey fabrics

TF	Ks	Kc	Kw	Kp	Relaxation state
L-TF	27.47±0.21	6.75±0.05	4.07±0.02	1.66±0.01	Dry relax cV% of K_p=9.67
M-TF	27.49±0.16	6.96±0.03	3.95±0.02	1.76±0.01	
H-TF	28.20±0.23	7.50±0.04	3.76±0.03	2.00±0.02	
L-TF	35.92±0.40	8.00±0.05	4.49±0.03	1.78±0.01	Wet relax cV% of K_p =7.16
M-TF	33.34±0.23	7.79±0.02	4.28±0.02	1.82±0.04	
H-TF	33.84±0.11	7.98±0.02	4.24±0.01	2.03±0.01	
L-TF	42.65±0.35	8.98±0.03	4.75±0.04	1.89±0.02	Full relax cV% of K_p =0.92
M-TF	42.79±022	8.99±0.03	4.76±0.02	1.89±0.01	
H-TF	43.00±0.47	8.94±0.04	4.81±0.05	1.86±0.01	
L-TF	45.73±0.42	9.24±0.02	4.95±0.04	1.86±0.02	W1 cV% of $K_{p=}$ 0.31
M-TF	43.78±0.37	9.01±0.03	4.86±0.04	1.85±0.02	
H-TF	42.76±0.37	8.89±0.04	4.81±0.03	1.85±0.02	
L-TF	45.76±0.55	9.19±0.07	4.98±0.04	1.84±0.02	W3 cV% of K_p=0.54
M-TF	44.01±0.29	9.02±0.03	4.88±0.03	1.85±0.01	
H-TF	43.14±0.38	8.95±0.04	4.82±0.04	1.86±0.02	
L-TF	46.80±0.48	9.25±0.04	5.06±0.04	1.83±0.01	W5 cV% of K_p=0.82
M-TF	44.59±0.28	9.10±0.04	4.90±0.03	1.85±0.02	
H-TF	43.79±0.36	9.02±0.06	4.85±0.05	1.86±0.02	
L-TF	47.05±0.60	9.30±0.02	5.06±0.06	1.84±0.02	W8 cV% of K_p=0.31
M-TF	45.44±0.22	9.12±0.02	4.95±0.02	1.84±0.01	
H-TF	44.11±0.36	9.04±0.03	4.88±0.04	1.85±0.01	
L-TF	47.56±0.41	9.40±0.06	5.06±0.05	1.86±0.01	W10 cV% of K_p=0.30
M-TF	47.13±0.32	9.39±0.02	5.02±0.03	1.87±0.01	
H-TF	44.49±0.35	9.10±0.04	4.89±0.03	1.86±0.01	

Note: all K-values calculated under 95% significant level

Table 5 Dimensional constants values (K-values) for CO single jersey fabrics

TF	Ks	Kc	Kw	Kp	Relaxation state
L-TF	18.95±0.20	5.46±0.02	3.47±0.03	1.57±0.02	Dry relax cV% of K_p=13.62
M-TF	19.19±0.20	5.78±0.04	3.32±0.03	1.74±0.02	
H-TF	21.47±0.21	6.65±0.02	3.23±0.03	2.05±0.02	
L-TF	21.80±0.22	5.65±0.02	3.87±0.03	1.45±0.01	Wet relax cV% of K_p=15.1
M-TF	22.01±0.20	5.99±0.04	3.67±0.02	1.63±0.01	
H-TF	23.32±0.23	6.74±0.03	3.46±0.03	1.95±0.02	
L-TF	23.30±0.25	5.87±0.02	3.97±0.03	1.48±0.02	Full relax cV% of K_p=1.77
M-TF	22.89±0.23	5.82±0.04	3.95±0.02	1.47±0.01	
H-TF	23.28±0.32	5.94±0.04	3.92±0.03	1.52±0.02	
L-TF	24.54±0.22	6.06±0.03	4.05±0.03	1.50±0.01	W1 cV% of Kp=2.35
M-TF	24.60±0.27	6.12±0.02	4.02±0.04	1.52±0.01	
H-TF	25.48±0.20	6.34±0.03	4.02±0.02	1.57±0.01	
L-TF	24.88±0.29	6.10±0.04	4.08±0.03	1.50±0.01	W3 cV% of Kp= 2.47
M-TF	24.98±0.29	6.14±0.04	4.07±0.04	1.51±0.02	
H-TF	25.98±0.19	6.40±0.04	4.06±0.01	1.57±0.01	
L-TF	25.13±0.38	6.13±0.02	4.10±0.04	1.50±0.01	W5 cV% of Kp=2.27
M-TF	25.28±0.26	6.15±0.02	4.11±0.03	1.50±0.01	
H-TF	26.31±0.18	6.42±0.04	4.10±0.04	1.56±0.01	
L-TF	25.35±0.25	6.20±0.04	4.09±0.03	1.52±0.02	W8 cV% of Kp=1.50
M-TF	25.72±0.24	6.28±0.04	4.10±0.02	1.52±0.01	
H-TF	26.35±0.22	6.41±0.03	4.11±0.03	1.56±0.01	
L-TF	25.62±0.32	6.25±0.04	4.10±0.03	1.52±0.02	W10 cV% of Kp=0.99
M-TF	25.76±0.32	6.30±0.03	4.09±0.04	1.54±0.02	
H-TF	26.45±0.25	6.41±0.01	4.12±0.03	1.55±0.01	

Note: all K-values calculated under 95% significant level

According to the cV% of Kp values given in Tables 6 & 7, CO-SP rib structures became to a more reasonable relax/stable state after W10, but CO rib structures need more vigorous treatments to come to a better stable state. Reason for more stable state of CO-SP 1x1 rib structures would be its' higher resiliency property, which makes higher stitch shape changes and therefore they quickly become to a minimum energy levels. Then, there is no potential energy for further changes. This helps to make a quick equilibrium between knitted stitch relaxation and consolidation mechanisms. Therefore, resiliency property of CO-SP yarns give valuable advantage to the single jersey and 1x1 rib structures to become to a quicker dimensionally stable level and also to have a lesser spirality deformations during relaxation, even though they made with same fabric tightness.

Compared with CO single jersey structures of CO, 1x1 rib CO structures became a poor stable state during our experimental conditions, according to the higher cV% given by single jersey CO than CO rib fabrics. Reasons would be the complexity of rib structure construction such as its double layer construction, which may be possible to release more potential energy to become to a stable state during treatments. Due to the high resiliency power of CO-SP yarns, CO-SP 1x1 rib structures would be able to eliminate these restrictions acting on interlacing points of a knitted stitch. It can be concluded that experimented CO-SP weft knitted structures were dimensionally more stable than the structures made from CO.

Table 6 Dimensional constant values (K-values) for CO-SP 1x1 rib fabrics

TF	Ks	Kc	Kw	Kp	Relaxation level
L-TF	73.49±0.46	11.36±0.06	6.46±0.03	1.76±0.01	Dry relax cV% of Kp= 2.77
M-TF	69.23±0.79	11.02±0.11	6.28±0.03	1.75±0.01	
H-TF	67.17±0.68	11.13±0.05	6.04±0.06	1.84±0.02	
L-TF	88.03±0.57	13.54±0.07	6.49±0.02	2.08±0.01	Wet relax cV% of Kp= 1.28
M-TF	82.41±0.54	12.96±0.08	6.35±0.03	2.04±0.02	
H-TF	77.34±0.78	12.74±0.09	6.07±0.04	2.09±0.02	
L-TF	100.54±0.66	14.68±0.06	6.85±0.02	2.14±0.01	Full relax cV% of Kp= 2.73
M-TF	94.09±0.84	14.41±0.11	6.53±0.01	2.21±0.01	
H-TF	106.15±0.77	15.50±0.06	6.84±0.03	2.26±0.01	
L-TF	106.15±0.77	15.50±0.06	6.84±0.03	2.26±0.01	W1 cV% of Kp=0.68
M-TF	98.67±0.66	14.89±0.07	6.62±0.02	2.24±0.02	
H-TF	93.65±0.69	14.79±0.09	6.33±0.02	2.33±0.01	
L-TF	98.67±0.66	14.89±0.07	6.62±0.02	2.24±0.02	W3 cV% of Kp=0.75
M-TF	93.65±0.69	14.79±0.09	6.33±0.02	2.33±0.01	
H-TF	107.63±0.91	15.70±0.10	6.87±0.04	2.28±0.02	
L-TF	100.93±0.68	15.17±0.07	6.65±0.01	2.28±0.01	W5 cV% of Kp=0.75
M-TF	93.36±0.38	14.69±0.04	6.35±0.01	2.31±0.01	
H-TF	106.68±0.77	15.61±0.08	6.83±0.02	2.28±0.01	
L-TF	99.76±0.67	15.10±0.09	6.61±0.01	2.28±0.01	W8 cV% of Kp= 0.66
M-TF	93.05±0.57	14.66±0.06	6.34±0.03	2.31±0.01	
H-TF	107.03±0.70	15.67±0.06	6.82±0.02	2.29±0.01	
L-TF	99.64±0.64	15.08±0.09	6.61±0.01	2.28±0.01	W10 cV% of Kp= 0.5
M-TF	90.40±0.51	14.46±0.04	6.25±0.02	2.31±0.01	
H-TF	106.86±0.62	15.64±0.05	6.83±0.02	2.28±0.01	

Note: all K-values calculated under 95% significant level

Table 7 Dimensional constant values (K-values) for CO 1x1 rib fabrics

TF	Ks	Kc	Kw	Kp	Relaxation level
L-TF	53.46±0.46	8.33±0.05	6.41±0.03	1.30±0.01	Dry relax cV% of Kp=12.9
M-TF	48.35±0.30	8.30±0.05	5.82±0.02	1.42±0.01	
H-TF	55.16±0.82	9.59±0.09	5.74±0.05	1.67±0.02	
L-TF	56.49±0.36	8.96±0.05	6.29±0.04	1.42±0.01	Wet relax cV% of Kp=8.57
M-TF	55.81±0.35	9.35±0.04	5.96±0.03	1.56±0.01	
H-TF	50.92±0.38	9.27±0.06	5.49±0.02	1.68±0.01	
L-TF	59.76±0.53	9.23±0.06	6.47±0.03	1.42±0.01	Full relax cV% of Kp=5.36
M-TF	60.21±0.04	9.59±0.04	6.27±0.02	1.52±0.01	
H-TF	57.86±0.41	9.57±0.05	6.04±0.01	1.58±0.01	
L-TF	60.64±0.36	9.45±0.03	6.41±0.02	1.47±0.01	W1 cV% of Kp=5.23
M-TF	59.60±0.44	9.56±0.38	6.24±0.04	1.53±0.02	
H-TF	58.38±0.53	9.75±0.03	5.99±0.03	1.63±0.02	
L-TF	60.52±0.33	9.47±0.04	6.38±0.02	1.48±0.01	W3 cV% of Kp=5.42
M-TF	61.00±0.53	9.79±0.05	6.23±0.04	1.57±0.03	
H-TF	58.79±0.54	9.84±0.07	5.97±0.02	1.65±0.01	
L-TF	60.70±0.36	9.50±0.05	6.38±0.02	1.49±0.02	W5 cV% of Kp=5.09
M-TF	61.81±0.49	9.90±0.03	6.24±0.04	1.58±0.03	
H-TF	58.80±0.63	9.78±0.07	5.93±0.03	1.65±0.01	
L-TF	60.96±0.47	9.53±0.05	6.39±0.02	1.49±0.01	W8 cV% of Kp=6.00
M-TF	61.93±0.53	9.90±0.03	6.25±0.04	1.58±0.01	
H-TF	58.79±0.36	9.96±0.04	5.90±0.02	1.68±0.01	
L-TF	61.02±0.43	9.53±0.05	6.40±0.03	1.49±0.01	W10 cV% of Kp= 5.99
M-TF	61.97±0.45	9.92±0.03	6.24±0.04	1.59±0.02	
H-TF	58.83±0.34	9.98±0.04	5.89±0.02	1.69±0.01	

Note: all K-values calculated under 95% significant level

5.4 Spirality variations of weft knitted fabrics under relaxation

During relaxing the weft knitted structures, shape of the stitches changes while reducing the structural spacing and increasing the stitch densities, which make the spirality deformations in the knitted structures. Figure 5 and 6 show the spirality variations of CO-SP and CO single jersey fabrics respectively. According to both figures, spirality deformation in weft knitted single jersey fabrics negatively correlate to fabric tightness. Because, higher fabric tightness makes the more stitch densities and lower structural spacing, which are not allowing the wales to displace from their position during relaxation.

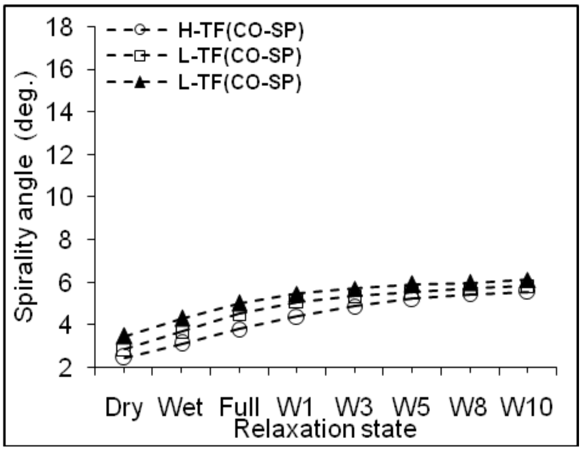


Figure 5 Spirality variations of CO-SP single jersey fabrics

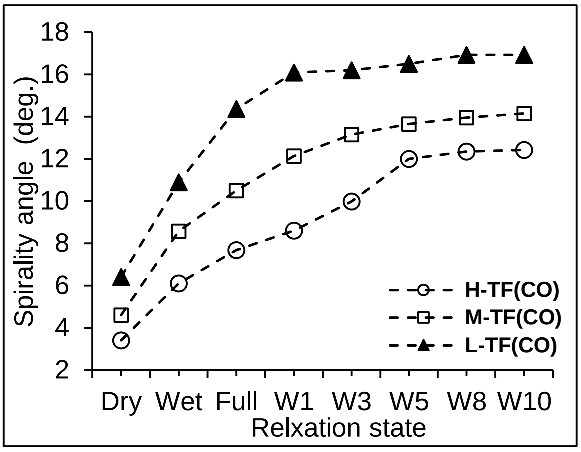


Figure 6 Spirality variations of CO single jersey fabrics

Thus, higher stitch densities may give more inter yarn frictional forces and compression to the wales to reduce the spirality deformations. Hence, spirality deformations increased with the relaxation of knitted structures. This would be that knitted loops are released their internal yarn forces when exert frictional, torsional and flexural forces during knitting to reach to a minimum energy state. This change the knitted loop shape, due to wetting with agitation and providing mechanical and heat energy in wet relax, full relax and also during washing treatments. Thus, it is possible to bend the knitted stitches into 3rd dimension. Ultimately, wale distortions take place due to vigorous washing actions. This leads to increase spirality angle. Similar tendency was reported by some other research works (Higgns *et al.*, 2003,Tao J. *et al.*, 1997 and Anad, *et. al.* 2002).

It is very clearly shows that CO single jersey fabrics given the much higher spirality values compared to that of CO-SP single jersey fabrics, even though both structures were knitted with same stitch lengths. Reason is the higher tightness factors and stitch density values given by CO-SP single jersey fabrics, which were occurred due to good resiliency power of CO/SP yarns. These high fabric tightness and stitch densities can give good inter yarn frictional forces and compressive forces against the wale distortions with making lesser structure spacing during progression of relaxation treatments.

Figure 7 and 8 show the spirality variations of 1x1 rib fabrics. Similar to single jersey fabrics, rib fabrics also showed the negative correlation between spirality and fabric tightness and more spirality deformation with the progression of relaxation treatments. Reasons would be same as for single jersey fabrics as given above.

Acceptable maximum spirality angle for weft knitted structures is considered as 5° in the industry. According to this, CO-SP single jersey fabrics gave the acceptable spirality variations compared to CO single jersey fabrics, even though both the types of single jersey fabrics we knitted using same stitch lengths. Thus our spirality results obtained during relaxation for single jersey fabrics are closer to the experiments done by other researcher with half plated CO and CO-SP single jersey fabrics, but, slightly higher spirality angles were obtained than full plated CO and Spandex single fabrics, which was reported as 1.25° to 1.75° (Marmarali, 2003). According to two figures, it can be observed that spirality angles are negatively correlated to fabric tightness factor.

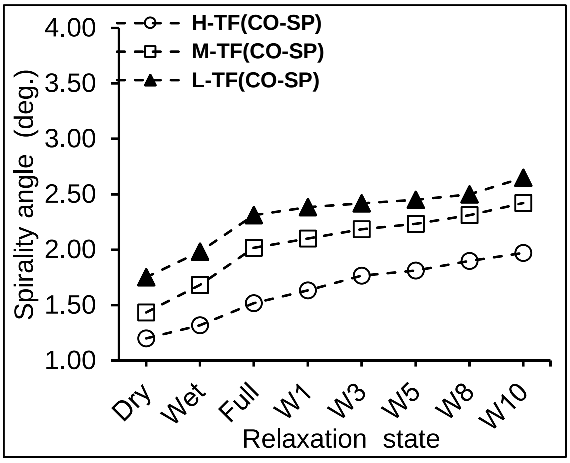


Figure 7 Spirality variations of CO-SP 1x1 rib fabrics

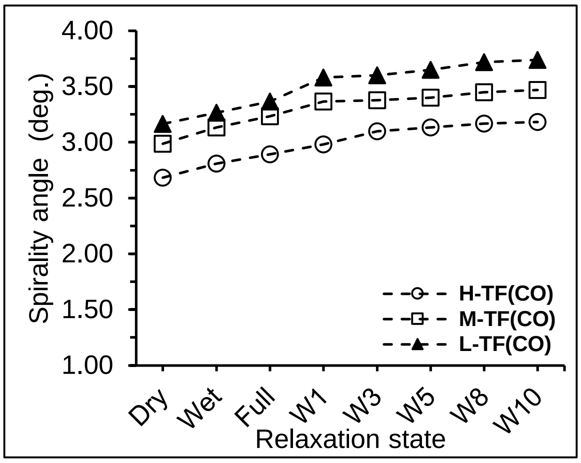


Figure 8 Spirality variations of CO 1x1 rib fabrics

Thus, spirality angle increased with the progression of relaxation treatments due to changing the stitch shapes while being relaxing them. These behaviors are same as in single jersey fabrics. However, CO-SP rib fabrics showed much lower spirality deformation angles than CO rib fabrics due to the their higher stitch densities and lower structural spacing, which may develop higher inter yarn frictional forces and compressive forces acting on wales, than in the case CO rib fabrics. Thus, it is important to note that both CO-SP and CO 1x1 rib structures showed the spirality angles lesser than 5°, which is the industry acceptable limit for spirality angle. Compared to single jersey fabrics, 1x1 rib fabrics showed very low spirality angles during each relaxation stage. Two reasons can be given for this behavior.

(i) Structural knit cell (SKC) of a 1x1 rib stitch has a straight yarn link part and therefore, rib stitches are made in two planes, which can balance the yarn forces in the knitted stitch, resulting a balanced structure. But, in single jersey structure, after one stitch made, yarn in sinker loop bend into same plane with increasing yarn forces, resulting an imbalance plain structure. Unlikely, structures like rib structures can well balance the forces acting on its' stitch during wetting and vigorous relaxation procedures. Therefore, wale displacements are lower during relaxation the rib stitches.

(ii) Rib structures show higher fabric tightness factor values than single jersey structures and make higher stitch densities with lower structural spacing. This also affects to lesser spirality values of rib structures compared to single jersey structures.

Thus, according to the literature survey, it was found that yarn twist can give a significant effect on spirality. As given in Table 1, CO-SP yarns had the higher twist than CO yarns and therefore, structures made from CO-SP could have higher spirality. But, according to the figures 5-8, CO-SP knitted structures have given lower spirality deformation than CO knitted structures. Reasons could be that the higher resiliency power, higher stitch densities and lower structural spacing may have control the effect given by yarn twist.

Thus, it is expected to give more restrictions such as higher inter yarn frictions, higher compressional forces acting on wales with increasing stitch densities, fabric tightness and reducing structural spacing during the relaxation treatments from dry relax to W10 causing to reduce spirality. But it was not observed by the figures 5-8 and they show the gradually increase the spirality with the treatment. Reasons would be that the effect from restriction forces has overrun by the effect given by changing the stitch shape during relaxation and also it is possible to bend the stitches into 3rd dimension with the treatments causing to displace the wales.

Further, it was established mathematical models for spirality variations of three structures based on single and multiple linear regressions with use of ANOVA (step-wise variable adding) technique, using the data from full relaxation up to 10th machine washing cycle, using SPSS software. Following tables 8-11 give the established models and the respective ANOVA summary, which has given for the model having highest correlation coefficients (R^2). ANOVA technique was used under 95% significant level. For establishing the correlation models, TF have calculated using the following formula (5),

$$\frac{\sqrt{tex}}{stitchlength};(tex^{1/2}\ cm^{-1}) \qquad (5)$$

Table 8 Single and multiple linear regression models for spirality angle of CO-SP single jersey fabrics

Model	Variables entered	Correlation model	Pr>F	R^2
1	TF	Y = 10.197-0.264TF	0.084	0.1750
2	Kp	Y = 23.969-10.065Kp	0.302	0.066
3	Ks	Y = -8.882+0.317Ks	<0.0001	0.7170
4	TF , Kp	Y = 36.931-0.31TF-13.951Kp	0.0710	0.2970
5	TF , Ks	Y = -7.172-0.058TF+0.303Ks	<0.0001	0.7240

Note: TF: tightness factor; Y: spirality

ANOVA summary of 5th regression model

Variable	Estimated coefficients	Standard error	Standardized estimate	t value	Pr> $\|t\|$	F value
Intercept	-7.172	3.559	0	-2.015	0.062	19.7
TF	-0.058	0.094	-0.093	-0.625	0.541	
Ks	0.303	0.056	0.809	5.457	0.0001	

Note: df: regression=2; residual=15 : $F_{0.05}$=3.68

Table 9 Establishment of single and multiple linear regression models for spirality angle of CO single jersey fabrics

Model	Variables entered	Correlation model	Pr>F	R^2
1	TF	Y = 66.634-2.99TF	0.0001	0.606
2	Kp	Y = 73.39-39.568Kp	0.0910	0.168
3	Ks	Y = 2.061+0.441Ks	0.5210	0.026
4	TF , Kp	Y = 13.167-4.771TF+56.04Kp	0.0004	0.7290
5	TF , Ks	Y = 42.778-4.047TF+1.704Ks	<0.0001	0.9220

Note: TF: tightness factor; Y: spirality

ANOVA summary of 5thregression model

Variable	Estimated coefficients	Standard error	Standardized estimate	t value	Pr> $\|t\|$	F value
Intercept	42.778	5.828	0	7.340	0.0001	97.8
TF	-4.047	0.308	-1.054	-	<0.0001	
Ks	1.704	0.219	0.626	7.793	0.0001	

Note: df: regression=2; residual=15 : $F_{0.05}$=3.68

Table 10 Establishment of single and multiple linear regression models for spirality angle of CO-SP 1x1 rib fabrics

Model	Variables entered	Correlation model	Pr>F	R^2
1	TF	Y = 6.508-0.228TF	<0.0001	0.7230
2	Kp	Y = 7.069-2.176Kp	0.227	0.0900
3	Ks	Y = -2.364+0.045Ks	<0.0001	0.8500
4	TF , Kp	Y = 3.084-0.265TF+1.824Kp	<0.0001	0.7670
5	TF , Ks	Y = -1.288-0.03TF+0.04ks	<0.0001	0.85200

Note: TF: tightness factor; Y: spirality

ANOVA summary of 5th regression model

Variable	Estimated coefficients	Standard error	Standardized estimate	t value	Pr> $\|t\|$	F value
Intercept	-1.288	2.218	0	-0.581	0.570	43.2
TF	-0.03	0.061	-0.113	-0.497	0.626	
Ks	0.04	0.011	0.820	3.613	0.003	

Note: df: regression=2; residual=15 : $F_{0.05}$=3.68

Table 11 Establishment of single and multiple linear regression models for spirality angle of CO 1x1 rib fabrics

Model	Variables entered	Correlation model	Pr>F	R^2
1	TF	Y = 8.467-0.285TF	<0.0001	0.8210
2	Kp	Y = 8.667-3.459Kp	0.0002	0.5980
3	KS	Y = -10.44+0.228Ks	<0.0001	0.7010
4	TF , Kp	Y = 6.525-0.688TF+5.943Kp	<0.0001	0.9520
5	TF , Ks	Y = -0.124-0.197TF+0.166Ks	<0.0001	0.9240

Note: TF: tightness factor; Y: spirality

ANOVA summary of 4th regression model

Variable	Estimated coefficients	Standard error	Standardized estimate	t value	Pr> $\|t\|$	F value
Intercept	6.525	0.446	0	14.6	0.0001	147.5
TF	-0.688	0.066	-2.184	10.4	<0.0001	
Kp	5.943	0.933	1.328	6.37	<0.0001	

Note: df: regression=2; residual=15 : $F_{0.05}$=3.68

According to the ANOVA analysis, CO-SP single jersey and 1x1 rib structures and CO single jersey structures have shown the good correlation models, which have the R^2>72%. All these structures have shown the significant effect collectively from fabric tightness factor (TF) and stitch density constant (Ks) or stitch shape factor (Kp) on their spirality deformations.

6 CONCLUSIONS

During dry-, wet-and full-relaxation treatments further in washing treatments, weft knitted structures are under gone relieving the heavy strains imposed on them and subjected to severe structural changes. Due to this, course and wale densities and stitch densities have changed and these changes have dependent on the fabric tightness.

Structural spacing of CO-SP and CO single jersey and 1x1 rib structures gradually decrease during relaxation of knitted fabric due to increasing the wale and course densities. In both types of knitted structures made from CO-SP and CO, structural spacing were proportionate to TF^{-1} and lower structural spacing give the lower spirality deformations. Compared to CO structures, CO-SP single jersey and 1x1 rib structures give higher wale and course densities with lower structural spacing. In addition, higher WPC^{-1} given by CO-SP and CO single jersey structures than their CPC^{-1}. However, an opposite behavior shows by CO-SP and CO 1x1 rib fabrics.

Higher stitch densities show by CO-SP single jersey and 1x1 rib structures than their CO structures and it is proportionate to TF. Stitch density increase with relaxation level, which causes to reduce the dimensional deformation and increase the dimensional stability. Dimensional constants change with the relaxation level and higher values given by CO-SP structures than CO structures, even though they made with same stitch lengths. CO-SP single jersey and 1x1 rib structures can become to a stable state faster than CO structures.

Spirality deformations are lower with CO-SP single jersey and 1x1 rib structures compared to same CO knitted structures and they proportionate to TF^{-1}. Both CO-SP and CO rib structures can give very much lower spirality deformations compared to single jersey structures. In spite of the effects given by the higher stitch densities, fabric tightness and lower structural spacing resulting from the progression of relaxation treatments, spirality deformation can also increase continuously during washing treatment of the garments.

REFERENCES

1. Munden D.L. (1966), Dimensional stability on plain knit fabrics. J. Text. Inst., 51(4): 200-209
2. Araujo M. D. and Smith G. W. (1989). Spirality of knitted fabrics, Part 1: The nature of spirality. Textile Res. J., 59(5): 247-256
3. Tao J., Dhingra R.C., Chan C. K. and Abbas M. S. (1997). Effects of yarn and fabric single jersey fabrics. Textile Res. J., 67(1): 57-68
4. Çeken F., and Kayacan Ö. (2007). The Effects of Some Machine Parameters on the Spirality in Single Jersey Fabrics. Fibers and Polymers, 8(1): 89-97
5. Marmarali A. B. (2003), Dimensional and physical properties of cotton/spandex single jersey fabrics. Textile Res. J., 73(1): 11-14
6. Anand S. C, Brown K. S. M., Higgins L. G., Holmes D. A., Hall M. E. and Conrad D. (2002). Effect of laundering on the dimensional stability and distortion of Fabrics. AUTEX Res. J., 2(2): 85-100
7. Herath C. N. and Bok Choon Kang (2008). Dimensional stability of core spun cotton/spandex single Jersey fabrics under relaxation. Textile Res. J., 78(3): 209-216.
8. Desale V., Raichurkar P.P, Shukla A. and Yadev A. (2008), Study on spirality of single jersey knitted fabrics. Fiber 2 fashion
9. Lau. Y., Tao X. and Dhingra R.C.(1995). Spirality in single-jersey fabrics. Textile Asia, 95-102
10. 10.Higgns L., Anand S. C., Hall M. E. and Holmes D. A. (2003). Factors during tumble drying that influence dimensional stability and distortion of cotton knitted fabrics. Int. J. Clothing Sci. and Tech.,15(2): 126-139

Journal of Engineering and Technology
of The Open University of Sri Lanka (JET-OUSL), Vol. 3, No.1, 2015, ISSN 2279-2627

Economical Oil Separator for Automobile Service Stations in Sri Lanka

K. A. Munasinghe[1] and B. C. L. Athapattu[2*]

[1]Centre for Environmental Studies & Sustainable Development (CESSD)
[2]Department of Civil Engineering, The Open University of Sri Lanka, Nawala, Nugegoda, Sri Lanka.

*Corresponding Author - email: bcliy@ou.ac.lk, Tele: +94112881111

Abstract - *In spite of the legitimate controls imposed by the Central Environment Authority, the disposals of untreated wastewater to the environment keep on increasing. Automobile service stations are one such source of pollution that has not been focused very much by the public. At present many of the automobile service stations look attractive with colourful signboards displayed. However at the back yard, unnoticeably the untreated wastewater either flows to a stream or to road side drains.*

On identifying the problem the necessity of developing a suitable system for wastewater treatment for vehicle service stations came to light. However, there are many methods adopted in vehicle service stations to cater for controlling oil. This study was aimed to develop an economical method to remove oil from wastewater and implement the developed method in vehicle service stations. On considering the high percentage of the disposal of oil in wastewater from automobile service stations, a prototype system to separate oil from wastewater was developed and tested. The developed system removes oil completely and directed the oil free wastewater into secondary treatment process.

Keywords - *Automobile service stations, oil and grease, removing oil, prototype, wastewater*

1 INTRODUCTION

Onsite wastewater treatment is one of the methods proposed by the Central Environment Authority of Sri Lanka (CEA) to reduce environment pollution, especially to inland water ways. The challenge in treatment of wastewater is to select an appropriate treatment process that is economical and simple.

Oil and grease and detergents including biodegradable detergents can be poisonous to fish, zooplankton and phytoplankton. The presence of cleaning agents and disinfectants can have detrimental impacts on wastewater treatment process. Oil and fuels are the second most frequent type of pollutant of inland waters in England as reported by the Environment Agency UK. However since the introduction of oil storage regulations the incidents reported have been halved compared to ten years ago.

Oil is a highly visible pollutant that affects the water environment. It can reduce levels of dissolved oxygen in water. The effect can be long term in oil polluted surface water and adversely affect drinking water supplies. Further the oil effortlessly spread throughout a surface of large volume of water from where the oil dispersed. The laboratory experiments showed that dispersant increased toxic hydrocarbon levels in fish by a factor of up to 100 and may kill fish eggs (Fominyen, 2010). Dispersed oil droplets infiltrate into deeper water and can lethally contaminate Corals products (Paxes, 1996). Oil emulsions may adhere to the gills of fish; destroy algae or other plankton due to hydrofluoric acid, ammonium bifluoride (http://www.epa.state.il.us/small-business/car-wash). Deposition of oil in the bottom sediments can serve to inhibit normal benthic growths thus interrupting the aquatic food chain (Fominyen, 2010). It is vital to know that wastewater discharged to treatment plants is non-toxic to the biological phase of the process.

There are undoubtedly many solutions to this issue.

The literature survey reveals oil pollutant removal methods such as catalytic degradation with nano MgO (Zhu et al., 2013), inject hot liquid using free-pressure pump are directly aimed to oil layer for oil recovery (Wang, 2012). Strain of microorganisms can remove oil containing wastewater effectively when the pH value was 7.0, the temperature was 30 degree Celsius, the rotation speed was 140 rev/min and the inoculation amount was 10% (Xu et al., 2009). With the tilted oil tank (Xie et al., 2012) and different improved oil recovery strategies, ranging from water flooding to solvent injection.

Zouboulis and Avranas (2000) treated oil-in-water by coagulation and dissolved-air flotation, which is commonly used though it is costly. Combined microfiltration and biological processes was used by Campos et al. (2002) while Delin et al., (2007) and Su et al (2007) have used biological aerated filter for oil-field produced water treatment. Xin et al., (2006) have introduced biological aerated filter by immobilized microorganisms in oil field wastewater treatment. Ahmed et al., (2005) have compared chitosan to activated carbon and bentonite as a potential residual oil remover for palm oil wastewater. Though the chitosan showed better result, it is inapplicable for removal oil and grease from automobile wastewater.

Pablo et al., (2008) used coagulation and electrocoagulation of oil-in-water emulsions. Mueller et al., (2003) tested adsorption after chemical de-emulsification for removal of oil, grease and chemical oxygen demand from oily automotive wastewater. However, the proposed method highlights the importance of pre-treatment and specially the removal of oil from wastewater before commencing a secondary treatment process without using chemicals or any other complicated systems an ordinary worker cannot handle.

A remarkable visual pollution that experiences in most vehicle service stations in Sri Lanka is the oil pollution. Service stations are seen with large oil spills and stagnant water around the floor. On a careful examination it is realized that ultimate destination of the oil path is leading to inland waterways. On highlighting the matter the National Environment Act 47, 1980 clause 23 V, in addition to pollution of inland waters, specifically mention about the prohibition on discharge of oil in to inland waters.

This study was aimed to identify the present treatment systems adopted for disposal of wastewater from automobile service stations and response from CEA to such disposal. Based on the findings it was targeted to propose a suitable economical method of wastewater treatment system to automobile service stations and to implement the proposed method in order to improve the quality of wastewater disposal to be in par with CEA Standards.

2 METHODOLOGY

The methodology of this research project basically comprised of two facets; i.e.:, Field survey along with collecting testing and analysis of service station effluent samples and design, fabrication and field testing of oil remover.

3 AUTHORITATIVE BACKGROUND

The Government Authority (CEA), who has the legal power to control pollution of surface waterways, was consulted. The information such as registration, categorization of Automobile service stations and the methods of disposal of wastewater and the minimum requirements needed to allow the wastewater to be disposed to the environment were known from CEA database. Discussions were carried out with the relevant staff of the CEA regarding the most remarkable and visible pollutant seen frequently in many of the vehicle service stations in Sri Lanka.

4 THE STUDY AREA

The sample area selected for data collection was the divisional secretariat division of *Kalutara*. The data collected through interviews based on a structured questionnaire from vehicle service owners of *Kalutara* divisional secretariat division. There were a total of thirty vehicle service stations within the division and out of which there were eleven major and nineteen minor categories.

5 DATA COLLECTION

The records of the Central Environment Authority of Sri Lanka indicated that there are five thousand one hundred Automobile Service Stations. The records of service stations were found in the database on a district basis. In order to implement a vehicle service station it has to be registered at the divisional secretariat. There were two hundred and six vehicle service stations in *Kalutara* District. The distribution of the vehicle service stations within *Kalutara* district in each of the Divisional Secretariat is shown in the Table 1.

Table 1Distribution of vehicle service stations within *Kalutara* District (As at Feb 2013)

No	D.S. Division	A70	B32	Total
1	Agalawatta	2	7	9
2	Bandaragama	9	13	21
3	Beruwala	11	19	30
4	Bulathsinhala	5	7	12
5	Dodangoda	2	11	13
6	Horana	10	14	24
7	Ingiriya	0	5	5
8	Kalutara	11	19	30

Table 1 (Cont.)

No	D.S.Division	A70	B32	Total
9	Madurawela	2	5	7
10	Mathugama	5	11	16
11	Millaniya	2	1	3
12	Palindanuwara	1	7	8
13	Panadura	7	12	19
14	Walallavita	2	6	8
	Total	69	137	206

The categorization done by the CEA was according to the handling capacity of the service stations and it identifies major and minor categories. The major category included the service stations capable of servicing Lorries, buses, vans and cars. The minor category stations serviced three wheelers and motor cycles only. CEA coded Major category as A 70 and the minor category as B 32.

5.1 Extent of Survey

The Questionnaire used for the survey had five main sub headings 1) Primary Information of the vehicle services, 2) Details of the Establishment, 3) Resources used at the time of inspection, 4) Use of chemicals and 5) Methods of Wastewater disposal adopted at the service station.

5.2 Questionnaire Survey

The questionnaire survey was carried out in thirty vehicle service stations throughout the Divisional Secretary's division in *Kalutara*. Visited eleven major service stations where heavy vehicles such as buses, Lorries and vans were serviced and nineteen minor service stations where only motorcycles or three wheelers were serviced. The owner or his representative of the vehicle service station was interviewed individually and the information was recorded as told by them without any amendments. Thus thirty vehicle service owners were interviewed and recorded.

5.3 Basic Amenities Available at Service Stations

During the survey it was noticed that a service station grouped under the category of major was located on the main street with hardly any space to manipulate vehicles. There were no cover to the service area and did not have the necessary hoists and other facilities. Only a concrete ramp served as a place to wash the under carriage of vehicles. Those stations that serviced buses and Lorries had 2 of 4 ton capacity hoists. There were three major service stations that serviced only vans and cars having hoists of less than 4 Ton capacity. The sanitary facilities were provided for workers as well as the clients and it was reported that the sewer lines were not connected to the waste water system.

Three of the service stations grouped under minor category had nicely arranged buildings and infrastructure facilities. These centers were guided by the respective three wheeler or the motor cycle dealers with the assistance of their importers. These had hoists of less than one Ton capacity capable of hoisting three wheelers. The waste water disposal system functioned as per the instructions given by the respective dealers. Details of basic amenities present at the respective service stations are shown in Table 2

Table 2 Basic amenities/ Infrastructure availability in service stations

Facility	Major (11)		Minor (19)	
	yes	No	Yes	No
Sufficient Land Area	10	01	03	16
Building for service	10	01	19	
compressors	11	-	19	
Water pumps	10	01	19	
Hoists	10	01	-	
Concrete ramp	08	03	19	
Wastewater disposal	11	-	19	
Treatment system	11	-	19	
Separate sewer disposal	11	-	19	

5.4 Use of Resources

All major and minor service centre owners had their water for washing from either dug wells or tube wells. The electricity was from the mains supply. Average daily consumption of water in major service centers was around 8000 liters whereas in minor stations it was about 2500 liters. Major service stations facilitate about seven to ten vehicles per day at least whereas the minor stations service about ten three wheelers/motor cycles per day.

Table 3 Use of oil and detergents and removal process in Vehicle service stations

Mode of oil removal	A70	B 32	Remarks
Pre-treatment system	No	No	
Manual	Yes (all)	Yes (all)	Sludge and oil remained at bottom of chamber
Oil separator with oil removing facility	No	No	

5.5 Removal of Used Oil and Detergents

Manual oil removal processes has been adopted by all service stations. It was reported that the collected oil was removed to barrels and sold to those who needed the used oil. Only two major service stations had a separate bay for oil removal. However no attention was paid to the use of detergents that mixed with wastewater. The table 3 shows the details of oil and detergents used in service stations.

Table 4 Analytical data for critical Determinants in Auto service stations (type A-70)

No	TSS (mg/l)	pH	Oil & Grease (mg/l)	BOD (mg/l)	COD (mg/l)
1	64	7.5	14	80	360
2	109	4.4	15	140	12
3	99	8.7	265	50	858
4	65	7.5	9	40	443
5	114	7.5	47	260	198
6	92	8.1	95	83	693
7	153	8.6	21	200	378
8	71	7.4	8.5	250	1122
9	75	7.2	27	45	1108
10	53	6.1	59	150	235
11	40	7.46	20	20	357

5.6 Wastewater Sampling and Analysis

The samples of wastewater from eleven major service stations and nineteen minor service stations were collected and analyzed in the Laboratory. Only the analytical data with reference to the most important determinants were recorded. The determinants whose analytical data was recorded for TSS, pH, Oil & Grease, BOD and COD.

Table 5 Analytical data for critical Determinants in Auto service stations (type B-32)

No	TSS (mg/l)	pH	Oil & Grease (mg/l)	BOD (mg/l)	COD (mg/l)
1	34	7.9	20	60	10
2	55	6.9	12	100	267
3	50	5.9	52	70	353
4	65	7.5	14	80	360
5	64	8.5	15	50	198
6	71	7.4	21	40	235
7	53	6.1	27	45	357
8	40	7.4	20	20	378
9	40	7.46	20	20	357
10	75	7.2	27	45	1108
11	153	8.6	21	200	378
12	114	7.5	47	260	198
13	92	8.1	95	83	693

Table 5 (Cont.)

No	TSS (mg/l)	pH	Oil & Grease (mg/l)	BOD (mg/l)	COD (mg/l)
14	99	8.7	265	50	858
15	109	4.4	15	140	12
16	71	7.4	8.5	250	1122
17	64	7.5	14	80	360
18	53	6.1	59	150	235
19	65	7.5	9	40	443

6 DATA ANALYSIS

The assessment started with analyzing randomly collected raw wastewater effluent samples and the analytical data were compared with the recommended parameters of the CEA. Analytical data values of prominent pollutants present in the effluent samples are shown in Table 4 and Table 5.

The analytical data of the effluent samples taken from Major Auto Service Stations were compared with the tolerance limits for TSS and it was found that almost all the effluent from the major stations had exceeded the tolerance limit. Effluent from only one service station was within the tolerance limit. Figure 1 shows the comparison of the tolerance limit and the analytical value of the Total Suspended Solids (TSS) for the Type A 70. 20% of the minor type of service stations where only three wheelers or motor cycles were serviced had the Total Suspended Solids within the tolerance limits. Analytical data revealed that out of the samples analyzed from nineteen minor service stations, four minor service stations had the TSS indications below the tolerance limit.

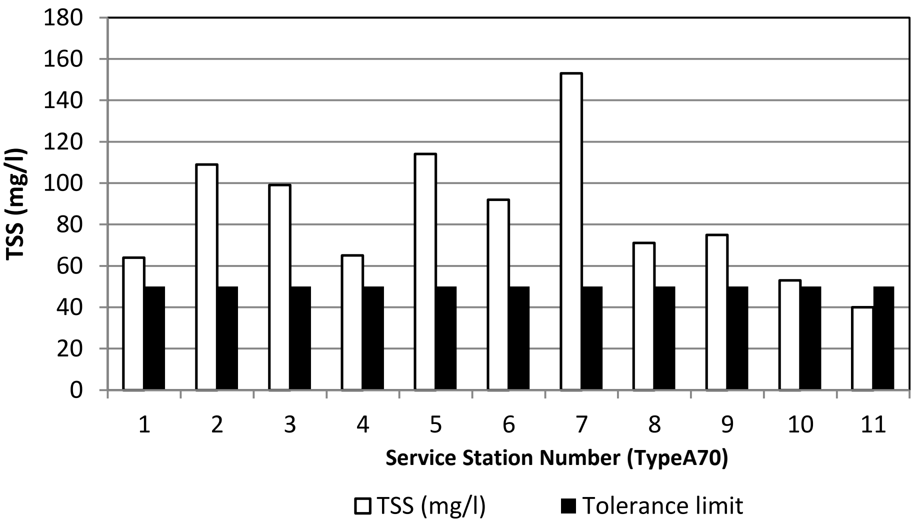


Figure 1 Increase over the Limits of TSS in TypeA70

The bigger vehicles may have higher amount of suspended solids as their tire sizes are bigger and the surface area of the under carriage is larger than that of a three wheeler. Therefore it may be advisable to introduce a suitable as well as affordable pre-treatment process before the waste water enters the actual treatment system. The comparison of analytical data of TSS from Type B32 is shown in Figure 2.

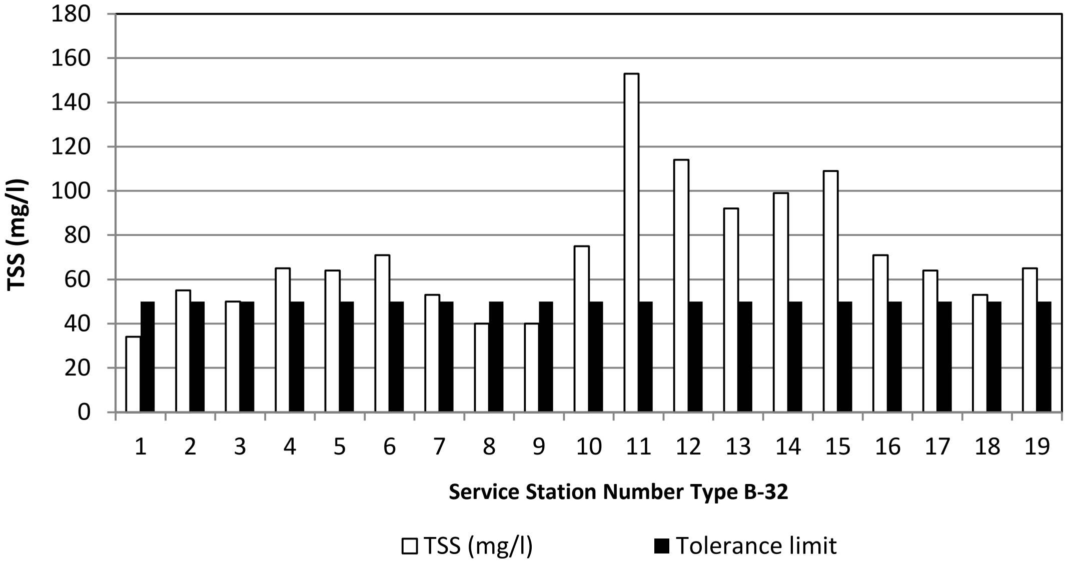


Figure 2 Increases over the Tolerance Limit of TSS in Type B-32

A prominent high percentage of Oil & Grease was seen from analytical reports of effluent samples when compared with the tolerance limit. It was about 200% increase over the limit of tolerance. Presence of oil spills at vehicle service stations is a common sight in Sri Lanka. During the survey it was observed that no suitable oil separation process was adopted in any of the service stations. Therefore it is necessary to draw much attention to the matter to restrict oil disposal to inland surface waters. Figures 3 & 4 show the difference of oil & Grease amount with the tolerance limit in vehicle service stations of Type A 70 and Type B32 Categories respectively.

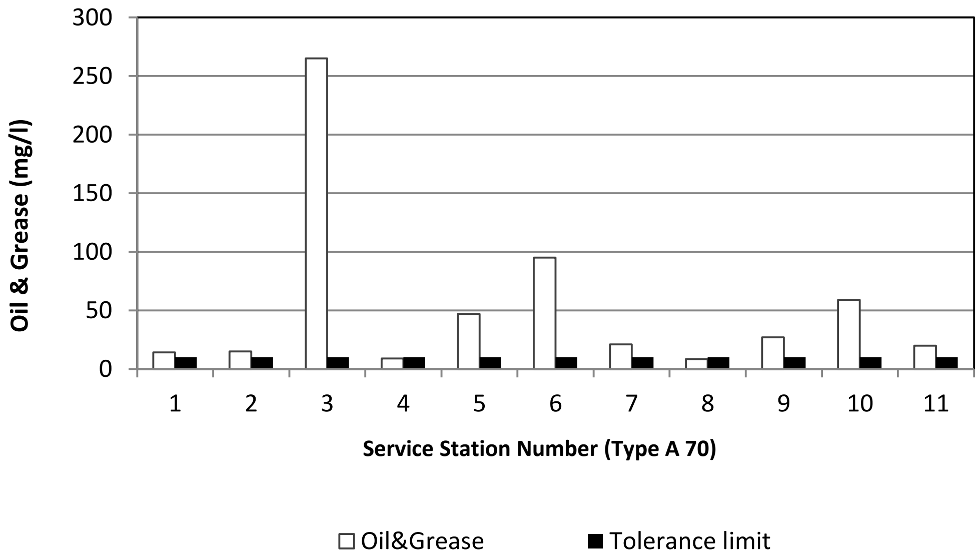


Figure 3 Increases over the Tolerance Limit of Oil & Grease in Type A 70

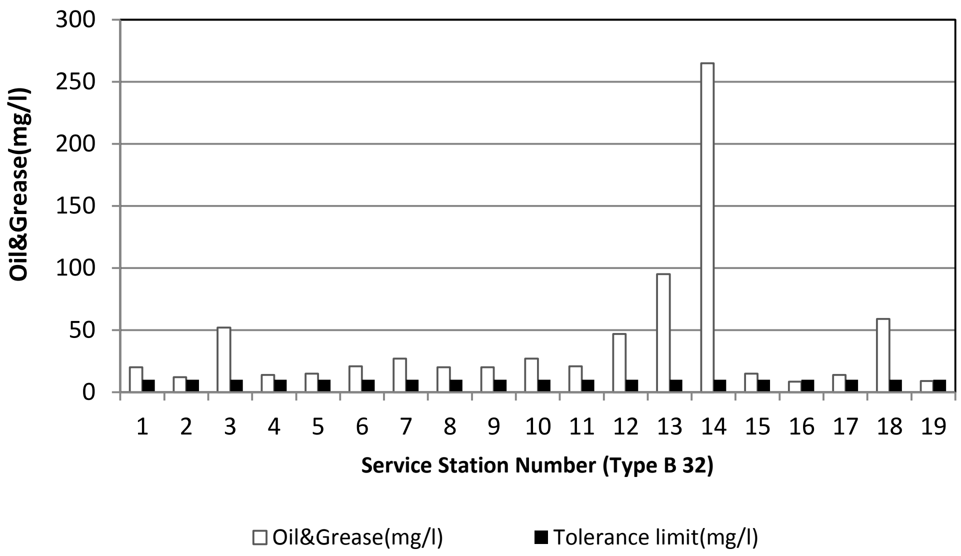


Figure 4 Increases over the Tolerance Limit of Oil & Grease in Type B 32

High values of BOD were observed from the analytical data from effluent samples of type A.70 service stations and it was as high as almost ten times the tolerance limit. Comparatively lesser values of BOD were shown from the effluents analysis in minor service stations (B 32). Figures 5 and 6 indicate the BOD differences compared with the tolerance limits in vehicle service station Type A 70 and Type B 32 categories respectively.

The analytical data from the effluent samples from type A 70 service stations as well as B32 indicated high values of COD. Figures 7 and 8 shows the difference of COD compared with the relevant tolerance limits in major and minor service station categories respectively.

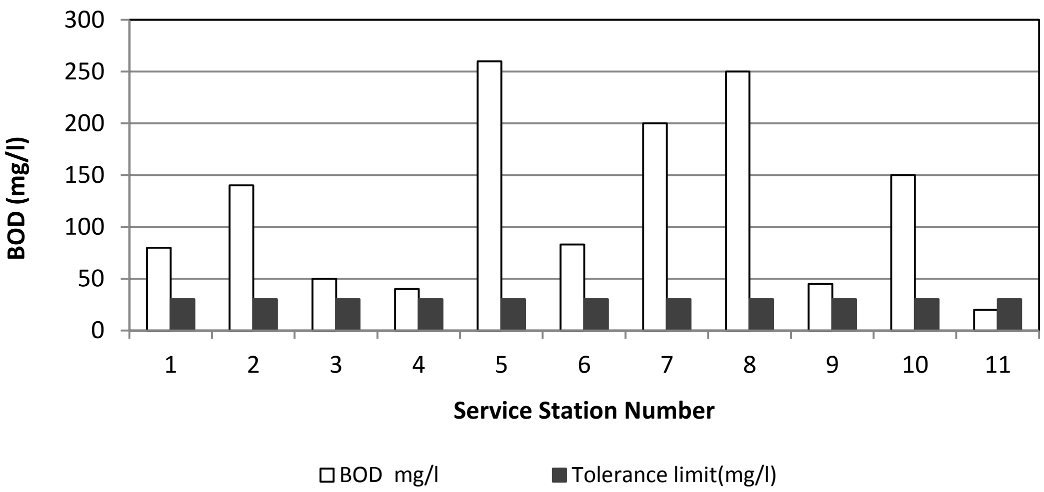


Figure 5 Increases over the Tolerance Limit of BOD in Type A 70

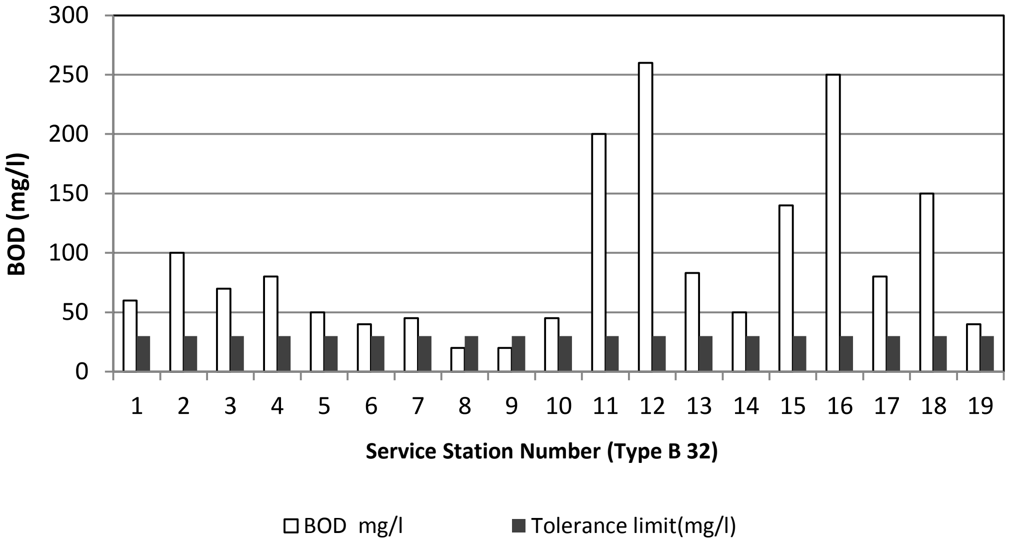


Figure 6 Increases over the Tolerance Limit of BOD in Type B 32

High percentages of contaminants were detected on analysing the wastewater samples from vehicle service stations. There were four such major pollutants. They were TSS, Oil &Grease, BOD and COD. Many methods have been developed to reduce BOD and COD. Therefore a suitable solution was selected from the reviewed literature survey to control the disposal of wastewater containing high amounts of TSS, Oil & Grease.

6.1 Necessity of an Appropriate Complete Oil Removal Device

On understanding the severity of the presence of oil in analytical samples, a need of a simple mechanism to get rid of the menace was highlighted. Hence designing and fabricating an oil separator capable of handling the situation was considered.

Thus an experimental set up to address the physical removal of oil and grease and TSS from wastewater was introduced.

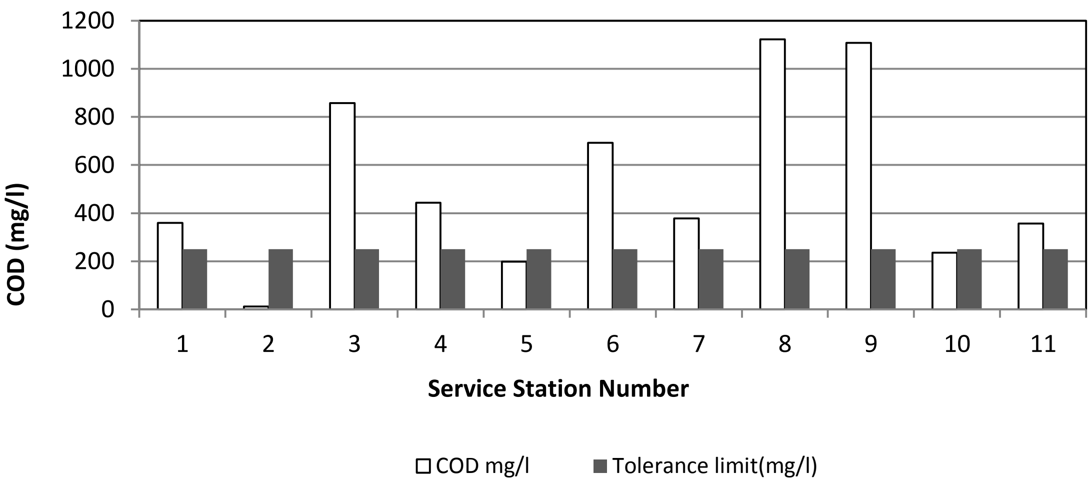


Figure 7 Increases over the Tolerance Limit of COD in Type A 70

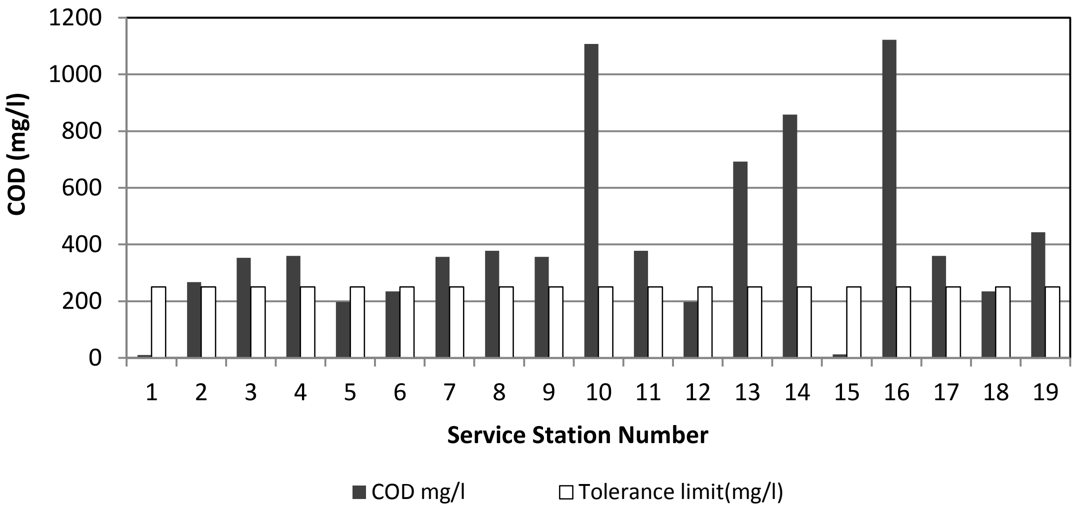


Figure 8 Increases over the Tolerance Limit of COD in Type B- 32

7 DESIGN OF AN OIL SEPARATOR

7.1 Oil/Water Separator-Theory of Design

The oil/water separators are devices that remove oil from wastewater by allowing the oil droplets to rise due to the hydraulic flow path of the separator, thereby extracting them from the wastewater flow.

In theory the flow through velocity (V) of a vessel is a function of the vessel size and flow rate (l/sec).The velocity is then compared to the rate of the rise of the oil droplet and the length of the vessel. If the resulting calculated trajectory (T) of a given droplet allows it to rise out of the effluent flow path to the surface before it reached the vessel's exit, it can be removed. This is purely an application of Stokes Law and terminal velocity to the rate of rise of a particle in a liquid medium.

The rise rate of oil droplets is also governed by Stokes Law. If the droplet size, specific gravity and viscosity of the continuous liquid are known, the rise rate can be calculated.

7.2 Operation of the Oil Separator

The main objective is to design and test a small scale oil separator to separate oil from wastewater. In general the effectiveness of an oil separator is increased by adopting slower flow rates into the separator and allowing a longer detention time. When wastewater enters the receiving chambers the velocity and turbulence of the fluid is reduced to allow the heavier solids to settle while the larger oil droplets to rise to the water surface. Further separation continues in the middle chamber where smaller droplets rise slowly to the surface joining the larger droplets. The resulting accumulated oil layer is then taken out by centrifugal action. The remaining wastewater is passed under the second baffle board to the outlet chamber where it is discharged to the secondary treatment system.

7.3 Operational and Flow Condition of Oil separator

A vehicle service station with three servicing bays was considered and assumed that the maximum work load took place when all the three servicing bays were in operation and the minimum work load took place when only one service bay was used.

An average raw water flow of 12000 liters per day was considered and the surface area of the proposed separator as 2m x 0.4m and thus the surface area of the separator is 0.8 m2 and the surface loading is 15000 $l/d/m^2$.

Average flow considered as 0.5 l/s by considering the 8hrs of a working day and the retention period of the tank is considered as 30 minutes if one bay is in operation. If one bay is at work then the volume required for average flow is 0.9 m^3.

When all three bays are at work the volume required for peak flow and therefore required separator must have a minimum volume of 1.35 m^3.

The design of the separator is subjected to the following constraints

Horizontal velocity (vh) through the separator should be less than or equal to 1.5 cm/s (0.015 m/s) or equal to 15 times the rate of the oil globule (vt), whichever is smaller. (American Petroleum Institute design guide)

$(v_t) = 0.0123(s_w - s_o)/\eta$ (Stokes equation)

s_w =Specific gravity of waste water

s_o =Specific gravity of oil

η = Kinematic viscosity of waste water at design temperature (v_t) = 0.108

Based on the design calculation, it is estimated that the separator dimensions are: D = 0.6 m, W=1.25 m and L = 1.8 m.

7.4 Fabrication of the Oil Separator

An experimental oil separator having a capacity of 90 litres was turned out with G.I plain sheets having a length about three times the width and the depth was kept at one meter maximum. Inlet pipe was fixed at depth of about 150mm from the bottom of the separator fixed with a 900 bend so that the inlet flow will not support horizontal flow of fluid thus minimizing the turbulence of the oil layers at the surface. Mild steel Grating was turned out and fixed at a 450 angle to the vertical behind the inlet pipe to arrest grits etc. Vertical mild steel rods having 12mm diameter was fixed at 100mm intervals across the separator to increase the separation of oil from water. Two adjustable baffle boards were fixed following the vertical rods. These baffle boards were turned out of 3mm thick G.I plates and allowed to move freely up down through the groove, slides on either sides across the separator. Slots having diameter of 6mm drilled in the grove and was provided with a 6 mm pin so as to adjust the baffle board suitably. Similar type of a baffle board was fixed at the outlet position. They control the inlet of effluent and the out let of separated oil and water. The dust particles settled at the bottom of the separator was allowed to get collected to a small ditch to which a wash out was fixed to takeout the sludge when necessary. The collected oil at the rear baffle board was taken out using a centrifugal mechanism. A perforated PVC pipe was fixed to a 16mm mild steel rod coaxially with a handle. The perforations were done only on the top side of the PVC pipe so that the oil entered the pipe through the perforations was force by the centrifugal action to lead out of the separator. By turning the handle the oil flow can be accelerated. The water at the bottom layers pass under the baffle board through the outlet and enter the secondary treatment system. Details are shown in figure 9 and fabricated oil separator is shown in figure 10.

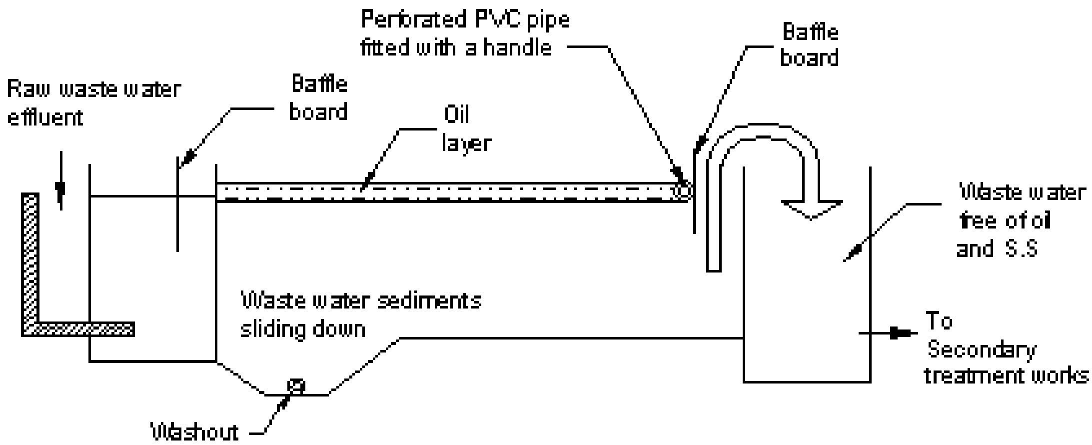


Figure 9 Longitudinal Section of Oil Separator

In designing the separator the inlet horizontal velocity of the incoming effluent was kept below 1.5 cm/s so as not to disturb the oil globules collected at the surface. The flow of effluent to the separator was controlled by the necessary adjustment to baffle board fixed near the inlet pipe. The depth of separator was kept at one meter and the length to width ratio kept at 3:1.

7.5 Proposed Oil Separator as an Economical Treatment Method

Separating oil by skimming is not an effective process as it does not separate oil completely.

Difficulty in removing sludge collected at the bottom of the chamber. Advantages of using the proposed oil separator

The proposed oil separator is portable and occupies less space. Free oil could be separated completely from wastewater effluent. Sludge that is collected at the bottom of the separator could be taken out from the washout. The effluent free of oil and sediments eases the work on secondary treatment system and thus a simple aeration method could be adopted using the existing compressed air at the vehicle service station.

The proposed method also suggests removing used oil from vehicles in an isolated location or in a bay that uses only for oil changing without allowing the oil to be disposed into effluent collecting tanks. The removed oil then could be taken into containers and carefully stacked in store. The used oil thus collected could be sold to those who need used oil for various purposes.

Figure 10 Fabricated Oil Separator

The oil spills that remain along with wastewater could be separated using the oil separator so that no oil is disposed along with wastewater to the secondary treatment system. The TSS present in the effluent could also be removed from the washout of the separator. The method also suggests minimizing the use of detergents and discourages mixing oil with detergents.

The proposed oil separator helps to reduce the load on the secondary treatment works by completely removing oil and the sediments. Separating detergents from oil and allowing oil and sediment free effluent into the secondary treatment system reduces the cost for using powerful aerators and pumping equipment to pump wastewater to elevated tanks.

Thus the method proposed is an economical method compared with the existing treatment system used in many of the vehicle service stations throughout Sri Lanka.

7.6 Testing of the Device

The pollutants of waste water effluents could be controlled by introducing suitable methods of treatment. However the proposed methods should be affordable to the owners of small scale service stations too. Thus an oil separator was designed and fabricated on an experimental basis to remove free oil completely from wastewater in vehicle service stations. The fabricated oil separator was tested for oil separation. The analytical data of effluent after passing through the oil separator is given in Table 6.

Table 6 Lab Test results of TSS and Oil before and after passing Oil Separator

Parameter	Raw value (mg/l)	Value After passing through oil separator	CEA Tolerance Limit (mg/l)
Oil& grease	164.6 ± 4.6	0	10
TSS	338.2 ± 5.1	53 ± 4.3	50

Oil and grease were tested in a laboratory according to the Standard methods for the examination of water and wastewater (APHA, 2005).

8 CONCLUSIONS AND RECOMMENDATIONS

Analytical data very clearly indicated that almost all the vehicle service stations dispose oil along with wastewater effluents. The negligence and the ignorance of the service station management had resulted in such a menace. Most of the service station owners were not aware of the dangers of disposing oil to the environment freely. Had they realized that having such simple mechanisms of arresting oil wastewater could be dispersed with minimum harm to environment, they would have definitely adopted same.

Following recommendations are made to safeguard surface waterways as well as to have a clean environment around vehicle service stations in Sri Lanka.

- CEA should approve the location of vehicle service stations along with Pradeshiya Saba so as to avoid public protests regarding residential area, sensitive issues such as polluting water resources.
- The vehicle service station owners and the workers attached to those stations should be educated of the consequences of oil seeping to surface waterways by distributing leaflets or having short seminars at site or a group meeting at one site for an hour at least. This can be arranged through regional offices of the CEA. The important points to discus at the seminar may include:
    - The importance of preparation prior to the service and impart them what pre-treatment is all about and introduce an innovative oil separator capable of arresting TSS as well as completely removing oil from wastewater.
    - The use of detergents - wash water mixed with detergents and soap should not allow to be disposed to oil collecting chambers.
    - Introduce management practices such as how to maintain the service station and preventing oil spills and cleaning floor wherever oil spread as it happens. Good operating practices and habit changes to care for the environment.
    - Vehicle tires to be clean first at a separate bay along with cleaning the under carriage for dust particles and wash water thus collected be directed to a separate chamber.
    - Oil changing to be done at a specific bay and the oil thus removed are collected to oil collecting chamber with no other wash water or wastewater in it.
    - The used oil filters and other used materials that contaminated with oil need to be stacked in specific collecting bins and disposed suitably.
    - Only wastewater without having suspended solids and oil may be allowed to be disposed to secondary treatment system.

REFERENCES

1. Ahmed A. L., Sumathi S. and Hameed B. H. (2005). Residual oil and suspended solid removal using natural adsorbents chitosan, bentonite and activated carbon: A comparative study. Chemical Engineering Journal; 108(1-2), pp. 179 – 185.
2. APHA 20th edition, 2003 Standard Methods for the Examination of Water and Wastewater, American Public Health Association, American Water works Association, and Water Environmental Federation, Washinton, D.C.
3. Campos J. C., Borges R. M. H., Oliveira Filho, A. M., Nobrega, R. and Sant'Anna, Jr., J. L. (2002). Oilfield wastewater treatment by combined microfiltration and biological processes. Water Research; 36(1), pp. 95-104.
4. Canizares P., Martinez F., Jimenez C., Saez C., and Rodrigo M. A. (2008). Coagulation and electrocoagulation of oil-in-water emulsions. Journal of Hazardous Materials; 151(1), pp. 44 - 51.
5. Debabrata M., and Somnath M., (2011) Treatment of Automobile Service Station Wastewater by Coagulation and Activated Sludge Process, International Journal of Environmental Science and Development, Vol.2, No.1, ISSN: 2010-0264
6. Dissanayake P., Tennakoon M., and Burmeister J., (2008) Guide to on-site Industrial waste water management for industrial & Commercial Institutions: guide for vehicle service station owners and managers IWMI-April 2008. https://ideas.repec.org/p/iwt/bosers/h041240.html
7. Fominyen G., (2010) The Effects of Oil Spills on Aquatic Life and Environments, https://suite.io/gwendoline-fominyen/3gd02p7 Visited 20th June 2013
8. Mohamed R.M.S.R., Rahman N.A., and Kassim A. H. M., (2014) Moringa oleifera and strychnos potatorum seeds as natural coagulant compared with synthetic common coagulants in treating car wash wastewater: case study 1. Asian Journal of Applied Sciences, Vol 2 Issue 5. pp. 693-700. ISSN 2321 – 0893
9. Mueller S. A., Kim B. R., Anderson J. E., Gaslightwala A., Szafranski M. J., and Gaines W. A., (2003). Removal of Oil and Grease and Chemical Oxygen Demand from Oily Automotive Wastewater by Adsorption after Chemical De-emulsification. Practice Periodical of Hazardous, Toxic, and Radioactive Waste Management; 7(3), pp. 156 – 162.
10. National Environment Act of Sri Lanka. Act No. 47 of 1980. Central Environmental Authority, Sri Lanka
11. Panpanit S., Visvanathan C., and Muttamara S. (2000) Separation of oil water from car washes,
12. Water Science and Technology Vol 41 No 10–11 pp 109–116
13. Paxeus N (1996). Vehicle washing as a source of organic pollutants in municipal wastewater. Water Science and Technology; 33(6), pp. 1-8.
14. Saroj G., Kuaanan T., and Chumpol Y., 2012, Effect of Industrial waste disposal on the surface water quality of U-tapao river, International Conference on Environment Science and Engieering. IPCBEE vol.3 2 pp 109-113. IACSIT Press, Singapoore
15. Su D.W. J., Kaiwen L., and Ding Z., (2007). Kinetic Performance of Oil-field Produced Water Treatment by Biological Aerated Filter. Chinese Journal of Chemical Engineering; 15(4), pp. 591-594.
16. Wang X., (2012) The hot water oil expulsion technique for geothermal resources. Geomaterials. Vol.2 No.2. DOI:10.4236/gm.2012.22007
17. Xie W., Wang X., Cui H. and Chen J., Optimization Model of Oil-Volume Marking with Tilted Oil Tank, Open Journal of Optimization, Vol. 1 No. 2, 2012, pp. 20-24. doi: 10.4236/ojop.2012.12004.
18. Xu X., Chen X. and Fan Y., "Screening and Domestication of High Effective Microorganism Used in Oil Containing Wastewater Remediation," Journal of Water Resource and Protection, Vol. 1 No. 2, 2009, pp. 145-151. doi: 10.4236/jwarp.2009.12019.
19. Yasin S., Iqbal T., Arshad Z., Rustam M.& Zafar M., (2012) Environmental Pollution from Automobile Vehicle Service Stations. Journal of Quality and Technology Management Volume VIII, Issue I, Page 61 – 70

20. Zhao X., Wang Y., Ye Z., Borthwick A.G.L., and Ni J. (2006). Oil field wastewater treatment in Biological Aerated Filter by immobilized microorganisms. Process Biochemistry. 41(7), pp. 1475-1483.
21. Zhu M., Deng C. , Su H., You X., Zhu L., Chen P., and Yuan Y. (2013) Oil Pollutants Degradation of Nano-MgO in Micro-Polluted Water. Computational Water, Energy, and Environmental Engineering, **2**, 12-15. doi: 10.4236/cweee.2013.23B003.
22. Zouboulis A. I., and Avranas A., (2000). Treatment of oil-in-water emulsions by coagulation and dissolved-air flotation. Colloids and Surfaces A: Physicochemical and Engineering Aspects; 172(1- 3), pp.153-161.
23. State of Illinois, (2002), Mobile power washing -keep it clean, Retrieved from http://www.epa.state.il.us/small-business/mobile-power-washing/mobile-power-washing.pdf, Accessed on February 23, 2015