Determining Pollution Levels Using Material Balance Methods

Final Research Report - Section 3

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Executive Summary

At present, the Department of Environment in Bangladesh has limited financial and human capacity to carry out regular water analysis to monitor industrial pollution. Such analysis can be very expensive and complicated and there is lack of expertise and equipment facilities to conduct such water analysis. This research aims to assess the feasibility of using a material balance approach to try to determine pollution load generated by factories. This approach involves gaining a detailed understanding of production process and identifies where, and how much, pollution is generated in terms of inputs and outputs of those production processes.

The work was undertaken with factories undertaking winch dyeing in the project area, and tried to generate rough estimates of pollution loads generated by these firms and then to compare them to the results from detailed water analysis. The protocol for conducting material balance in the dyeing industry included collection of data from factory staff and management team. This was done through interviews, dialogues and questionnaires sent to seven factories. All these data were used to generate a profile on the inputs and outputs from the dyeing production process. Sampling was undertaken at various stages of the production process and composite sampling was done at the final discharge point. Water analysis was conducted for different parameters such as biological oxygen demand (BOD_5), chemical oxygen demand (COD), total dissolved solids (TDS), sulphate and various heavy metals. The values were then used to estimate total amount of wastewater generated and also pollution loads both in terms of concentration and weight.

The results show that there is great variation in terms of pollution loads depending on age of machinery, whether they are manual or automatic, and different shades of colour dyed. Dark colours and whites generate very different pollution loads.

Data were collected on the number and size of winch dyeing factories in the project area. Using a material balance approach it was possible to assimilate all this data and provide best guesstimate of the pollution load flowing into the local water body.

Determining Pollution Levels Using Material Balance Methods

1 Background

Water quality analysis is an expensive and, for some parameters, a complicated procedure requiring expert knowledge and specialist equipment. The situation is made even more complex because industrial waste is rarely uniform through time. For example, textile dyeing of knitted fabrics involves several process baths that will be dropped at intervals and each will contain a range of pollutants at various concentrations depending on the individual process. For these reasons monitoring of industrial effluent is not regularly undertaken in Bangladesh or in any other country. However, the limitations in the financial and human resources available at the Department of Environment (DoE) mean that even a monitoring programme based on spot checks on factories is currently beyond the scope of the department.

One means to overcome these problems may be the development of an approach that enables regulatory bodies such as DoE and even the factories themselves, to estimate pollution concentrations and loads from certain industrial processes using a material balance approach or cleaner production audit methodology. The approach is used to determine where and how much pollution is generated by production processes. Such an approach could feasibly be undertaken on any industrial process, although some are more complicated than others.

In Bangladesh, garment production is a major industry and one of the largest foreign currency earners. In Kaliakoir Upazila, Gazipur District, Bangladesh, where the research for this project was undertaken, the predominant industries are t-shirt and shirt producers. These factories, known as composite or vertical units, knit, dye and finish cotton fabrics, to be used to make t-shirts and shirts.

2 A Material Balance Approach

2.1 Preparation

The preparation for a material balance is crucial as the approach must be methodical, reasonably rapid and participatory. It is important that the senior management approve and support the material balance process and that all factory staff are aware of, and engaged in, the process. Without support from the senior management access to factory will be difficult and without the engagement of the factory staff it will be hard to gain a full understanding of actual factory practices.

Choosing the audit team is also crucial. At least one of the team should have technical knowledge about the general production process. Some industrial processes are quite complex and unless these complexities can be understood an accurate material balance will not be produced.

If any analysis is to be performed on inputs or outputs this must be planned in advance to ensure that the necessary facilities, such as analytical laboratories, and equipment are available.

How the information required to perform a material balance is actually collected can take various forms and should also be planned in advance. These methods include reviewing of factory records and interviews with various staff. The Plant Manager will be able to provide information on production, resource consumption, operating practices and overall information inputs; the stores staff will have records of resource consumption, as will the accounts section; and the utilities manager or engineer will know the level of water consumption and will have knowledge of the operation of the equipment. Though planning is required flexibility is also advisable and alternative options should be available. For example if records of chemical use are not available it may be necessary to calculate average chemical use and to follow this by requesting that the stores manager keeps accurate in future. Alternatives also provide the opportunity for cross checking the information obtained.

2.2 Production Units

To undertake a material balance it is necessary to gain an initial understanding of the production process, the layout of the plant and the equipment being used. This will be translated into a schematic or flow diagram of the production process. Some factories may already have a schematic of the production process but for others it will be necessary to draw it out. In either case it is useful to take a tour of the factory floor and to note any observations about the equipment such as age, type and state of repair. Notes may also be taken about how the process is being undertaken by the operatives, as this may differ from that described by management.

Textile dyeing, as with many other industrial processes, involves various stages or unit processes. These include pre-treatment, dyeing, washing and finishing. The initial flow diagram produced of these unit processes will be very simple (Figure 1) but will be developed to be more detailed as information is gathered.

2.3 Inputs and outputs

The next phase requires gaining an understanding of the inputs to the production process. In some audits it may be applicable to consider the whole production process as one unit but in most it will be divided into several individual processes that have specific inputs. The nature and goal of the material balance will determine whether only some or all of the production units are included. However caution must be exercised if only certain units are selected as other units may have more of an effect on these unit processes than anticipated. For example, when auditing a dye house, it may be deemed unnecessary to consider the knitting floor, but the way in which a fabric is knitted can effect dye uptake and therefore the quantity of dye wasted, or the quality of the dyeing, which may ultimately result in the fabric being rejected and re-dyed, causing additional pollution problems and production costs.

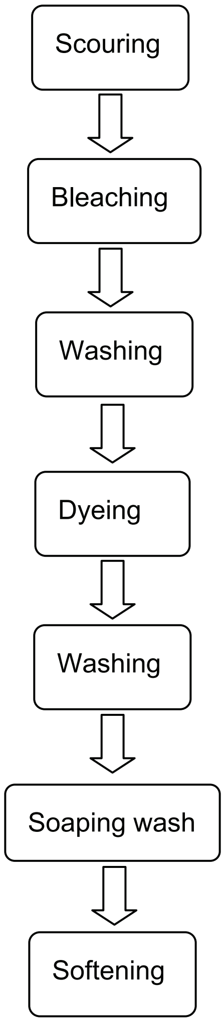

Figure 1: The Winch Dyeing Process

In the case of a material balance for wastewater the inputs include all solid, liquid and gas inputs. Other audits may also include energy. It is necessary to know a number of things about the inputs including:

- The nature, purity and concentration of chemical and material inputs. This requires knowledge of how inputs are prepared and stored. For dyeing this includes all colorants and auxiliaries such as dyes, fabric, electrolytes, carriers, reducing agents and oxidising agents; and
- The quality (e.g. presence of certain metal ions) and quantity of the water used.

To understand how these inputs function, their effectiveness and therefore the quantity and form in which they leave the process, it is important to have a more thorough understanding of each stage of the production process and general factory management. As stated previously actual production practices may differ from those set out in written procedures, so both factory protocols and factory practices should be recorded. In textile dyeing for example it is necessary to know:

- How fabric and chemical inputs are handled and stored.
- The application method of the dye. Factors such as machinery and equipment used, liquor to goods ratio, addition and mixing rates and methods, temperature, pH and time are all important;
- Methods used to “fix” the colorants and those used to remove “unfixed” colorants; and
- All post coloration treatments (e.g. finishing treatments).

This information can then be used to determine outputs from each process and the probable concentrations of pollutants in the wastewater (Figure 2). In all processes the outputs will include desired outputs i.e. the product, and also waste. In the case of textile dyeing the required output is dyed fabric, and the wastewater will contain some or all of the auxiliaries and residual dyes that have not been fixed to the fabric.

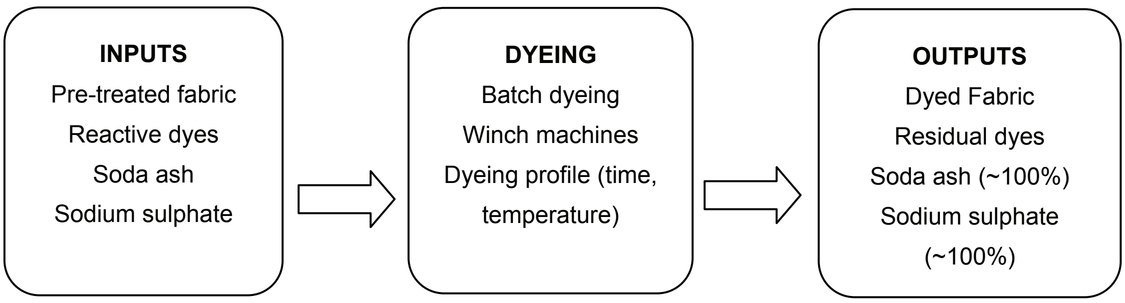

Figure 2: Input – Output Process Diagram

An input-output process diagram like this should be produced for each of the unit processes being considered. Greater detail can be included which will improve the accuracy of the material balance. In some factories there may be slight variations within each unit process and these must be factored in. For example, in a knitted fabric dyeing plant there may be several winch dyeing machines, which take different quantities of fabric and therefore different quantities of chemicals. Some of the machines may be more modern and have automatic dosing, which will improve efficiency and reduce waste. All these factors must be recorded and included in the material balance calculation.

3 Methods and Methodologies

This research undertaken in Bangladesh focussed on developing a material balance for batch dyeing of knitted fabrics using winch-dyeing machines. This section describes the specifics of that approach, the data obtained and the material balance developed. The purpose of this approach was to enable calculation of pollution load from winch dyeing and identify ways to minimize this pollution through alternate cleaner production. The following sections make up the development of a protocol in utilizing this material balance approach for the textile dyeing industry.

As mentioned in section 2.3, the first step in developing a material balance approach is an understanding of the inputs and outputs of production within a winch dyeing factory. Firstly information had to be collected from individual industries by interviewing factory workers and the management team, as well as reviewing their books and records.

3.1 Identification of dyes and chemicals used

Detailed information was collected from seven individual industries which consisted of all chemicals and dyes used each year. The data also included how much fabric was dyed each year and what shades were produced. The idea was to collect as much information as possible about all substances that produced the input section of the material balance. Some of the chemicals such as softeners and sequesters had common local names and had to be identified via consultation with the factory staff. Also, most of these chemicals did not have any material safety data sheet; hence, it was not possible to identify the chemical properties that were present in these substances. The properties of these unknown substances were roughly identified by finding out what they are used for. For example, if one such chemical is identified to be a softener, it was assumed to have the properties expected from a generic softener used for textile batch dyeing.

3.2 Identification of stages of production

The individual steps involved in the dyeing process of textiles can be quite lengthy and complicated. Each batch of fabric can take from ten to twelve hours to finish one complete cycle from pre-treatment till the final wash. The individual steps involved in the production process were observed closely and identified in terms of what and how much chemicals and dyes are used in each step. The amount of fabric dyed per batch and the wastewater produced during the entire cycle was calculated as well. At first recipes were collected from dye managers. These recipes included the quantity of dyes and chemicals used in each production cycle and how the production process was carried out. Appendix I shows the different chemicals and dyes that are used for different shades of fabric and also how much percent of each is used during the production process. All this data formed the input section of the material balance model.

3.3 Consideration of other factors

Other factors had to be considered as well in developing a material balance model to predict pollution loads. These included:

Fabric

(a) The type of fibres/fabrics being used by each company:
- Cotton
- Polyester
- polyester-cotton blends

(b) Quantity (tonnage)of fabric being dyed:
- Annually
- Under each process

(c) Fabric pre-treatment processes

Dyes

(d) The dye classes being used:
- Application type (e.g. reactive, vat, direct etc)
- Chemical class if possible (e.g. azo, anthraquinone)

(e) How dyes are stored

Process

(f) How often (once per week, once per month etc) each process is used (to facilitate calculation of output)

(g) Quantity of water required

(h) Equipment in use:
- Type
- Age

Sampling

(i) Samples that will be required:
- Dyes
- Other chemicals used in the treatment process
- Fabrics
- Effluent
- Open water

(j) For each of these it is necessary to consider:

- How the sample will be collected
- How the sample will be stored
- What volumes are required
- Where the samples will be analysed

- What analysis will be carried out (this will arise from greater knowledge of the industries and processes)

3.4 Calculation of Pollution Loads

Once all the data was collected, the dyeing process itself had to be broken down in into various steps and sampling was done at each step. The individual ingredients and how much of it is used for different shades of colour is shown in Table 1. Samples were collected every time the wastewater is dropped after a new ingredient is added to the machine. The total amount of wastewater from one cycle of production and the amount of fabric dyed in one cycle had to be noted to calculate the pollution load. This allowed calculation in terms of wastewater produced per unit of fabric dyed. The recipes collected from the factory staff had information on how much salt, soda ash and other ingredients were added in each production cycle. All this information allowed calculation of pollution loads in terms of weight, for e.g salt used per kg of fabric.

The samples collected at each stage of production were analyzed for different parameters such as BOD, COD, sulphide etc. Sampling was also done at the final discharge point and this forms the output section of the material balance. Data from all processes were then analyzed to calculate pollution in terms of concentration. Comparison was done between sample analysis of wastewater at different stages of production and at the final discharge point to see if there was any kind of correlation between the two. This data can then be used to predict the quantity of pollution generated from dyeing a specified amount of fabric. Once these figures are generated in terms of input and output, it will then be possible to calculate probable pollution loads for future production cycles in winch dyeing industries.

The pollution load calculation was conducted by using the data collected by the sampling from machine outlet. In the sampling process sample was taken from each stage of dyeing process for different dye shade (dark, medium, light & white). Different parameters such as pH, Total Dissolved Solid (TDS), Total Suspended Solid (TSS), Biochemical Oxygen Demand for 5 days (BOD_5), Chemical Oxygen Demand (COD), Sulfate (SO_4^{-2}), Sodium (Na) had bee tested for each sample. Except pH all other parameters are showing the concentration value (in milligram per litre, mg/L).

There are a number of stages in the entire dyeing process; for any stage if the concentration value (mg/L) of any specific parameter is multiplied by the corresponding water volume (litre), then the value of that parameter in milligram, mg will be generated. The summation of each mg value from each stage will give the total value of that parameter for that specific dyeing process. On the other hand the total volume of water used in the dyeing process can be found by adding the water volume (litre) involved in each stage.

Table 1: Comparison of Dyeing ingredients

	Chemical	Amount (%), Kg of chemicals for 100Kg of fabric			
		Dark Shade	Medium Shade	Light Shade	White
Pre-Treatment					
Detergent	Feloson-NOF	0.5	0.5	0.5	0.75
Sequesterent	Lana-HTS/ Sirriz 2UD/ Komplexon OSD	0.3	0.15	1	0.75
Anti-creaser	C2G/ Imcogliss CV	0.5	0.5	0.5	1
Stabilizer	Stabilisator9188/ Stabilizer HP/ Lanapex-HTX	0.3	0.3	0.3	0.75
Antifoam	Antimussol-HTS	0	0	0	0.3
Detergent	Sandoclean PCLF	0.5	0.5	0.5	0
Alkali	Caustic-Soda	2.5	2.5	2.5	2
Bleaching Agent	H_2O_2	2	3	3	6
Brightener (Cotton)	Uvitex 2B	0	0	0	0.58
Brightener (Cotton)	Syno-White 4BK	0	0	0	0
Brightener (Polyester)	0	0	0	0	0
Soaping / After-Treatment					
Soaping Agent	Dekol SN	0.15	0.15	0.15	0.5
Peroxide Killer	Na-thaiosulphite	0.2	0.2	0.2	0
Neutralization					
Acid	Acetic Acid	7.5	1	1	1
Dyeing					
Sequesterent	Dekol SN	0.5	1.5	1	0
Anti-creaser	C2G/ Imcogliss CV	0.5	0.5	0.5	0
Levelling Agent	Drimagen-E2R	1	0	1	0
Anti-foam	Antimussol-HTS/ Kollasol-CDA	0.2	0.3	0.3	0
Dyes (yellow)	Kem Yell. XF RL	2.043	0.286	0.29	0
Dyes (Red)	Kem. Red 3BS/ Kem. Red 3BS	1.22	0.26	0.0037	0
Dyes (Blue)	Kem. Black GR/ Kem Black GR	7.57	1.54	0.005	0
Electrolyte	Globar Salt	280	95.24	38.33	0
Alkali	Soda Ash		23.8	9.67	0
	Caustic		0	0	0
Hot Wash with Soaping Agent					
Soaping Agent	Dekol SN	0.75	0.75	0.5	0
Neutralization					
Acid	Acetic Acid	0.5	0.5	0.5	0
Fixing					
Acid	Acetic Acid	0.1	0	0	0
Fixer	Cyclonol ERL	0.75	0	0	0
Softener					
Acid	Acetic Acid	0.25	0.25	0.25	0
Nonionic Softener	CL		0	0	1.5
Cationic Softener	Ceranin-KWL/ TUB HD2	1	0.75	1	0.5
Cationinv Softener	Basosoft F-EUK	0.5	0.5	0.5	0

Dividing this value (in mg unit) of that particular parameter for that dyeing process by the corresponding total volume of water involved as well as the total amount of fabric that had been dyeing, the respective concentration of that parameter in mg/L of water discharged and mg/Kg of fabric processed can be found. Similar method can be applied for other parameter (except pH) and other dye shade. Dividing the total volume of water by the corresponding amount of fabric we will find the volume of water produced per kg of fabric processing. For average pH calculation the concentration of H^+ and concentration of OH^- have to calculate first. Then using these concentrations average pH for the total process can be calculated by using the above mentioned method. Appendix III has examples of how these calculations have been carried out and data has been generated.

For a composite textile industry having dyeing unit of 5ton per day capacity and annually produce 30% dark shade fabric, 18% medium shade fabric, 30% light shade fabric and 22% white fabric,; the composite pollution indicating data are calculated as follows:

Using the above percentage of fabric production the average amount of fabric of different shade produced in 24 hours can be calculated, such as, according to the above mentioned percentage in a particular day that industry produce on average 1500 kg dark shade fabric, 900 kg medium shade fabric, 1500 kg light shade fabric and 1100 kg white fabric. Now if previous data of how much water discharged is known for 400 kg dark shade fabric then it is possible to make a projection about the volume of water that can be discharged for 1500 kg dark shade fabric. Similarly, calculations can be done for the amount of water produced for other shades. Summation of water volume of individual shade will give the total volume of water discharged in 24 hours.

Once again, since it is known that 2,941 gm at 51.24 mg/L TSS is produced against 400 kg dark shade fabric then it is possible to calculate the amount of TSS that will be produced for 1500 kg dark shade fabric. Similarly TSS (in gm) can be calculated for other shades. Summation of TSS for individual shade will give the total value of TSS (gm) that can be produced in 24 hours. Dividing this value with the amount of total fabric processed (5ton) or total water discharged in 24 hours will give the composite value of TSS respectively in g/Kg of fabric processed or g/L of water discharged. Similarly composite values of other parameters (TDS, BOD_5, COD, SO_4^{-2}, Na, $[H^+]$, $[OH^-]$) for 24 hours can be calculated.

4 Results and Analysis of Data

4.1 Stages of production in winch dyeing

Research showed that the majority of textile factories in Kaliakoir are undertaking dyeing of knitted cotton fabrics, with x number of factories dyeing cotton or poly-cotton. The dye types used are principally fibre reactive dyes and a limited quantity of sulphur and disperse dyes. In addition there are two textile printing factories, which undertake continuous dyeing with reactive dyes and pigment printing, and one recently established wool dyeing plant. Furthermore all factories conduct a variety of pre-treatments including bleaching and scouring, and finishes. In developing the material balance approach, research was carried out in seven factories to identify the key processes involved in the dyeing of cotton. These steps are described below.

Sizing and Desizing

This is carried out before weaving to increase the strength and smoothness of the yarn. Desizing removes size to prevent inhibition of chemical penetration in later stages. Desizing effluents have high organic concentrations contributing 40-50 % of the total organic load from the fabric preparation process

Scouring

This is done to remove impurities in the cotton. This is done at temperatures of approximately 100^{o}C with sodium hydroxide, which produces highly alkaline effluents (pH 12.5) with high organic loads and high TDS.

Bleaching

To whiten fabric using sodium hypochlorite or hydrogen peroxide. Most factories use hydrogen peroxide as sodium hypochlorite is highly toxic; however it is also cheaper than hydrogen peroxide. Effluents are generally alkaline (pH 9-12) and have high TDS levels.

Dyeing

Fibre reactive dyes, of both the vinyl sulphone and mono chloro triazine type are predominantly used in Kaliakoir for knitted cotton fabrics. They require large quantities of salt and alkaline conditions for fixation onto the fabric, and as the salt is not used up in the process, effluents contain high concentrations of salt. In Kaliakoir, Glaubers salt (sodium sulphate) is used in preference to common salt (sodium chloride) because it is purer and therefore less damaging to the equipment, but results in high sulphate concentrations in the effluent. A number of auxiliaries are also used and effluents contain unfixed dye (10 – 50 % of the quantity added to the dyebath), surfactants and defoamers and are strongly alkali (pH 9-11).

Some polyester and polyester blends are also dyed using disperse dyes, although quantities are much lower that for direct dyes. The effluents contain unfixed dyes

(10-30 % of quantity added to the dyebath), organic acids, carriers, reducing agents, levelling agents, defoamers, levelling agents and dispersants.

Softening and Finishing

After several rinses and washes, softeners are generally applied to knitted cotton fabrics and finishers may also be used. This stage provides the fabric with its aesthetic, chemical and mechanical properties, such as flame retardant, mildew resistant and wrinkle resistant. The waste water from this component of the process may contain toxic materials, solvents and suspended solids.

Consequently, the main pollutants expected to be found in the effluent are: unfixed dyes and pigments, which create the colour problem and are extremely difficult to remove; sulphate, which is likely to be converted to sulphide and produce poisonous hydrogen sulphide gas; high pH (9 – 12); COD and BOD; and suspended and dissolved solids. There will also be a complex mixture of organic dye breakdown products and auxiliaries, which are difficult and expensive to detect individually.

4.2 Analysis of wastewater samples

Sample analysis was done in house and also sent to Bangladesh University of Engineering and Technology (BUET), which is the only verifiable place in Dhaka where accurate water analysis can be carried out. The different parameters tested for include:

- pH
- TDS
- TSS
- BOD
- COD
- Sulphate (SO4)
- Sulfide (S2)
- Chlorine (Cl)
- Sodium (Na)
- Magnesium (Mg)
- Calcium (Ca)
- Ammonia (NH3)
- Nitrate (NO3)

Research showed that there are many factors that lead to variation in this data. One of the main ones is the colour shade being produced. Other factors include redyeing and re-shading of fabric dyed. The conditions of machineries and whether they are manual or automatic also make a difference in pollution load.

4.3 Calculation of pollution load

Using this material balance approach and following the calculations in section 3.4, a rough estimation of pollution load can be generated. Once there is a clear understanding of the production process and of all the inputs and outputs within a dyeing industry, it is then possible to calculate pollution loads in terms of concentration and weight. Using this approach it was possible to quantify the amount of wastewater generated in terms of weight of fabric dyed each year. This can be seen in Table 2. Comparison was also made between data collected in 2003 and then in 2005. This can be seen in Table 3. There is great variation in some of the parameters such as BOD and TDS. At Factory 45 the amount of fabric dyed is half that of factory 24, but it was producing more than double the amount of BOD and TDS. Difference in machinery can be a probable reason for this vast difference. From this data, it is also possible to quantify total pollution loads in terms of the different parameters tested for.

Table 2: Pollution Concentrations by Dye Shade

Type of Shade	Amount of Fabric (Kg/day)	Vol. of water used (litres)	pH	TDS (mg/L)	TSS (mg/L)	BOD_5 (mg/L)	COD (mg/L)	SO_4^{2-} (mg/L)	Na (mg/L)
Dark Shade	1500	298784	10.4	8891	544	719	1705	374	107
Medium Shade									
Light Shade	1250	162500	11.0	2771	267	104	663	45	859
White	1100	109471	8.3	1480	139	192	340	32	
Composite	3850	570754	10.6	5727	387	443	114	215	301
BD Standard			6.5-9.0	2100	100	150	400	400	200

Table 3: Data comparison between 2003 and 2005

Type of shade	Factory	Amount of Fabric (Kg)	Water used (litre)	TDS (mg/L)	TSS (mg/L)	BOD_5 (mg/L)	COD (mg/L)	SO_4^{2-} (mg/L)
Dark Shade	2003	400	**57400**	**4690**	**51**	**334**	**1296**	**3632**
	2005	259	**51590**	**8891**	**544**	**719**	**1705**	**374**
Medium Shade	2003	189	**33500**	**8051**	**125**	**482**	**1474**	**3086**
Light Shade	2003	600	**83400**	**7859**	**143**	**549**	**1654**	**5052**
	2005	250	**32500**	**2771**	**267**	**104**	**663**	**45**
White	2003	286	**8400**	**5847**	**166**	**1550**	**4222**	**2**
	2005	340	**37220**	**1480**	**139**	**192**	**914**	**32**
Bangladesh Standard				**2100**	**100**	**150**	**400**	**400**

4.4 Factors leading to pollution data variation

There are many factors that can lead to differences in pollution load. Different shades of colour produces different amounts of pollution load. Whites tend to produce less pollution, whereas darker shades tended to have more dyes and more chemicals in the waste stream. The breakdown of the different shades consisted of dark shades, medium shade, light shade and whites. Sampling was done at each stage of all three categories of colour dyeing and the breakdown in terms of chemicals used in each step is shown in Appendix III. Other factors that can cause variation in pollution load is when redyeing and reshading takes places. Research shows that this happens almost 30 percent of batches dyed. Dye efficiency is also a major factor in the amount of colour present in the wastewater. Average exhaustion and fixation tends to vary between 60-80 percent for exhaustion and 40-60 percent for fixation. This tends to vary between industries depending on the type of machinery, whether they are automatic or manual, and other external factors such as staff training.

5 Limitations of Material Balance Approach

5.1 Issues Redyeing and reshading

One of the main reasons that made it difficult to develop a model for calculating pollution loads using material balance approach was the issue of re-shading and re-dyeing. Research showed that factories end up re-shading 30 percent of the time, and end up adding extra dyes, salt and soda ash during each cycle. This makes it extremely difficult to predict what the pollution load will be at the end of the cycle.

Sometimes entire shipments have to be re-dyed completely, which means that the total production cycle including pre-treatment has to be carried out. This results in scouring and bleaching which adds further chemicals in the equation for calculation of pollution loads.

5.2 Housekeeping Issues

One of the objectives for the use of this material balance is so that a ‘cleaner production audit’ can be done and ways to reduce pollution can be identified. Using the material balance approach, it is possible to identify poor housekeeping which results in inefficient production and increased pollution loads. Poor storage facilities and incorrect measurement of dyes and chemicals makes it difficult to get high exhaustion and fixation. This results in more dye being in the waste stream and also more chemicals when re-dyeing and re-shading have to take place. This makes it hard to calculate pollution load in terms of input and output when they keep on changing frequently.

6 Validating the Material Balance Approach

When the material balance model is being developed the accuracy of estimations can be checked by comparison with existing data or "standard data" for an industry, if it exists. Alternatively process monitoring and water quality analysis can be undertaken for individual unit processes and for the overall factory waste streams. When the analyses have been used to inform the model and any necessary adjustments made, the model can be employed without the need for water quality analysis, although occasional analysis to ensure that the model remains accurate, especially if factors change dramatically, may be necessary.

6.1 Cleaner Production Audit

Once the material balance results are determined it is possible to identify pollution reduction measures. Whilst it is impossible to predict exactly what these will be they are likely to include:

- Identification of alternative raw materials (including safer/better colorants and auxiliaries);
- Identification of alternative routes to desired products (possibly through more advanced application/processing technology);
- Optimising existing processing, e.g. coloration operations (possibly by greater control of (i) temperature, (ii) pH, (iii) addition rates, (iv) mixing methods, (v) fabric and chemical preparation including weighing and wetting out);
- Evaluation of recycling options for selected "waste" streams;
- Better use of recipe match prediction and colour measurement to enable "right first time" production; and
- Any (preferably simple/low cost) on site effluent treatments to remove, or to reduce the concentration of, potential pollutants whilst they are at their highest concentration.

Based on these findings, it is possible to conduct discussions with industries to devise a pollution reduction and mitigation action plan. The research also aims to try to establish the source-pollution impact relationships. A variety of methodologies will be used to achieve this. In parallel to the derivation of the material balance investigation of the impacts of pollution will take place. Participatory tools including observation, focus group meetings and interviews will be used in combination with analysis of grey literature to determine the environmental and human impacts of pollution. This information when assessed with the results of the material balance will enable the team to establish the source-pollutant-impact "web". These discussions will also try to highlight potential indicators, bio and others, of the key components of pollution.

The project's research framework also aims to mitigate for existing pollution. This element of the research is envisaged to take place at various locations in the area. These can be categorised as: on-site (within the bounds of the various industrial units) and undertaken in collaboration with the factories, within the drainage canals leading to the water bodies (where they will be undertaken through industry-community partnership), and within the community at specific sites adjacent to villages or which are a focus for livelihood activities.

7 Conclusions

The purpose of the material balance approach assessment was to determine whether it was feasible to utilise the approach as a means of determining the amount of pollution generated by a factory without water sampling and analysis. Analysis also showed that there are many factors which affect the amount of pollution generated, including machinery and housekeeping. Data collected during the project shows that newer machinery made a significant difference in pollution concentration and load. Using this material balance approach, it was possible to determine values both in terms of a total weight generated and also concentrations. In terms of concentration, there is a different concentration for each stage of a dye cycle. Also there is a dilution at the final discharge point primarily because of addition water discharges that dilute the concentrations.

Despite these factors it was possible to get a total count for the different parameters such as BOD in terms of mg/L and then using the amount of total wastewater it was possible to get the figures in mg. Larger factories with automated machinery, on average, tend to utilise slightly more water (148 litre/kg of fabric) than those with older semi-automated machinery (123 litre/kg of fabric). In terms of pollution load concentration the breakdown is given under two categories: shade percentage and type of machinery. These results are shown in Appendix I. From this study it can be seen that the average pollution load for different parameters does not vary when using the two different types of machinery. This is because darker shade produces more pollution when using manual machinery. However, whites and lighter shade produces more concentrated amounts of pollution with semi-automatic machinery. This is because this type of machinery produces less wastewater per kg of fabric.

These results highlight some important points when categorizing dye houses and estimating pollution loads. The Department of Environment or other concerned parties can collect the required information described in this report and be able to estimate pollution concentrations and total load in terms of shade percentage and the kinds of machinery present in factories. Indeed, much of this information is already required and collected by them as part of the application process to be granted and Environmental Clearance Certificate. In the project area there are sixty textile dyeing factories in operation (this changes almost monthly) that produce, on average, ten tonnes of fabric per day. The mean pollution concentration, derived from analysis of the production of different shades of fabric and overall, for a variety of parameters that flows into the local water body, Mokesh Beel, from these factories is shown in Table 4. All of these values exceed the national environmental quality standards. The beel area is approximately 40 hectares during the dry season into which over 56 tonnes of sodium and nearly 55 tonnes of suphate flow each year.

The project also explored the relationship between the values derived from the average concentration values determine from a complete dye cycle for various shades and those at the discharge point. The results indicate lower values at the discharge point primarily as a result of additional flow of cleaner water from the factory such as waste water from basins and additional washings of fabric that is too dark in shade. However, as is now widely accepted, the solution to pollution is not dilution. The complex chemistry of these areas and the chemical inflows for a variety of industrials discharging waste mean that there is very little certainty in terms of what is occurring in these local water bodies. Substances can, and do accumulate and persist and may make their way into the food chain.

Appendix I: Pollutant Concentrations and Total Mass per Year for the 60 Dye Houses in Kaliakoir

Calculation Basis:

1. 60 industries are dyeing fabric among 162 Textile related industries
2. These industries are dyeing 600 tonnes of fabric per day (based on an average of 10 tonnes/day for each factory)
3. These industries are operated 340 days a year on average
4. Approximately half of the machines are semi-automatic
5. Approximately half of the machines are semi-automatic
6. A rough estimation is that on average, these industries are producing 35% dark, 20% white and the remained medium & light shade fabric per year.

Type of Shade	**Type of Machine**	**Amount of Fabric (Kg)**	**Volume of water used (litre)**	pH	TDS (mg/L)	TSS (mg/L)	BOD_5 (mg/L)	COD (mg/L)	SO_4^{2-} (mg/L)	Na (mg/L)
Dark Shade	Semi Automated	400	**57400**	**10.81**	**4690**	**51**	**334**	**1296**	**3632**	**1963**
	Manual	259	**51590**	**10.42**	**8891**	**544**	**719**	**1705**	**374**	**107**
	All Dark	71400000	**12234004054**	**10.63**	**7132**	**338**	**558**	**1534**	**1738**	**884**
Light & Medium Shade	Semi Automated	600	**83400**	**9.56**	**7859**	**143**	**549**	**1654**	**5052**	**6265**
	Manual	250	**32500**	**9.44**	**2771**	**267**	**104**	**663**	**45**	**859**
	All Light& Medium	91800000	**12347100000**	**9.51**	**5400**	**203**	**334**	**1175**	**2632**	**3652**
White	Semi Automated	286	**8400**	**6.29**	**5847**	**166**	**1550**	**4222**	**2**	**553**
	Manual	340	**37220**	**10.95**	**1480**	**139**	**192**	**914**	**32**	
	All White	40800000	**2832360839**	**10.85**	**2404**	**145**	**479**	**1614**	**26**	**117**
Composite	Semi Automated	102000000	**12102210839**	**10.47**	**6418**	**105**	**507**	**1630**	**4201**	**4161**
	Manual	102000000	**15311254054**	**10.42**	**5425**	**377**	**403**	**1184**	**196**	**384**
	All Shades	204000000	**27413464893**	**10.44**	**5863**	**257**	**449**	**1381**	**1964**	**2052**
BD Standard				**6.5-9**	**2100**	**100**	**150**	**400**	**400**	**200**

Type of Shade	Type of Machine	Water used (litre/Kg)		TDS (g/Kg)	TSS (g/Kg)	BOD_5 (g/Kg)	COD (g/Kg)	SO_4^{2-} (g/Kg)	Na (g/Kg)
Dark Shade	Semi Automated	144							
	Manual	199		1771	108	143	340	74	21
Light & Medium Shade	Semi Automated	139		1092	20	76	230	702	871
	Manual	130		360	35	14	86	6	112
White	Semi Automated	29		172	5	46	124	0	16
	Manual	109		162	15	21	100	4	
Composite	**Semi Automated**	**123**		**824**	**13**	**63**	**199**	**466**	**401**
	Manual	**148**		**849**	**57**	**66**	**170**	**32**	**45**

Type of Shade	Type of Machine	Fabric (T/year)	Water used (T/year)		TDS (T/year)	TSS (T/year)	BOD_5 (T/year)	COD (T/year)	SO_4^{2-} (T/year)	Na (T/year)
Dark Shade	Semi Automated	35700	5122950		24027	262	1709	6638	18608	10058
	Manual	35700	7111054		63224	3868	5113	12124	2660	761
	All Dark	**71400**	**12234004**		**87251**	**4131**	**6822**	**18762**	**21267**	**10819**
Light & Medium Shade	Semi Automated	45900	6380100		50140	913	3503	10554	32235	39970
	Manual	45900	5967000		16535	1591	622	3957	266	5125
	All Light and Medium	**91800**	**12347100**		**66675**	**2504**	**4125**	**14512**	**32501**	**45095**
White	Semi Automated	20400	599161		3503	100	929	2529	1	331
	Manual	20400	2233200		3305	310	429	2041	71	0
	Composite of White	**40800**	**2832361**		**6808**	**410**	**1357**	**4571**	**73**	**331**
Composite	Semi Automated	102000	12102211		**77670**	**1276**	**6141**	**19722**	**50844**	**50359**
	Manual	102000	15311254		**83064**	**5770**	**6164**	**18123**	**2997**	**5886**
	All Shades	**204000**	**27413465**		**160734**	**7045**	**12305**	**37845**	**53841**	**56245**