CHAPTER III

MANUFACTURING PROCESS AND OVERVIEW OF ENERGY UTILIZATION

Introduction

The company that was used for this study belongs to the BIS Group and is one of the three nylon fiber manufacturing factories in Thailand. This company was founded in 1975 and has grown to a company whose factory now employs nearly 280 workers.

At first the nylon product was used within Thailand, but in 1985 the company started exporting its product to the Republic of China.

Since the company was founded in 1975, nylon filament has been produced using, as a raw material, caprolactam imported from Poland and Italy. The technology for this production process was developed by the Chemtex Fibers, Inc. of the United States.

Raw Material of the Factory

Caprolactam, the raw material that is used in producing the Nylon-6 filament, can be produced by two different processes. These processes differ in the raw material that is used and in the by-products that are obtained.

In producing caprolactam two basic ingredients are required: cyclohexanone and hydroxylamine (see Figure 3.1).

Cyclohexanone is obtained from either benzene or phenol. From benzene the cyclohexanone is produced by hydrogenation to cyclohexane and subsequent oxidation. From phenol, however, it is produced by hydrogenation directly.

Hydroxylamine may be obtained from either the Raschig process or the HPO process. The Raschig process using ammonia, sulphur dioxide and ammonium nitrite produces hydroxylamine in the form of a sulphate salt. The HPO process uses ammonium nitrate, hydrogen and phosphoric acid to obtain hydroxylamine. These two processes can be represented in chemical equations as follows:

The Raschig process:

$$NH_4OH + SO_2 + NH_4NO_2 \longrightarrow \underset{\text{hydroxylamine sulphate}}{(NH_2OH)_2H_2SO_4}$$

The HPO process:

$$2H^+ + NO_3^- + 3H_2 \xrightarrow[\text{is used as a buffer}]{\text{phosphoric acid}} NH_3OH^+ + 2H_2O$$

The main characteristic of the HPO process is that no ammonium sulphate is produced along with the hydroxylamine as in the conventional Raschig synthesis.

In the third step of the process, cyclohexanone oxime is produced by combining cyclohexanone and hydroxylamine. Caprolactam is, finally, produced by Beckmann rearrangement of the oxime with the aid of oleum. This reaction is followed by a neutrallization in which ammonium sulphate is formed as a by-product. The crude lactam is subjected to extensive purification which yields an extremely pure caprolactam of constant quality. Figure 3.1 illustrates the two routes of caprolactam production processes.

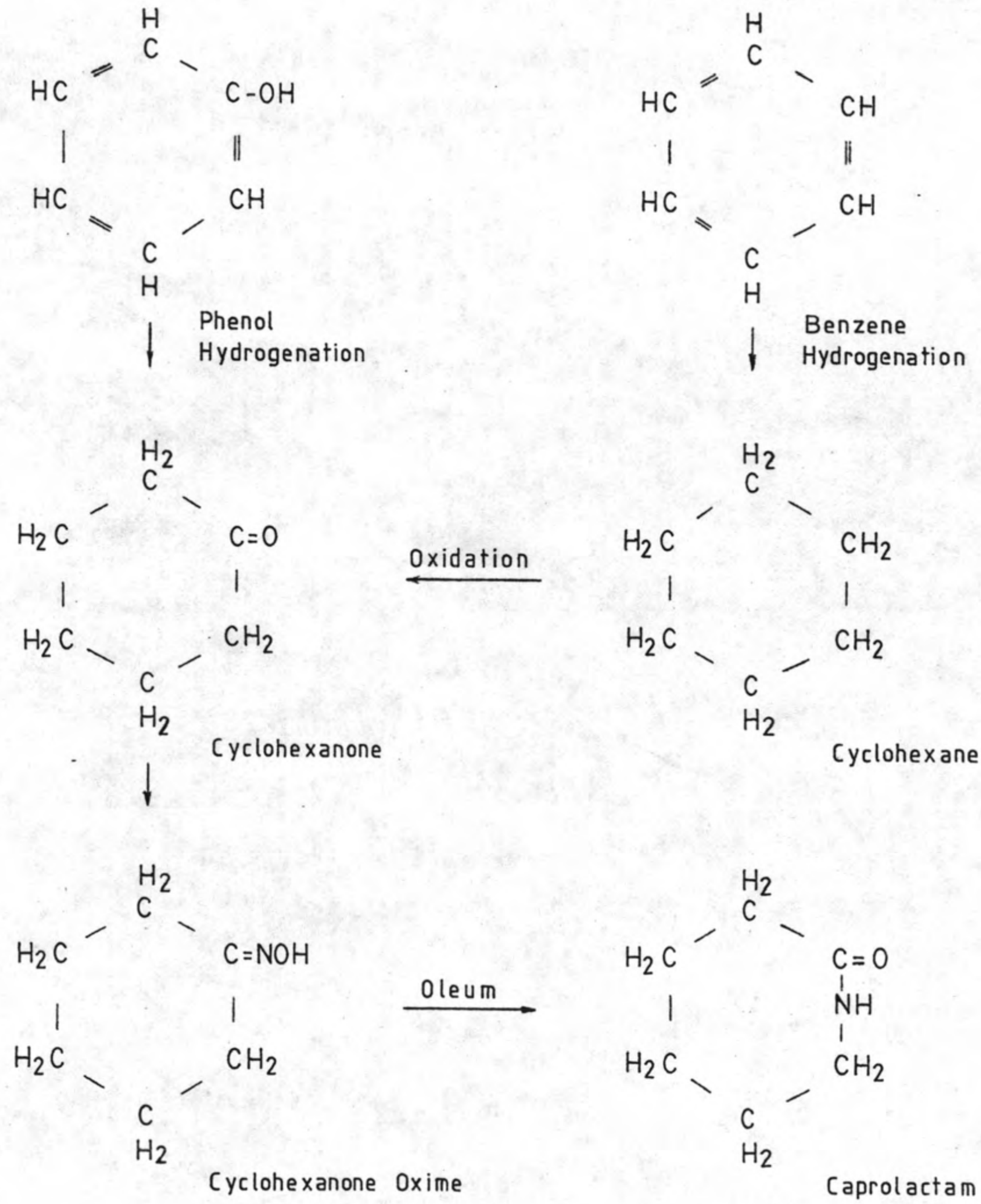


Figure 3.1 Flow Diagram Showing Production Process of Caprolactam

Caprolactam possesses the following physical properties:

Formula: $C_6H_{11}ON$

Appearance:

Solid: white, hygroscopic crystalline substance with a faint characteristic odour, readily soluble in water

Liquid: clear colourless liquid

Mol. weight: 113.16

Melting point: 69.2°C

Boiling point: 268°C at 1 bar

Flash point: 141°C

Heat of Combustion: 31977 kJ/kg

Heat of fusion: 138 kJ/kg

Heat of sublimation: 804 kJ/kg (average value between 35 and 60°C)

Heat of vaporization: 573 kJ/kg (average value between 100 and 160°C)

Surface tension at 130°C: 33.4 dynes per cm.

Bulk density: 600-700 kg/m^3

Specific heat, C_p:

Solid: 1.46 kJ/kg°C

Liquid: 2.92 kJ/kg°C at 80°C

3.09 kJ/kg°C at 140°C

Caprolactam can be polymerized either in the presence or absence of water. During the polymerization in the presence of water, three main equilibrium reactions occur: the ring-opening reaction, the polycondensation reaction, and the polyaddition reaction.

Polymerization where water is absence, caprolactam is polymerized by monomer casting.

Manufacturing Process for Nylon-6 Filament

The factory currently processes approximately 14 tons per day of caprolactam. The first step in the process is to crush the caprolactam into small grains and dust. The raw material, arriving in plastic bags of 25 kilograms each, is emptied into a crush mill to start the process. After that, the material is fed into a melting tank. Steam, of about 0.5 kg/cm^2g, is then applied to the tank's jacket to melt the material. When the material has been melted it is transfered from the melting tank, through filters, to a blending tank. In the blending tank acitic acid, titanium dioxide and water are added. The blended material then forms "monomer" and is transfered to two monomer storage tanks. These tanks are the starting point for the two polymer production lines in this factory. (see Figure 3.3).

Monomer from the storage tank of each line is transfered by a "transfering pump" to a pre-polymerization tank and finishing tower The polymer material from the finishing tower is then extruded to form polymer spaghetti. This spaghetti is quenched in a water trough as a hardening process. It is then drawn through a cutter to obtain small chips of about 3 mm. long and 3 mm. in diameter. The chips obtained are then screened and blown, by a raw chip transfering blower, into an extraction tower so that the about 11% of monomer remaining in the produced polymer can be separated and removed by the extracting water which overflows into a tank, called the wash water collection Tank. This water mixture, with 5% monomer concentration, from the collection tank is pumped into the first effect and then the second effect evaporators. After the second effect evaporator, the

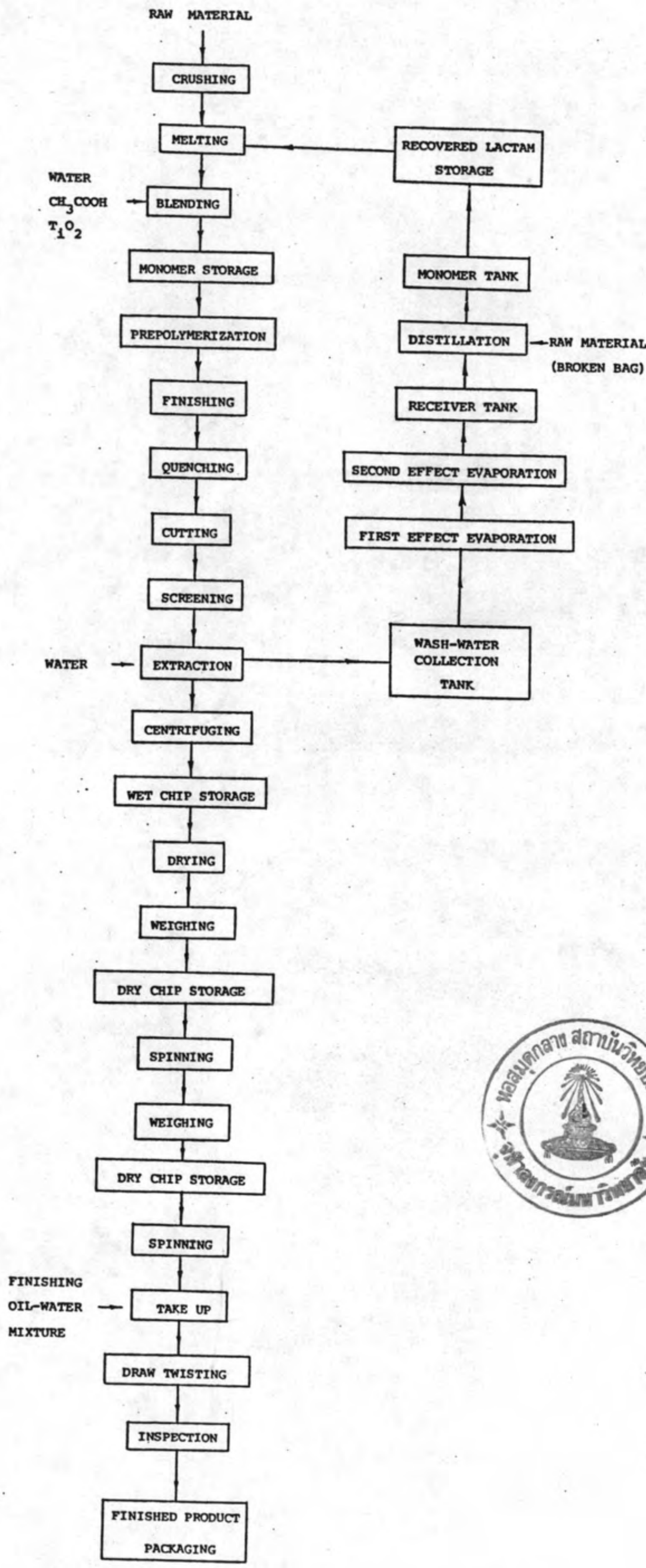


Figure 3.2 Flow Diagram Showing Manufacturing Process of Nylon-6 Filament.

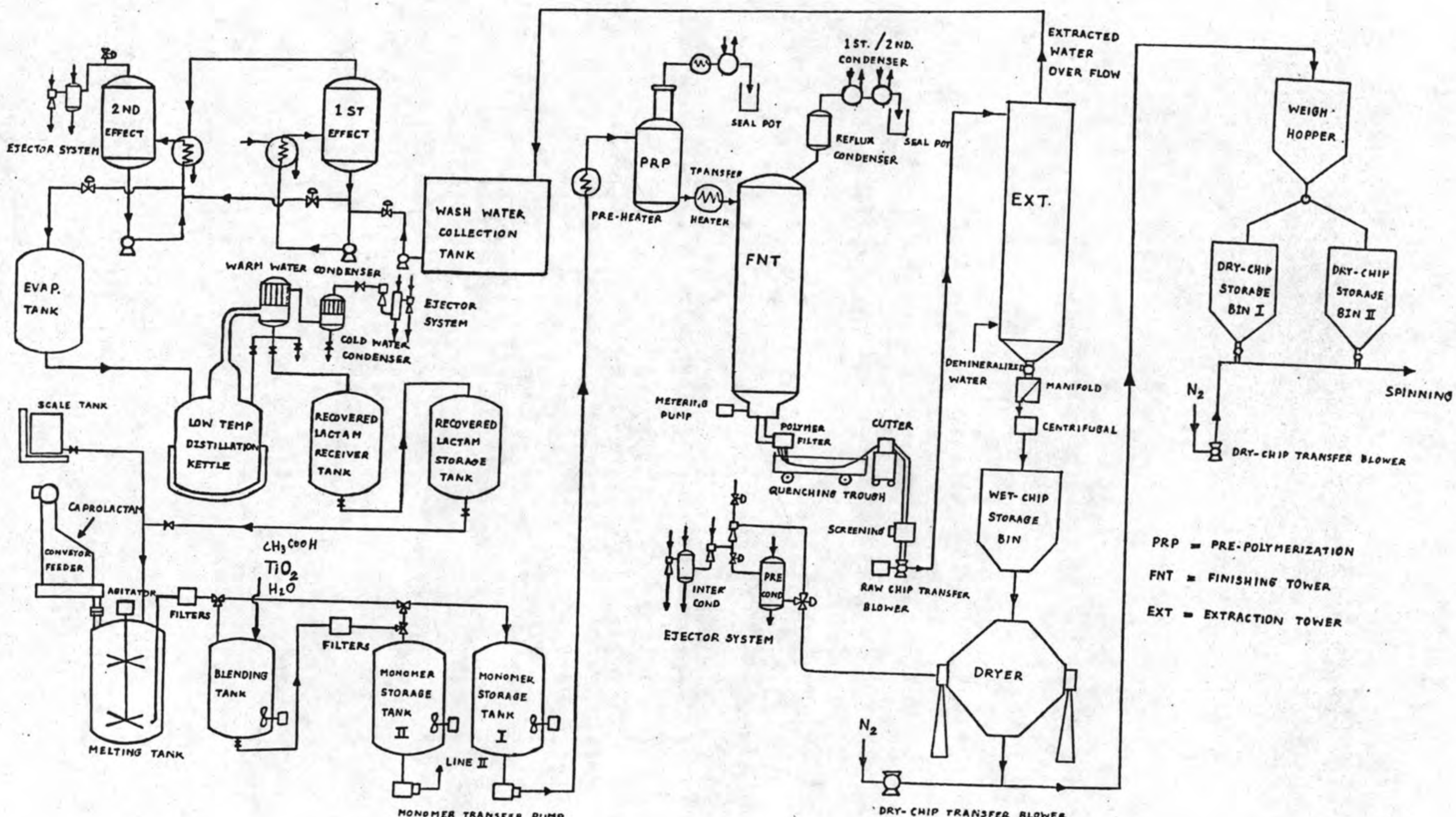
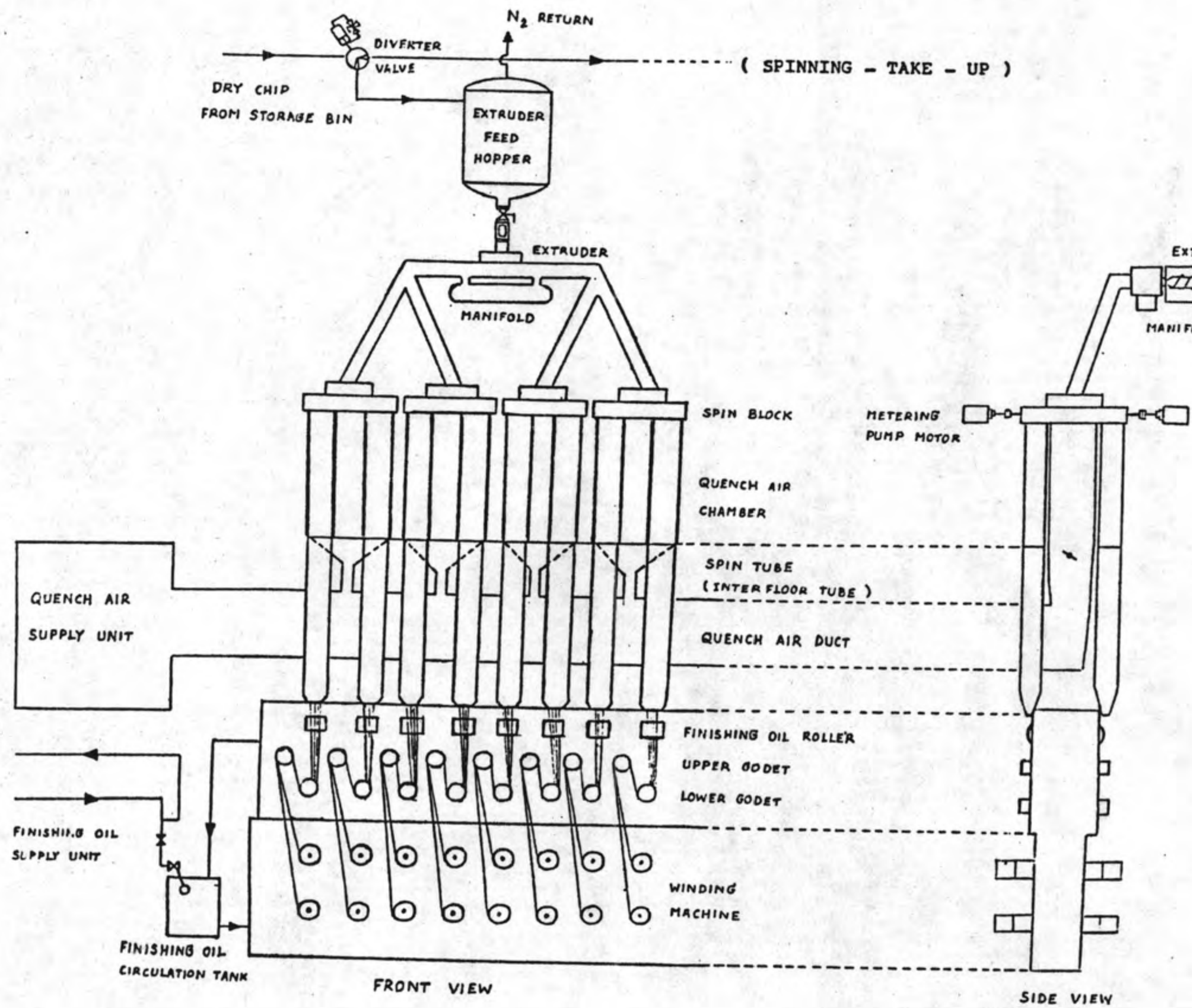


Figure 3.3 Schematic Diagram Showing the Manufacturing Process of Nylon-6 Filament.



ONE EXTRUDER (ONE BEAM) CONSIST OF :-

- 4 SPIN BLOCKS
- 2x8 METERING PUMPS
- 2x8 QUENCH AIR CHAMBERS
- 2x16 WINDING SPINDLES
- 2x32 BOBBINS

TOTAL 6 EXTRUDERS

DRAW - TWISTING MACHINE CONSIST OF :-

- 2x72 SPINDLES / MACHINE

TOTAL 17 MACHINES

Figure 3.3 (Con't)

monomer concentration in this mixture becomes 55% and is transfered to an evaporation tank waiting for distillation.

In the distillation kettle, some mixture from the evaporation tank, about 6100 kg, is distilled, batch by batch, into 2000 kg of pure caprolactam. This material will then be stored in a recovered lactam storage tank and, later, returned to the melting tank as a raw material. Besides the mixture from the evaporation tank, the broken bag caprolactam which is delivered from an outside agent is poured into the distillation kettle to yield recovered lactam before processing in the melting tank.

The polymer chips with less than 0.5 percent of low polymer (monomer and other incomplete form of polymer) in the extraction tower are allowed to flow out with water from the bottom of the tower into a centrifugal machine. In the centrifugal machine, water and polymer chips are separated from each other. The wet chips are discharged to a pair of wet chip storage bins while the water with temperature of nearly 90°C is pumped to mix with demineralized water and hot water from the ejector system and heat exchanger of the second effect evaporator. This water mixture at temperature of 55°C is then returned to the extraction tower via a steam heat exchanger. The water temperature after heat exchanger is approximately 95°C.

In each vacuum dryer under the wet chip storage bins, the chips having moisture content of about 10% are placed batch by batch. After 15 hours of drying process, the moisture content is reduced to 0.01%. At this state, the batch of dry chips is carried by blowing nitrogen gas through a vertical pipe into a weighing hopper. Upon reaching the desired weight, the dry chips from this hopper are dropped into one of the two dry chip storage bins and are ready to be transfered to spinning process.

The spinning process starts with the dry chips being fed into the extruder feed hopper, the arriving dry chips will be heated in order to melt the chips at temperature of 260°C. The molten polymer is then pressed through an extruder manifold to produce fibers. These fibers will be metered through high pressure pump, passed through a melt spinnerette and then running through the quench air chamber to be hardened.

Take up is the following step. The fibers being drawn by winding spindles will receive oiling at finishing oil rollers so that its surface tension coefficient can be reduced to a suitable level from which static electricity occuring may be protected. Godets of this processing region are working as the speed control for the fibers being wound to the spindles at the winding machine. The schematic diagram representing the spinning and the take-up process is shown in Figure 3.3.

After the take up process, the spindles of fiber need draw-twisting so that their strength and stability may be improved. Normally, three-fold of lengthening by draw-twisting is essential for the production at this factory.

Upon completion of draw-twisting, the fibers obtained will be sent to the quality department for final inspection. The results for the final inspection and testing are recorded. The fiber is now nylon-6 filament and after the product is packed it is ready to be shipped to the customers.

Investigation of Historical Data

The data sources for this section come from past electricity consumption data, as billed by the Provincial Electricity Authority (PEA), and heavy fuel oil consumption as recorded by the factory's utility department from 1982 through 1985.

Electricity is used in various departments for lighting, air conditioning, motors, electric heating, compressors and others. The heavy fuel oil is used only in the boilers to generate steam. The data as well as some relavant computations are provided in Table 3.2 and Table 3.3.

Monthly electrical power consumption as billed by the PEA for the three years are available in Table 3.1 A, Table 3.1 B and Table 3.1 C, respectively. From each table, monthly kilowatthours, maximum demand, energy charge and load factors are given and the average for these values have been calculated. Considering these average values, we see that the consumption rates vary from 16.46×10^6 kWh/yr to 17.63×10^6 kWh/yr, energy charge from 25.83 to 28.00 million baht/yr, and maximum demand from 2055 to 2190 kW whereas the load factor (%) and energy charge (baht/kWh), on annually average, are nearly constant. The values of maximum demand and of the load factor are ploted, month by month, in Figure 3.4. In Figure 3.4A, the load factor in the year 1984 shows the widest range of fluctuation and this fluctuation ranges from 86% in April to 96.20% in January. The graph of maximum demand for each year is constructed in Figure 3.4 B where the monthly peak demand locus of the year 1983 appear to be the upper boundary, These unusual peak values possibly occured because of power failure in the plant.

Table 3.1A Monthly Electrical Energy Consumption, Billed By PEA, 1983

Month	Consumption kWh	Max. Demand kW	Total Charge Bahts	Days Metered	Average Power kW	Load Factor %	Average Charge Bahts/kWh
January	1,497,120	2100	2,455,137.60	32	1949.43	92.83	1.6399
February	1,336,800	2160	2,224,704.00	28	1989.36	92.10	1.6642
March	1,481,700	2220	2,445,996.00	31	1991.56	89.71	1.6508
April	1,510,860	2280	2,373,360.60	30	2098.51	92.04	1.5709*
May	1,531,920	2220	2,396,659.20	31	2059.05	92.75	1.5645
June	1,457,520	2220	2,291,755.20	30	2024.42	91.19	1.5724
July	1,514,340	2220	2,371,871.40	31	2035.30	91.68	1.5663
August	1,537,260	2220	2,404,188.60	31	2066.15	93.07	1.5639
September	1,491,480	2280	2,346,034.80	30	2071.61	90.86	1.5730
October	1,502,520	2160	2,348,809.20	31	2019.60	93.50	1.5632
November	1,374,720	2100	2,162,215.20	30	1909.32	90.92	1.5728
December	1,390,440	2100	2,184,380.40	30	1931.16	91.96	1.5710
Total	17,626,680	26,280	28,005,111.96	365		1102.61	
Average	1,468,890	2190	2,333,759.35		2012.17	91.88	1.5888

*New rate of electricity charge has been issued.

Table 3.1B Monthty Electrical Energy Consumption, Billed By PEA, 1984

Month	Consumption kWh	Max. Demand kW	Total Charge Bahts	Days Metered	Average Power kW	Load Factor %	Average Charge Bahts/kWh
January	1,460,220	2040	2,265,707.14	31	1962.48	96.20	1.5516
February	1,314,780	2100	2,077,699.80	29	1888.95	89.95	1.5803
March	1,409,820	2040	2,205,310.20	31	1894.75	92.88	1.5642
April	1,300,980	2100	2,058,241.80	30	1806.00	86.00	1.5821
May	1,326,000	1980	2,080,728.00	31	1782.00	90.00	1.5692
June	1,275,120	1980	2,008,987.20	30	1771.11	89.45	1.5755
July	1,400,640	2100	2,198,762.40	31	1882.65	89.65	1.5698
August	1,464,600	2160	2,295,342.00	31	1967.76	91.10	1.5672
September	1,399,920	2100	2,197,747.20	30	1944.18	92.58	1.5699
October	1,445,160	2040	2,255,139.60	31	1942.28	95.21	1.5605
November	1,342,530	2040	2,110,431.30	30	1864.56	91.40	1.5720
December	1,325,280	1980	2,079,712.80	30	1840.61	92.96	1.5693
Total	16,465,050	24,660	25,833,809.44	365		1097.38	
Average	1,372,087.5	2055	2,152,817.453		1879.30	91.45	1.5690

Table 3.1C Monthly Electrical Energy Consumption, Billed By PEA, 1985

Month	Consumption kWh	Max. Demand kW	Total Charge Bahts	Days Metered	Average Power kW	Load Facter %	Average Charge Bahts/kWh
January	1,411,740	2040	2,208,017.4	32	1838.04	90.10	1.5640
February	1,235,520	2040	1,959,547.2	28	1838.57	90.13	1.5860
March	1,391,340	2040	2,179,253.4	31	1868.64	91.60	1.5663
April	1,360,860	2100	2,142,672.6	30	1890.00	90.00	1.5745
May	1,425,300	2100	2,233,533.0	31	1915.20	91.20	1.5671
June	1,371,000	2040	2,150,574.0	30	1904.14	93.34	1.5686
July	1,421,580	2160	2,234,683.8	31	1909.66	88.41	1.5720
August	1,441,320	2040	2,249,725.2	31	1937.18	94.96	1.5609
September	1,382,760	2040	2,167,155.6	30	1920.46	94.14	1.5673
October	1,428,420	2100	2,237,932.9	31	1919.82	91.42	1.5667
November	1,324,260	1980	2,078,274.6	30	1839.22	92.89	1.5694
December	1,288,080	1980	2,027,260.8	30	1787.94	90.30	1.5739
Total	16,482,182	24,660	25,868,630.5	365		1098.51	
Average	1,373,515	2055	2,155,719.208		1881.15	91.54	1.5697

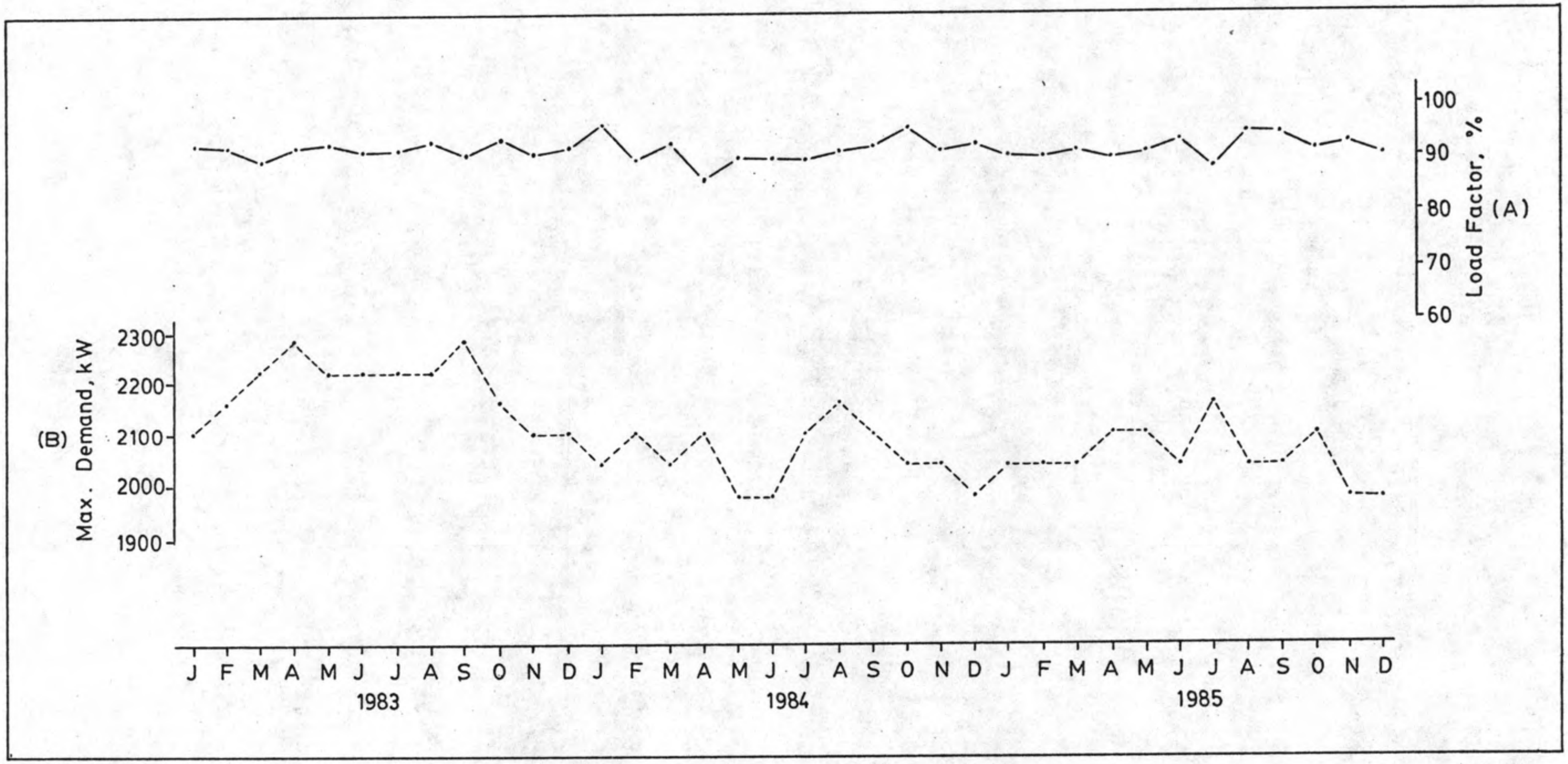


Figure 3.4 Trends of (A) Monthly Load Factor, % and (B) Monthly Maximum Power Demand, kW.

Average daily consumption for electricity and fuel oil are summarized in Table 3.2. The GJ ratio of 1.138:1.000 indicates that more energy from the heavy fuel oil than from electricity has been utilizing in this factory. However, the cost ratio of 0.254:1.000 shows the opposite result. This means that energy from electricity is more expensive than that from heavy fuel oil*. Figure 3.5 is constructed to illustrate a comparison of the two energy utilization characteristics. The graph of 1984 in this figure shows a decreasing trend for the first half of the year but an increasing trend for the second half. This situation was a result of a shift in production capacity at the corresponding period, see figure 3.8 A. Table 3.3 demonstrates a detailed analysis of energy utilization in 1985. The amount of energy required by the factory shown in this table is 357.395 gigajoule per day, 45% from electricity and the rest from heavy fuel oil. The company must pay this energy 89,924.84 bahts a day and the electric energy charge accounts for 78.81% of the cost. From this analysis, each gigajoule of energy from electricity costs 435.97 bahts. This is nearly four times the cost per gigajoule of energy from fuel oil of 97.79 bahts. These percentages are shown as pie charts in Figure 3.6 A and Figure 3.6 B.

Specific Energy Consumption

The amount of energy required by each kilogram of filament product will be studied in this section. In relating energy input to

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*Boustead I. and G.F. Hancock gave in the Handbook of Industrial Energy Analysis, Table 6.13, p. 146 that energy production efficiency of electricity is 24.0% while that of heavy fuel oil is 82.7%.

Table 3.2 Average Daily Energy Consumption for Each Month In 1983, 1984 and 1985

Year / Month	1983		1984		1985	
	Fuel Oil 1/day	Electricity kWh / day	Fuel Oil 1/day	Electricity kWh / day	Fuel Oil 1/day	Electricity kWh / day
January	4652.7	46,785.0	5065.6	47,103.9	4297.2	44,116.9
February	4397.1	47,742.8	4570.9	45,337.2	4653.0	44,125.7
March	4276.3	47,796.8	4260.6	45,478.1	4985.8	44,881.9
April	4638.4	50,362.0	3718.0	43,366.0	4928.9	45,362.0
May	4548.0	494 16.8	3652.0	42,774.2	4843.8	45,977.4
June	4472.0	48,584.0	3864.8	42,504.0	4857.5	45,700.0
July	4415.0	48,849.7	4616.7	45,181.9	4750.0	45,857.4
August	4268.0	49,589.0	4685.4	47,245.2	4568.4	46,494.2
September	4301.8	49,716.0	4773.0	46,664.0	4742.0	46,092.0
October	4409.0	48,468.4	4602.6	46,618.1	4625.0	46,078.1
November	4643.1	45,824.0	4348.9	44,751.0	4342.0	44,142.0
December	5018.2	46,348.3	4308.3	44,176.0	4168.2	42,936.0
Total/yr	1,643,704.5	17,626,680.0	1,600,250.8	16,465,050	1,696,082	16,482,180
Average/d	4503.3	48,292.3	4372.3	45,109.7	4646.8	45,156.7
GJ/d	188.81	173.85	183.32	162.39	194.83	162.56
GJ Ratio	1.086	1.000	1.129	1.000	1.199	1.000
Cost/d	18,463.53	76,726.33	17,926.43	70,777.56	19,051.88	70,872.96
Cost Ratio	0.241	1.000	0,253	1,000	0.269	1.000

Note 1. 1 kWh = 3.6×10^{-3} GJ and 1 liter of Heavy Fuel Oil = $41,928 \times 10^{-3}$ GJ .

2. The average GJ ratio is 1,138: 1.000 and the average cost ratio is 0.254: 1.000.

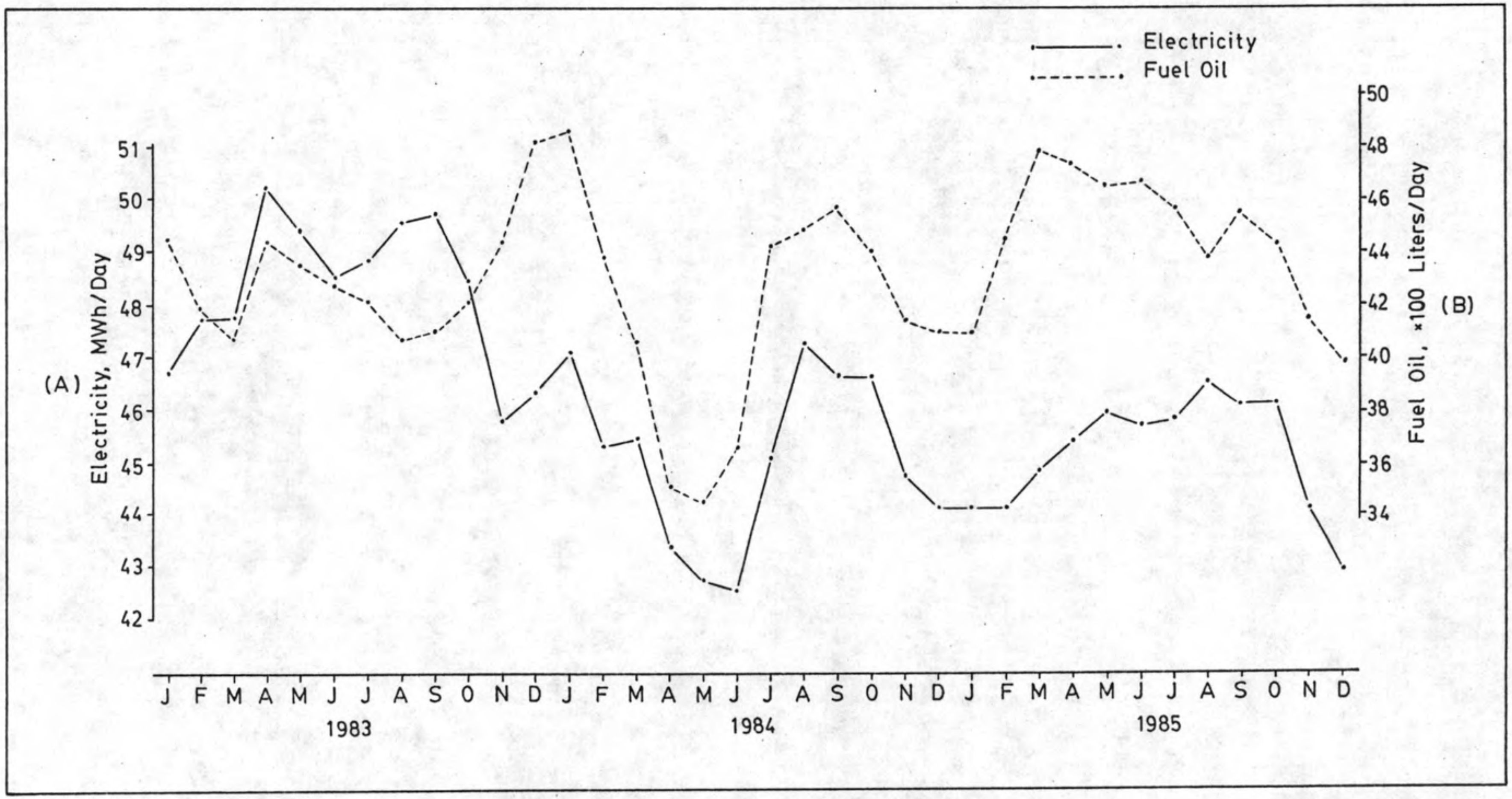


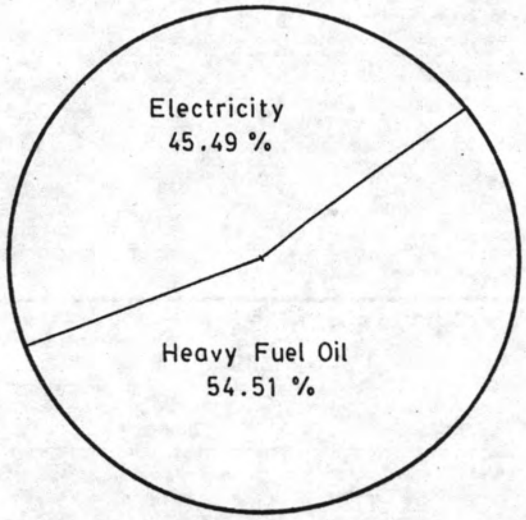
Figure 3.5 Trends of Average Daily Consumption: (A) Electricity, MWh/Day and (B) Heavy Fuel Oil, x100 Liters/Day.

Table 3.3 Analysis of Energy Utilization in 1985 (Also See Table 3.1 and 3.2)

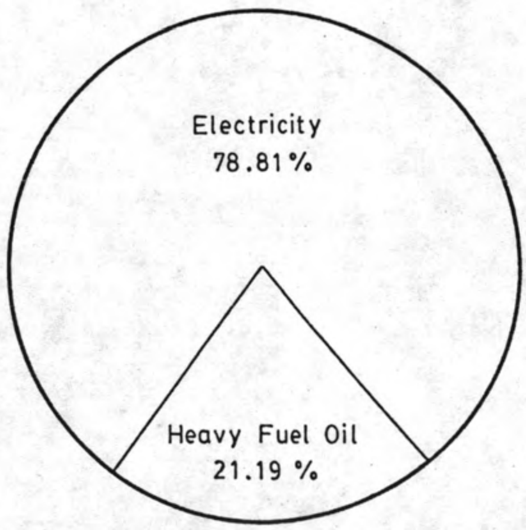
Source of Energy	Quantity (per day)	Equivalent Energy, GJ/day	Percent of Total Energy	Energy Cost (Bahts/day)	Percent of Total Cost	Unit Energy Cost, Bahts/GJ
Electricity	45,156.7 kWh	162.564	45.49	70,872.96	78.81	435.97
Heavy Fuel Oil	4,646.8 liters	194,831	54.51	19,051.88	21.19	97.79
Total		357.395	100.00	89,924.84	100.00	

<u>Remark:</u> Conversion factor: 1 kWh = 3.6×10^{-3} GJ

1 liter of heavy fuel oil = 41.928×10^{-3} GJ



(A) By Energy Type



(B) By Energy Cost

Figure 3.6 Beakdown of Energy Requirement for the Factory in 1985.

Table 3.4 Monthly Production And the Relevant Processing Material (kg/mo) In 1983, 1984 And 1985

Year / Month	1983				1984				1985			
	Filament Product	Wastes	Recovered Lactam	Broken Bag Lactam	Filament Product	Wastes	Recovered Lactam	Broken Bag Lactam	Filament Product	Wastes	Recovered Lactam	Broken Bag Lactam
January	376,280	14,804	31,000	1,090	404,420	12,830	33,720	685	390,440	20,693	29,267	1,073
February	298,455	11,916	23,514	1,521	355,000	12,183	27,395	-	358,285	15,381	24,771	1,381
March	386,480	16,022	18,480	-	354,835	13,072	28,180	-	417,855	18,862	28,195	1,995
April	391,740	17,164	22,850	-	219,970	9,872	13,180	299	401,525	16,557	35,595	-
May	403,735	16,859	32,169	-	239,960	9,722	18,009	598	423,485	18,207	33,980	4,14 7
June	393,420	15,539	30,771	12,500	296,045	12,367	16,500	-	386,255	15,762	25,550	-
July	393,685	14,040	28,980	12,070	407,045	15,785	28,182	1,377	394,880	18,465	32,735	2,451
August	416,951	12,521	30,411	9,885	414,650	14,718	26,696	-	392,167	16,417	33,180	1,500
September	389,860	13,415	33,955	20,577	397,165	16,438	32,715	2,542	404,715	20,016	33,090	-
October	408,420	12,733	28,478	-	414,395	16,182	31,395	3,198	444,800	20,313	37,210	2,138
November	392,010	12,903	28,821	-	374,705	17,791	31,275	811	405,300	19,237	35,460	1,164
December	412,260	12,582	30,620	-	404,295	19,321	24,585	2,401	436,295	17,145	37,290	3,854
Total	4,663,296	170,498	340,049	57,643	4,282,485	170,281	311,782	11,911	4,856,002	216,455	386,323	19,703
Average	388,608	14,208.17	28,337.42	4,803.58	356,873.75	14,190.08	25,981.83	992.58	404,666.83	18,037.92	32,193.58	1,641.92

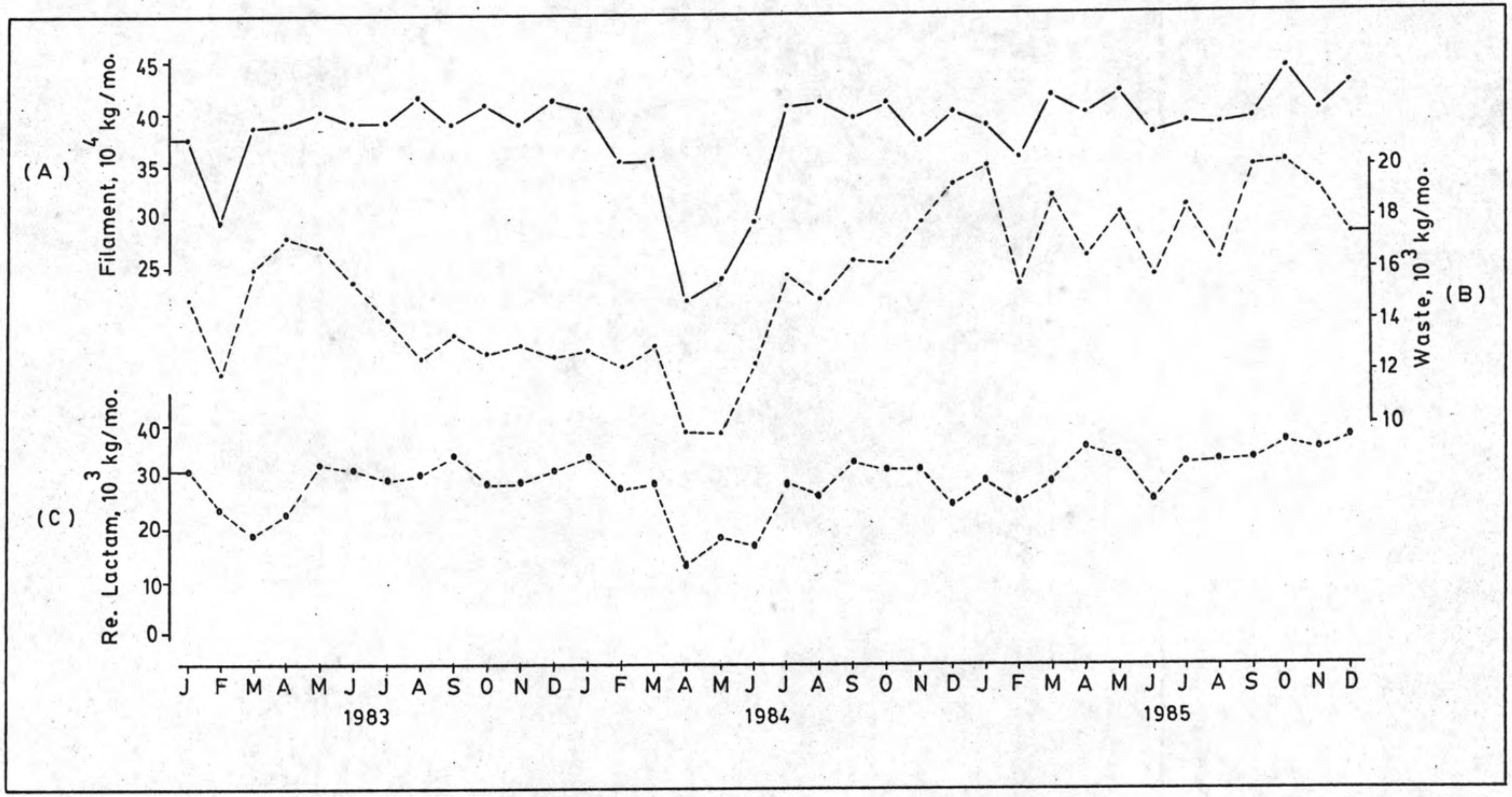


Figure 3.7 Trends of Monthly (A) Filament Product, 10^4 kg/mo; (B) Waste, 10^3 kg/mo; and (C) Recovered Lactam, 10^3 kg/mo.

saleable output, the system under study is defined as follows:

System input material: Caprolactam

System output material: Saleable filament product

Sub-systems included:

(a) All manufacturing operation within the factory which convert caprolactam to saleable filament product

(b) All administrative functions within the factory office.

With the system defined in this way, the numerical analysis can now be performed. Data and some related calculations are shown in Table 3.4 and Table 3.5. In Table 3.4, monthly production and other relevant materials are given. Nylon-6 filament is the saleable output of the factory. Wastes refer to all kinds of material obtained throughout the process that cannot be recovered as a usable raw material or a finished product. Recovered lactam is the material that is recovered from distillation system and it will be returned to the melting tank as raw material. Under normal working condition, 7 to 11 per cent of pure caprolactam will remain as incomplete polymer after the polymerization process and must be extracted from other processing material, see Figure 3.3 for more detail. Broken bag lactam is also the pure caprolactam being delivered by outside agent. Unfortunately, its plastic bag is torn during delivery period. The data colected in Table 3.4 are plotted to demonstrate the distribution patterns as shown in Figure 3.7 from where an increasing trend of filament product can easily be observed. It can be seen that the production capacity in April, May and June of 1984 was reduced to a level much lower than the average monthly production rate of 356.8 tons of this year. The reduction in the production level will normally depend upon the market situation.

It can also be seen from this figure that the distribution patterns of both wastes and recovered lactam are proportional to the production level of the corresponding period.

Specific energy consumption or energy required by each kilogram of filament product is summarized in Table 3.5. Each entry of the first column in this table, kg/d of filament product, is taken from Table 3.4 and devided by the number of days in that month. Fuel oil, l/kg, for the second column is obtained by deviding the fuel oil, l/day, from Table 3.2 by the corresponding entry of kg/d of filament product from the first column of Table 3.5. The third column, kWh/kg, shows electrical energy consumed by each kilogram of saleable product or the Electric Power Specific Unit (EPSU) as preferred by some researchers. It can be computed by deviding the average daily electrical energy consumption, kWh/day, from Table 3.2 by its corresponding filament product of Table 3.5. The last column is the sum of the two types of energy required by each kilogram of finished product. In this column, the entries are expressed in kilojoule of total energy per kilogram of product so that the summation of the two types of energy can be achieved. The average, on annual basis, for specific energy consumption is also given in Table 3.5 from which a comparison of the figures for the three years can be seen. A graph showing the distribution patterns of specific energy consumption is shown in Figure 3.8.

Considering the results that were obtained for the three years studied, the specific energy consumption of 1985 is the lowest, while that of 1984 is the highest. After some investigations, we found that the amount of energy required by each unit of output varied in the opposite direction to production level. This evidence can be proved

Table 3.5 Specific Energy Consumption for 1983, 1984 And 1985

Year / Month	1983				1984				1985			
	Filament Product kg/d	Fuel Oil l/kg	Electricity kWh/kg	Sum of Energy kJ/kg	Filament Product kg/d	Fuel Oil l/kg	Electricity kWh/kg	Sum of Energy kJ/kg	Filament Product kg/d	Fuel Oil l/d	Electricity kWh/kg	Sum of Energy kJ/kg
January	12,138.06	.3833	3.8544	2.467	13,045.81	.3883	3.6107	2.244	12,594.84	.3412	3.5028	2.137
February	10,659.11	.4125	4.4791	3.135	12,241.38	.3734	3.7036	2.368	12,795.89	.3636	3.4484	2.162
March	12,467.10	.3430	3.8338	2.261	11,446.29	.3722	3.9732	2.613	13,479.19	.3699	3.3297	2.040
April	13,058.00	.3552	3.8568	2.204	7,332.33	.5071	5.9144	5.804	13,384.17	.3683	3.3892	2.065
May	13,023.71	.3492	3.7944	2.173	7,740.65	.4718	5.5292	5.127	13,660.81	.3546	3.3656	1.975
June	13,114.00	.3410	3.7047	2.107	9,868.17	.3916	4.3072	3.235	12,875.17	.3773	3.5495	2.221
July	12,699.52	.3477	3.8466	2.238	13,130.48	.3516	3.4410	2.066	12,738.06	.3729	3.6000	2.245
August	13,450.03	.3173	3.6869	1.976	13,375.81	.3503	3.5321	2.049	12,650.55	.3611	3.6753	2.243
September	12,995.33	.3310	3.8257	2.128	13,238.83	.3605	3.5248	2.100	13,490.50	.3515	3.4166	2.004
October	13,174.84	.3347	3.6789	2.070	13,367.58	.3443	3.4874	2.019	14,348.39	.3223	3.2114	1.747
November	13,067.00	.3553	3.5068	2.106	12,490.17	.3482	3.5829	2.202	13,510.00	.3214	3.2674	1.868
December	13,298.71	.3773	3.4852	2.133	13,041.77	.3303	3.3873	1.997	14,074.03	.2962	3.0507	1.663
Average	12,776.15	.3525	3.7799	2.222	11,700.78	.3737	3.8553	2.525	13,304.12	.3493	3.3942	2.019

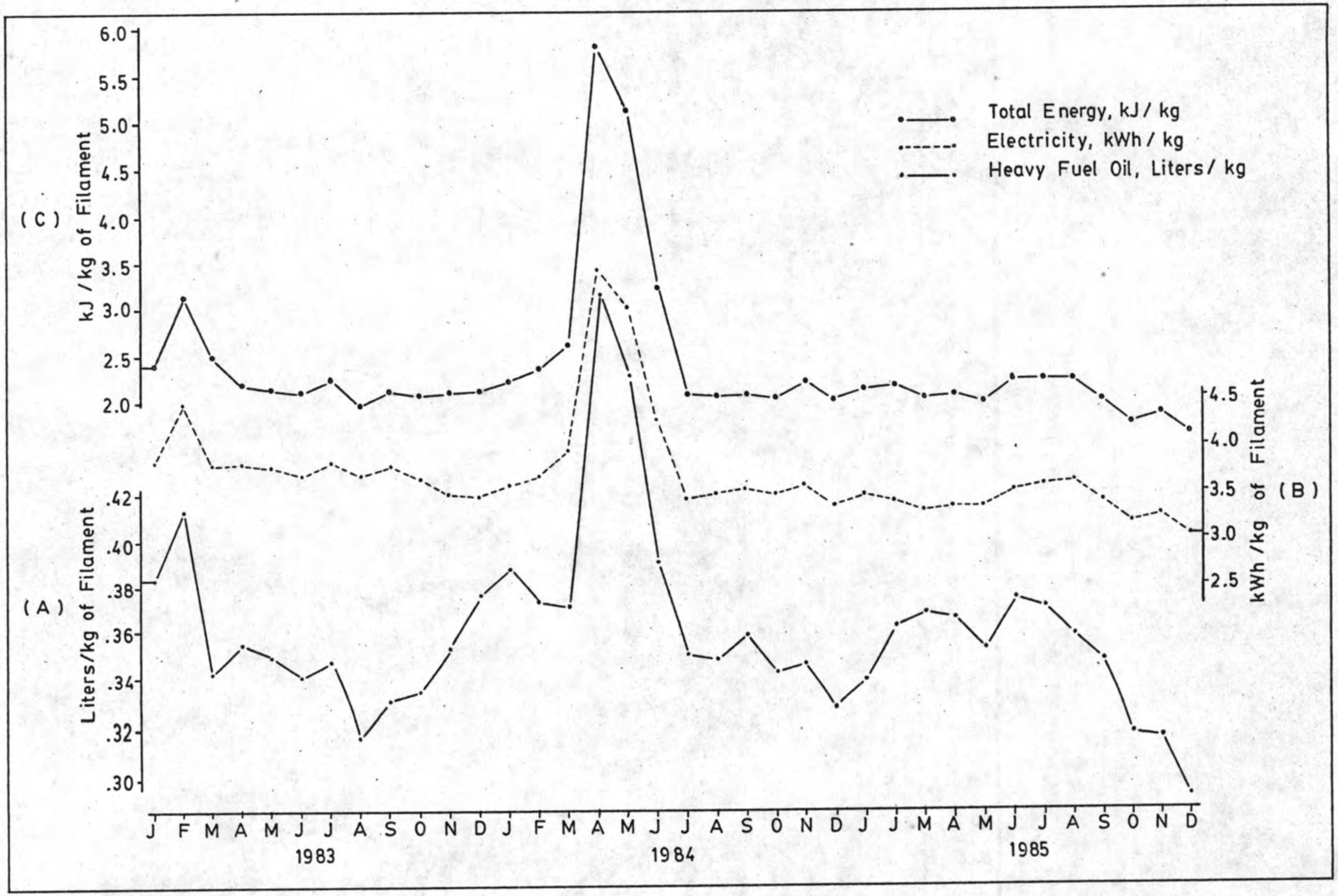


Figure 3.8 Trends of Specific Energy Consumption: (A) Heavy Fuel Oil, Liters/kg of Filament, (B) Electricity, kWh/kg of Filament, and (C) Total Energy Used, kJ/kg of Filament.

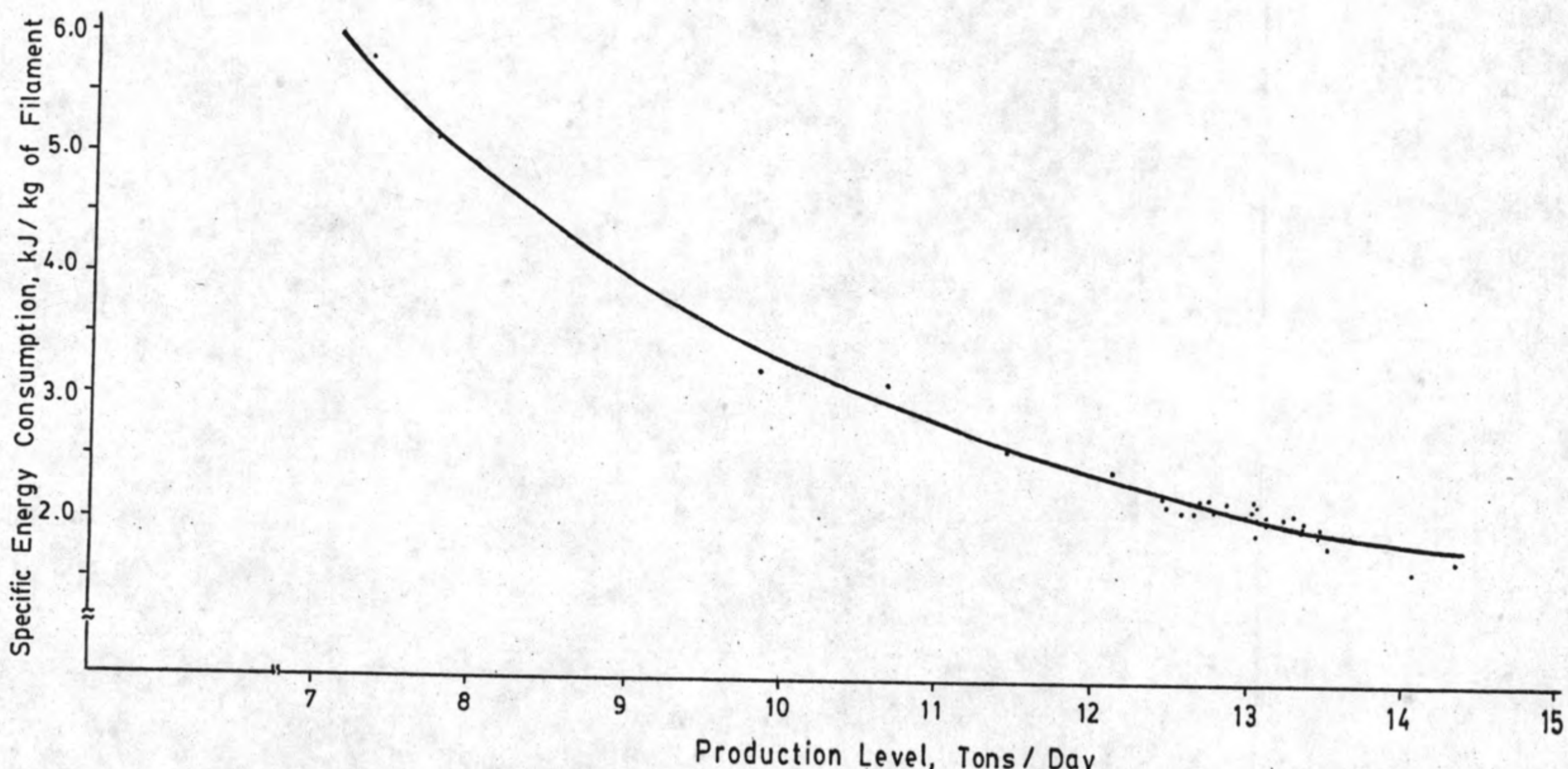


Figure 3.9 Relationship Between Production Level and Specific Energy Consumption.

by Figure 3.5, Figre 3.7, and Figure 3.9. In April, May, and June of 1984, for instance, production levels were reduced due to weak market, the energy of each type consumed also dropped. However, while production rates were reducing the energy consuming equipment such as those for lighting and air conditioning could not be reduced proportionally. In this situation, most of the equipment works at a lower efficiency, this effect may be seen by the load factor of April 1984 which appears to be the lowest point in Figure 3.4 A. Figure 3.9 provides a better explanation, the specific energy consumption during the higher production period is less than that during the lower one.

Table 3.6 illustrates specific energy costs, the expenditure for total energy required by each kilogram of filament product in 1983, 1984 and 1985. In this table cost of fuel oil, bahts per kg., for the first column can be achieved by multiplying fuel oil of each month from Table 3.5 by 4.10 bahts per liter of the purchasing price for heavy fuel oil to obtain the fuel oil expenses per kilogram of product. Cost of electricity, bahts per kg, for the second column is a result accomplished by multiplying the electrical energy, kWh/kg, of Table 3.5 by the average electricity charge, annual basis, of the respective year from Table 3.1. For instance, specific electrical energy consumption of January 1983 is 3.8544 kWh/kg and the average electricity charge for 1983, from the last entry of Table 3.1 A, is 1.5888 bahts/kWh, so, we arrive at a cost of 6.1239 bahts per kilogram of filament produced. The sum of energy costs in the third column is, straight forward, the combination of expenses of the two sorts of energy mentioned above.

Distribution patterns for specific energy costs are similar to that of specific energy consumption shown is Figure 3.8 since the resutts

Table 3.6 Specific Energy Cost (Baht per kg. of Filament Product) for 1983, 1984 And 1985

Year / Month	1983			1984			1985		
	Cost of Fuel Oil (฿ / kg)	Cost of Electricity (฿ / kg)	Sum of Energy Cost (฿ / kg)	Cost of Fuel Oil (฿ / kg)	Cost of Electricity (฿ / kg)	Sum of Energy Cost (฿ / kg)	Cost of Fuel Oil (฿ / kg)	Cost of Electricity (฿ / kg)	Sum of Energy Cost (฿ / kg)
January	1.5715	6.1239	7.6954	1.5920	5.6652	7.2572	1.3989	5.4983	6.8972
February	1.6912	7.1164	8.8076	1.5309	5.8109	7.3418	1.4908	5.4129	6.9037
March	1.4063	6.0911	7.4974	1.5260	6.2340	7.7600	1.5165	5.2266	6.7431
April	1.4563	6.1277	7.5840	2.0791	9.2797	11.3588	1.5100	5.3200	6.8300
May	1.4317	6.0285	7.4602	1.9344	8.6753	10.6097	1.4539	5.2830	6.7369
June	1.3981	5.8860	7.2841	1.6056	6.7580	8.3636	1.5469	5.5717	7.1186
July	1.4256	6.1115	7.5371	1.4416	5.3989	6.8405	1.5289	5.6509	7.1798
August	1.3009	5.8577	7.1586	1.4362	5.5419	6.9781	1.4805	5.7691	7.2496
September	1.3571	6.0783	7.4354	1.4780	5.5304	7.0084	1.4411	5.3630	6.8041
October	1.3723	5.8450	7.2173	1.4116	5.4717	6.8833	1.3214	5.0409	6.3623
November	1.4567	5.5716	7.0283	1.4276	5.6216	7.0492	1.3177	5.1288	6.4465
December	1.5469	5.5373	7.0842	1.3542	5.3147	6.6689	1.2144	4.7887	6.0031
Average	1.4452	6.0055	7.4507	1.5322	6.0490	7.5812	1.4321	5.3279	6.7600

obtained by each column of Table 3.6 come from the corresponding column of Table 3.5 multiplied by the average purchasing price of each type of energy.

The specific energy consumption and the specific energy costs described in this section can be illustrated as shown in Figure 3.10.

Summary

An attempt was made in this chapter to present a broad view of the factory studied, emphasizing the manufacturing process and energy utilization.

The process employed in the manufacture of Nylon-6 filament was described using information available from several chemical engineering handbooks as well as those provided by the factory.

Energy consumption of the whole factory was investigated to disclose the distribution pattern for both electricity and heavy fuel oil. The past records for the last three years (1983 to 1985) were collected and then plotted to provide the trend comparisons.

The study also considered the relationship between production levels and the amount of energy consumed in order to identify the optimum level using specific energy consumption as the basis.

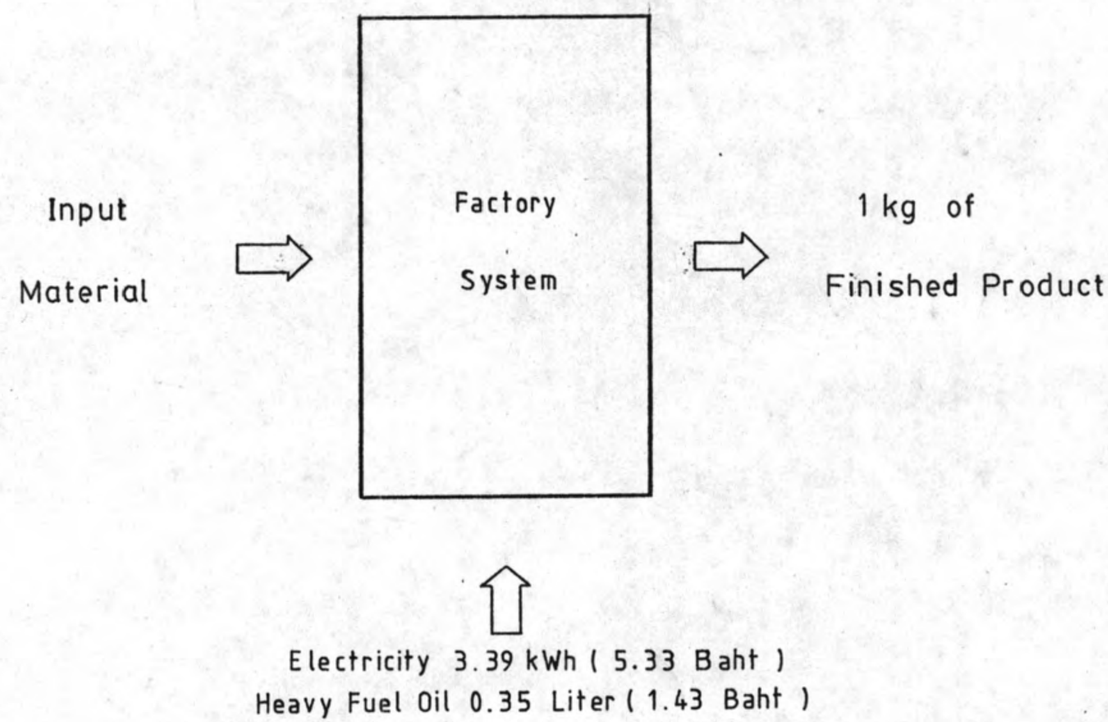


Figure 3.10 Summary of Energy (Cost) in Producing 1 kg of Filament Product. (Using Information of 1985 from Table 3.5 and 3.6.)