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The Editorial Board invites papers on energy related issues for publication in the SLEMA Journal.

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DOWNSTREAM PETROLEUM INDUSTRY IN SRI LANKA*

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Introduction

The downstream petroleum industry is a complex and often misunderstood business. The term downstream refers to all aspects of refining and marketing of petroleum products. It includes petroleum refining, product distribution systems, and the marketing and retailing of petroleum products to businesses and individual consumers. This paper will discuss the supply chain for petroleum products, from the sources of the crude oil to the delivery of the products to the final user. It will also look at the evolution of the downstream petroleum industry in Sri Lanka from early use of petroleum fuels to the present time.

Evolution of Downstream Petroleum Industry

The evolution of downstream petroleum industry in Sri Lanka can be divided into three distinct periods.

Early Period up to 1962
Import and marketing of petroleum products by international oil companies

Mid Period 1962 – 1992
-Formation of state oil company Ceylon Petroleum Corporation
-CPC in competition with International Oil Companies
-CPC monopoly

Present Period 1992 onwards
-Liberalization of Some Sectors (LPG, Lubricants Bunkering)
-Restructuring of the Retail Marketing Sector

Early Period

The import of petroleum products to the country has started in the latter part of the 19^{th} century. Main product that has been imported was kerosene. First record of import of kerosene is noted in the Blue Book (Administrative Reports) of 1886, where it is stated that kerosene to the value of Rs. 208,170/- was imported. Petrol has been imported from 1903 with the import of the first motor car. Records show that 62,075 gallons (279,337 liters) of benzene (petrol) was imported in 1907. Consumption of both products has increased at a moderate rate and it is recorded that in 1920, nearly five million gallons of kerosene and one million gallons of petrol has been imported.

Other petroleum products that have been imported are Patent Fuel, Liquid Fuel and Bitumen. Patent fuel was for use in industrial machines and appears to be a type of industrial diesel. Liquid fuel is furnace oil for boilers. Whilst, furnace oil has been imported initially as ships' bunkers, later on an inland demand developed especially in the estate sector. It is estimated that 7,000,000 gallons (31,500,000 liters) of furnace oil was used internally in 1922.

Initially, kerosene in packaged form has been imported by various trading houses. As the market developed, three companies, namely Asiatic Petroleum Co Ltd of London, Anglo Saxon Petroleum Co. of London and Shell Transport and Trading Co of London supplied all the products. Petroleum products were distributed and marketed by their local agent through a bulk installation in Colombo and Depots spread island wide.

* This paper was presented at the SLEMA Annual Sessions 2007, held in Colombo on 28th July 2007

Bulk of the petroleum products imported up to 1910 came from Russia. After 1910, due to unrest in Russia, the supply shifted to Dutch East Indies (Sumatra, Borneo), Persia (Iran) and USA.

With increase in consumption of petroleum products, infrastructure development for import, storage and distribution took place. Kolonnawa Oil Installation and associated pipelines from Port were commissioned in June 1921. By this period, three International Oil Majors, Shell, Caltex and Esso were handling the import and distribution of petroleum products in the country. Imported products were stored at the main installation at Kolonnawa and distributed island wide by railway and bowser fleet, and sold through the chain of retail outlets owned by the three companies.

Mid Period
Formation of CPC

Before the establishment of Ceylon Petroleum Corporation, three Oil Majors, Shell, Caltex and Esso were handling the import and distribution of petroleum products in Sri Lanka. Although the three companies appear to be competing with each other they have formed into a virtual cartel by fixing the retail prices of products by mutual agreement. Although the oil companies obtained large discounts from oil refineries based on so called benchmark prices, their imports were priced at benchmark price.

Government has realized that oil companies were draining a large chunk of scarce foreign exchange by invoicing the imported oil at the higher prices based on the benchmark prices. With the view to saving valuable foreign exchange and to give a fair deal to the consumers, the Government has requested the three Oil Majors to import petroleum products at discounted benchmark prices. This request was turned down by the oil companies. At this stage, with a view to minimize the outflow of foreign exchange and also to pass on the benefit of discounted prices to the consumer, the Government decided to enter into the oil business. As a result, Ceylon Petroleum Corporation was established under the CPC Act No.28 of 1961.

CPC commenced business in April 1962, in competition with the three Oil Majors. As the first step, CPC took over some of the distribution facilities of the oil companies – about 175 retail outlets throughout the country and some of the bulk storage depots and some of the storage facilities at the main installation in Kolonnawa. In order to safeguard CPC from unfair competition by the oil companies, the minimum sales price of petroleum products were decreed by the Government by Gazette notification on 20th March 1962. The minimum prices were fixed such that the new prices were the same or lower than the prices at which the oil companies were marketing the products at the time. CPC was able to import products at lower cif prices than the three Oil Majors and pass on the benefits to the consumers.

First imports of products, namely petrol, kerosene, auto-diesel and heavy diesel by CPC was made from Soviet Union while lubricating oils were imported from ICPA of USA. CPC gradually managed to increase its share of the petroleum market and at the time of complete take over of oil companies business in 1964, enjoyed a market share of about 40%.

Nationalization of Oil Companies

With the increase in volume of CPC sales, it was pointed out by the Central Bank, if the entire requirements of petroleum products are imported at cif prices at which the CPC imported products, the country would save valuable foreign exchange. Pursuant to this, the Government requested oil companies to reduce the cif price of products, which was turned down. Having failed all avenues to persuade oil companies to reduce prices, the Government decided that oil companies would be allowed to import products on the basis of a fixed maximum price with a 5% premium above the cif prices of the CPC. The oil companies took the stand that they could not import products with those ceiling prices. After discussions with the oil companies, the Govt. decided to allocate to the oil companies a foreign exchange quota equivalent to the cost of their share of the sales but at the cif prices of the CPC. Oil companies were not willing to work within this quota system and hinted of a possible disruption to the supply if the Government pursued such a policy.

In these circumstances, the Government decided to fully nationalize the distribution of petroleum products in the country. Petroleum Corporation (Amendment) Act No.5 of 1963 was enacted in August 1963, empowering the CPC as the sole importer and distributor of petroleum products in the country. CPC took over the entire distribution network from 1st January 1964.

While importing and inland distribution of petroleum products was nationalized and became a monopoly of the CPC in 1964, Bunkering and Aviation business continued to be handled by the oil companies. In 1972, CPC took over the Bunkering and Aviation facilities as well, thus completing the nationalization of the entire petroleum business in Sri Lanka.

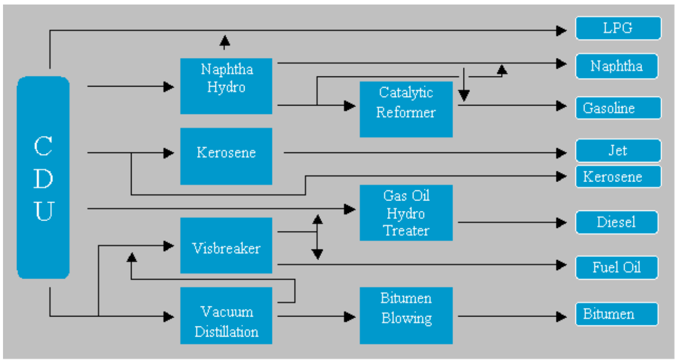
Following the nationalization, CPC embarked on the task of supplying petroleum products to meet the country's total requirement. Until the construction of the Refinery, bulk of the CPC's imports came from Soviet Union, Rumania, Egypt and Iraq. All these supplies were under the terms of Government to Government bilateral trade agreements. Lubricating oils were imported from ICPA of USA.

Refining

The downstream petroleum industry which was confined to importing and marketing of petroleum products expanded to refining of petroleum with the setting up of Sapugaskanda refinery in 1969.

From the very start of partial take over of import and distribution of petroleum products, it became clear that rather than import refined products, it is more economical to import crude oil and refine by setting up a refinery. It was estimated that by establishing a refinery, 25% of the foreign exchange spent on import of refined petroleum products could be saved. In the light of this, CPC Management decided to construct a refinery and International Tenders were called in 1965. After evaluation of the tenders by both French Petroleum Institute and Egyptian General Petroleum Corporation, the contract was awarded to SNAM Progetti of Italy.

Sapugaskande Refinery Configuration



Sri Lanka being a mainly middle distillate (kerosene, diesel) oriented market, refinery configuration and the types of crude oil selection was made to suit this condition. The refinery was originally designed to process Iranian Light crude which has a high middle distillates yield. Hydro-skimming type configuration was found to be the best suited to match the product slate. The original capacity was 38,000 BPD[1], capable of meeting total inland requirements of refined products.

Refinery construction commenced in May 1967 at the 165 acre site at Sapugaskanda, and it was started up on the 6th of August 1969. The total cost of the project was 175 million rupees.

The refinery was revamped subsequently to increase the capacity to the present value of 50,000 BPD. The crude distillation unit, which was originally designed to process Iranian Light crude oil, had limited flexibility to process crude oils of different compositions which were more suited to the changing market conditions in the country. The crude unit was redesigned to handle lighter crude rich in middle distillates as well as heavier high sulphur crude oils which had to be processed at times. The catalytic reformer which produces blending components for gasoline was revamped to increase the capacity to enable CPC to produce unleaded gasoline. The basic configuration of the refinery, though, remained as before, a hydro-skimming type.

Crude oil for the refinery could be imported only using small tankers of 30,000 MT[2]

[1] Barrels per day
[2] Metric Ton

capacity due to restrictions at Colombo Port, and this made the freight rates very high. In 1987/1988 CPC built a Single Point Buoy Mooring facility and a submarine pipeline capable of handling large tankers up to 120,000 MT, at a cost of Rs.842 million. A new crude oil tank farm at Orugodawatte was completed with this project.

The refinery today processes a wide range of crude oils such as Arabian Light, Iranian Light, Upper Zakum and Suez Blend, all from Middle East and Miri Light from Malaysia. Due to the increase in domestic consumption of petroleum products, the refinery can only supply about 45% of the country's product requirement.

The pressures to produce more environmentally friendly fuels and to maintain a positive refining margin are the main challenges faced by the refinery today. Phasing out of lead from gasoline has been already achieved by increasing the reformer capacity and producing higher octane blending component. However, meeting the targets for producing low sulphur diesel is not achievable in the time frame given for this. Originally, the refinery was producing diesel at 1% sulphur. Reduction of diesel sulphur to current level of 0.3% was done by hydro-treating the bulk of diesel production. By 2008, auto diesel sulphur has to be below 0.05%. In order to bring down sulphur to this level, major modification/ modernization has to be carried out in the refinery. Even if the implementation of these modernisation work commences now, it would not be possible to meet the time targets.

The other major problem faced by CPC refinery is the maintaining of a positive refinery margin. Gross refining margin of hydro-skimming refineries are very low even under stable market conditions. Under volatile market conditions such as those experienced in the latter half of 2006, most of the hydro-treating refineries operated at a negative margin. Sapugaskanda refinery being of hydro-skimming type, with nearly 40% of the products coming out as fuel oil, is very vulnerable to this kind of market conditions. Cracking refineries enjoy much higher margins. For its survival in the future, the CPC refinery needs to consider major process configuration change, to upgrade the residue make to higher value lighter products.

Downstream Marketing Sector Reforms in 2002

The Government in 2002 decided to liberalise the downstream petroleum marketing sector. The basis of liberalisation was to remove the CPC monopoly in marketing and to limit the number of marketing companies to three for the initial five years. All available downstream infrastructure such as the Kolonnawa Installation, islandwide bulk depot network and the new import and distribution terminal at Muthurajawela was formed into a common user company, Ceylon Petroleum Storage Terminals Ltd (CPSTL) to be equally owned and shared by the three marketing companies. CPC was to retain the refinery and about 130 retail outlets while the balance retail outlets owned by CPC (about 210) to be divested to the other two new market players. All market players are to be allowed to negotiate for the 600 franchise retail outlets to market their products.

The Government through the Government of India invited Indian Oil Corporation to enter into the downstream retail marketing of petroleum products. IOC was offered the China Bay tank farm on a long-term lease and they were allowed to choose and purchase 100 retail outlets belonging to CPC. IOC also purchased 1/3 rd share in the common user company CPSTL. IOC registered a subsidiary company Lanka Indian Oil Corporation and commenced business in 2003.

Due to subsequent policy changes by the Government. entry of the third player to the market has been suspended.

The monthly price adjustment formula was revised with the inclusion of profit margins to the common user facility handling storage and distribution, and the marketing company. Due to this revised formula, the retail price of every product increased by about Rs.3/- to Rs. 4/- per liter.

As per agreements, 95% of the country's throughput of petroleum products must be handled through the CPSTL. This has forced the virtual shutdown of CPC's mini distribution terminal at Sapugaskanda, while LIOC was allowed to distribute the balance 5% volume from the China Bay terminal. This anomaly has been corrected to a certain extent by the recent decision to allow both China Bay and Sapugaskanda mini-terminal to handle 5% each of the total country's throughput.

It should be noted that importing refined products through China Bay is more advantageous, as some of the pass-through cost items in the pricing formula are not applicable when importing and distributing through China Bay.

The primary intention of restructuring of the petroleum market was to give the benefit of competitive marketing to the consumer. It is seen that the opposite has happened with the increase in cost to the consumer. Quality of service appears to have improved with the modernising of the retail outlets, which would not have happened if marketing remained a monopoly of the CPC.

Under the restructuring scheme, the initial period of 5 years has been defined as a regulated market. Unfortunately a proper regulatory mechanism is yet to be introduced. Although PUCSL has been designated as the sector regulator, legal framework required for PUCSL to take over regulatory functions is still not put in place.

Downstream Gas Sector

With no natural gas resources, the downstream gas sector in Sri Lanka is confined to distribution and marketing of Liquefied Petroleum Gas.

LPG was first produced and bottled for domestic consumption at the refinery in 1971 on a limited scale. Marketing and distribution was done by CPC.

Colombo Gas and Water Company was supplying coal gas by a network of pipelines to domestic and industrial consumers in the city of Colombo starting as far back as 1872. By 1975, Gas Co was no longer producing coal gas, but kept the city gas supply going with the LPG supplied by CPC. In 1975, the distribution and marketing of LPG was handed over to the Gas Company. The refinery continued to produce and bottle LPG.

Gas Company expanded the distribution and marketing network and took over the bottling as well in 1984. CPC refinery supplied LPG in bulk to the Gas Company.

As the market demand for LPG increased, Gas Co had to supplement refinery production with imports. The infrastructure facilities available for import and storage of LPG were inadequate. There were frequent market shortages especially during refinery shutdowns. Due to lack of storage, import parcel sizes were small, causing imports to be very costly due to high freight rates.

In 1996, under the public sector reform program, the Government decided to privatise the Colombo Gas Company. The rationale was that a private entrepreneur would give a better service to the consumers by developing the infrastructure. Bids were called from international companies and following evaluation, the bid offered by the Shell Company was accepted and all assets of the Gas Company were transferred to the new company Shell Gas Lanka Limited.

Under the privatisation agreement, Shell was granted monopoly rights to import and market LPG for a period of five years. Shell constructed a storage terminal at Muthurajawela for LPG storage with a Single-point Buoy Mooring system with associated pipelines for discharging tankers. The Gas Company storage facility at Orugodawatte as well as the original equipment at Pettah site was dismantled by Shell and all operations were moved to Muthurajawela and Mabima sites.

As the demand for LPG rose rapidly, the refinery could produce only a fraction of the market demand. Bulk of the LPG had to be imported. Initially Shell too continued to import LPG through Colombo Port and used road tankers to transfer LPG from tankers to filling plants. When the construction of Muthurajawela storage complex was completed along with the SBM, this practice was discontinued and LPG is now discharged directly from tankers to storage via the SBM.

With the privatisation the service to the consumers improved as the supply shortages that were frequent were eliminated with added infrastructure for storage. However, the consumer had to pay a much higher price for the LPG. LPG price was strictly controlled by theGovernmentwhen the business was handled by Gas Co. LPG produced at the CPC refinery was sold to Gas Co. at a discounted price. The privatisation agreement forced CPC to sell LPG produced at the refinery to Shell Gas at a much higher discount. This was based on the argument that Shell could import LPG at a lower freight rate by importing larger parcels of LPG at a time, and hence, the import parity price of LPG would be lower than that charged by CPC. In spite of this, almost immediately after privatisation, the market price of LPG doubled. Shell has claimed that the company has invested a substantial capital in developing the storage terminal and the SBM, justifying the increase of LPG price. In the absence of a proper regulatory mechanism, there is no way to ascertain whether the operator is making undue profits at the expense of the consumer.

The privatisation agreements did not require Shell Gas to take off the LPG produced at the refinery. On several occasions, CPC refinery was forced to flare LPG to the atmosphere for extended periods as Shell Gas declined to lift LPG from the refinery.

When the five-year monopoly period granted to Shell Gas expired, a second operator Laugfs Gas entered the LPG market. Laugfs Gas started by marketing LPG for automotive use and later expanded their business to supply bottled gas to domestic consumers. Laugfs Gas purchased the entire production of LPG from CPC refinery and imported a small quantity of gas to supplement its sales when the refinery was shutdown for maintenance. Entry of the second operator did not appear to create a workable competition beneficial to the consumer as the retail price of LPG marketed by both companies moved in tandem. Attempts made by a third company Mundo Gas to enter the LPG market were not successful, due to the lack of infrastructure facilities for the import of gas.

Lubricants Market

Before the CPC monopoly in marketing, branded lubricants were imported and marketed by the oil companies. After nationalisation of the oil companies, CPC imported lubricants from ICPA and marketed under the “Lanka” brand. In 1969, CPC constructed a lubricating oil blending facility at Kolonnawa, and commenced blending of lubricants from imported base stock. Approximately 95% of the lubricants sold in the country were blended at the lubricating oil blending plant and the balance was imported by CPC or others who obtained authorisation to import from CPC.

In 1992, the Lubricant Section and the Blending Plant was separated from CPC and converted into a Public Company with GOSL owning 100% of the issued share capital of the Company. Lanka Lubricants Ltd as the company was named acquired the exclusivity to conduct the lubricants business in Sri Lanka.

In July 1994, GOSL divested 90% of share in Lanka Lubricants Ltd to Caltex Trading and Transport Company of Dubai, with 10% of the shares gifted to the employees. The company now known as Caltex Lubricants Lanka Ltd was given the exclusive rights to import, manufacture and distribute lubricants in Sri Lanka for a period of 10 years till July 2004. However, the privatisation agreement allowed the GOSL to permit other companies in addition to Caltex to import and distribute finished lubricants prior to 2004 under certain agreed conditions.

Besides being granted the exclusive rights to manufacture lubricants, Caltex was granted other concessions under the privatisation agreement. Caltex was given the exclusive rights to distribute and market its lubricants through the filling stations operated by CPC. Also no importation of lubricants was to be allowed at prices lower than ex-factory price of Caltex.

As it was felt that partial liberalisation of lubricants market would be beneficial to the consumers, in 1998 GOSL called for expressions of interest from reputed international companies with experience in lubricant industry interested in commencing business in Sri Lanka. After evaluation of tenders six companies, namely BP Middle East, Castrol Asia Pacific, Indian Oil Corporation, Mobil Asia Pacific, Shell Trading Middle East and Valvoline International were granted permission to enter the market, valid for a period of five years until 2004.

It is worthwhile examining whether liberalisation of the lubricants market has achieved its objective of benefiting the consumer. During the period of monopoly by CPC, the customers had no choice but to use CPC branded lubricants blended locally. CPC being a public sector venture, the prices of lubricants blended and marketed by CPC remained reasonably stable With the monopoly rights granted to Caltex for manufacturing lubricants, the status quo remained virtually unchanged, where only the brand name of lubricant changed from Lanka to Caltex. Although the market was partially liberalised allowing 6 other companies to import and distribute lubricants, very favorable concessions granted to Caltex by privatising agreements (preferential tariff on locally blended lubricants against imported, exclusive rights to market Caltex lubricants through CPC service station network) made it virtually impossible for others to effectively compete with Caltex. Caltex presently enjoys 70 % market share of the lubricants market. Consumers only benefited by having a limited choice of brands to select from, but at a much higher price than when the sector was publicly owned.

In 2006, the Government decided to further liberalise the lubricants market by granting licenses to import finished lubricants as well as setting up blending plants. This is currently in process and several companies have already obtained the required licenses to import and market finished lubricants. Lanka IOC was given a license to set up a Blending Plant and they are in the process of constructing a facility at China Bay.

Bunkering Operations

Supply of bunker fuels to ships, which was handled originally by CPC, was taken over by Lanka Marine Services Ltd in 1993. Lanka Marine Services which was 100% owned by GOSL, continued to operate under CPC management as a profitable business venture.

Fuels supplied to ships are fuel oil, marine diesel and marine gas oil. The tank farm installation at Bloemendhal, which had interconnecting pipelines to Colombo Port, Kolonnawa Installation and the refinery stored the marine fuels. There are two modes of refueling the ships. Products could be supplied to ships berthed at South Jetty of Port directly from shore tanks at Bloemendhal by pipeline transfer. Ships that are anchored in mid harbor are refueled by barges, which were loaded with fuel at South Jetty.

Bunker fuel sales of CPC and subsequently by Lanka Marine Services were relatively small mainly due lack of facilities to improve the business. Virtually all bunker sales were so called inner harbor sales supplied to ships anchored inside the port. Very little outer harbor refueling was done due to lack of ocean going barges. Due to small volume of fuels handled and the monopoly nature of the business, the price of bunker fuels at Colombo harbor was relatively high compared to Singapore and other ports in the region. Colombo being situated on the main sea lane to far east, it was felt that potentially large market could be created by supplying fuel to ships passing Colombo, besides the ships that call over at the Port. It was also noted that if bunker fuels could be provided at prices competitive to those at other regional ports, more ships would call over at Colombo bringing additional revenue to the Port. With these objectives GOSL in 2002 decided to liberalise the bunker industry.

As the first step, it was decided to privatise Lanka Marine Services Ltd and tenders were called for this purpose. After evaluation and negotiations, the bid submitted by John Keels Holdings was accepted, and 90% of the shares of Lanka Marine Services Ltd were transferred to John Keels Group.

During the privatisation, ownership of the tank farm at Bloemendhal and other assets such as barges remained with LMSL/John Keels, while the common facilities used for bunkering were grouped together as Common User Facility with the ownership remaining with SLPA and CPC, who were to jointly maintain this system. Common User Facility consisted of The Dolphin Berth, The South Jetty in Colombo Port and the pipelines between Dolphin Berth and Bloemendhal tanks including interconnecting lines to South Jetty. Along with the privatisation, LMSL entered into an agreement with GOSL/SLPA/CPC relating to the use of Common User Facility.

As the Bunkering business was liberalised, additional licenses were issued to 4 other companies to engage in bunker operations, by the Minister of Power and Energy, on the recommendation of the ESC which was the interim regulator for the petroleum sector. These operators unlike LMSL did not have shore based storage for fuels, but used floating storage to stock their supplies. They refueled ships mid sea using barges both inside and outside harbor.

Shortly after other operators entered bunker business, LMSL and John Keels observed that mode of bunker supply by other operators is in violation of certain provisions of the Common User Facility agreement, and requested revocation of their licenses. LMSL was referring to a clause in the CUF agreement which state that " GOSL/SLPA/CPC shall ensure that all bunker/marine fuels handled and transported within Port of Colombo would be handled and transported using CUF'. If this is implemented bunkering becomes a monopoly of LMSL/John Keels as they are the only party that has shore storage tanks connected to the CUF system. LMS filed action in courts to get other licenses annulled. However, courts ruled that licenses issued to other parties as legally valid and can continue bunkering operations.

Even under private entrepreneurs, the bunker market remains under developed. As Sri Lanka is located on the sea route to Far East, there is a vast potential for supplying bunkers to the ships passing close to Sri Lanka. No attempt so far has been made to tap this market.

Pricing of Petroleum Products

Up to the year 2002, there was no laid down pricing policy with respect to petroleum products. CPC as the sole marketer arbitrarily fixed prices in consultation with the Government. Revisions were always upward and any reductions in international market prices were never passed on to the consumer.

A study on the pricing of petroleum products was conducted by the Asian Development Bank in the year 2001. ADB proposed a formula based on the average Singapore "Platts" posted prices and average exchange rate for the calculation of retail price of petroleum product on a monthly basis. This formula was implemented from 2002 February. The formula is weighed in favour of the marketing company and has hidden profits over and above the net margin indicated.

FOB Singapore price used in the formula is given at the standard temperature, while the products are marketed at the average ambient temperature of about 28°C. From 15°C to 28°C there is a volume gain, which varies from 1% to 1.5% depending on the product. On the volume gain, marketing companies get an extra profit which remains hidden. Price of 90 RON petrol is calculated based on Singapore price for RON 92 petrol which is priced higher. The values used for ocean loss and insurance also are higher than the actual costs.

The formula was revised after the restructuring to include separate profit margins for the storage terminal company CPSTL and the marketing company.

In this current formula, there is storage terminal cost (item 14), which includes the operational cost of the terminal. There is no transparent mechanism how this cost is calculated. By allowing the total operating cost to be passed on to the consumer without proper monitoring, all the inefficiencies in the system are passed on to the consumer. In this format, there is no incentive for the operator to improve efficiency.

Fixing product prices based on a formula is a positive step. The shortcomings in the present formula should be looked into and this highlights once again the need for a sector regulator.

In 1971/1972 Ceylon Petroleum Corporation entered Bunker supply and Aviation refueling business with facilities taken over from oil companies. Both these activities generated large foreign exchange earnings.

APPENDIX I

Pricing Formula For Petroleum Products

(prior to restructuring)

Singapore FOB Price in US $/bbl

+	Freight/loss/insurance in US S/bbl
=	CIF Price in US $/bbl
x	Currency Exchange Rate (Rupees per US Dollar)/litres per bbl (158.99)
=	CIF Price in Rupees/litre (rs/litre)
+	Jetty Pipeline (US$ 3/ton)
+	Stamp Duty (1.2% of CIF incl. bank commission)
=	Landed Cost (a surrogate ex-refinery price) in Rs/litre
+	Customs Duty if appropriate
+	GST (12.5% of CIF +CD + Excise)
+	NSL (6.5% of (CIF+CD) x1.25
+	Excise Duty (where applicable)
=	Tax paid landed cost
+	CPC Finance Charges (fixed amount of 1.75 Rs/l on gasoline and diesel)
+	CPC wholesale costs
+	CPC margin
=	Whole price
+	Marketing/ distribution
+	Dealer Discounts
=	Consumer retail price (Rs/litre)*

* Subject to:
1) minimum increment of 0.25 Rs/l,
2) maximum monthly increment possibly of 2.0 Rs/l,
3) possible stipulated ceiling prices for kerosene, in particular and heavy fuel oils

APPENDIX II

Pricing Formula For Petroleum Products

(After Restructuring)

No	Component	Basis
1	FOB Price	A) The FOB price will be determined as the average of the mean of the daily quotes for the different products as published by PLATTS under heading "MOP Singapore" during the previous month on the Singapore Market. This will be adjusted for premiums/discounts as published be PLATTS. B) Prices shall be calculated to fourth decimal place i.e. by ignoring the fifth decimal place less than 5 and rounding up the fifth decimal place equal to// more than 5 C) Product Specifications * see notes i. Petrol 90 Ron –"Mogas 92 unl" ii Auto Diesel – "Gas oil 0.5% S" now and "Gas Oil 2.55 S" iii. Kerosene – "Kero"
2	Freight	Freight will be assessed over world scale based on average of AFRA, as published by The London Tanker Brokers' Panel Ltd. For MR Size vessel for the available latest month for round trip voyage from load port Singapore to Colombo.
3	Insurance	US$ 0.06/MT – to be reviewed regularly
4	Losses due to evaporation & contamination of products	0.5% of CIF value – to be reviewed regularly.
5	Exchange Rate	At average selling exchange rate of commercial banks as published.
6	**CIF VALUE = (1+2+3+4) x 5**	
7	Jetty and pipeline charges	Actual as charged by SLPA
9	LC Charges	0.2% of CIF value
10	Landed Cost	(6+7+8+9)
11	Customs Duty	As per actual (statutory)
12	Excise Duty	As power actual (statutory)
13	Finance cost of working capital	Value of 50/365 days of (10+11+12) at average month and Prime Lending Rate (PLR) of commercial banks
14	Storage Terminal Cost	Operational cost (inclusive of depreciation) and interest cost on loans
15	**Wholesale Cost = 10+11+12+13+14**	
16	Margin at CUF	Refer Note 5 below
17	Terminal Gate Price	15+16
18	Marketing and Distribution Cost	Rs. 0.40 per litre
19	**Base Retail Price = 17+18**	
20	Profit Margin	5% OF 19
21	Delivered Dealer Price (before TT & VAT)	19=20
22	Provisional Council Tax on Imported Refined Products	As per actual (statutory)
23	Provisional Council Turnover Tax on Dealer	As per actual (statutory)
24	**Retail Price before VAT**	**21+22+23**
25	VAT	As per actual (statutory)
26	Retail Price after VAT	24+25
27	Dealer Margin	1.75% on 26
28	**Maximum Retail Price to Consumer (MRP)**	**26+27**

* Notes

1. Petrol 95 RON – for premium grade 95 RON as defined in Sri Lanka specifications a minimum quality premium of SLR 2/- litre over MRP will be applicable to arrive at the Retail Price.

Auto Diesel – "Gas Oil Reg. 0.5% S", PLATTS quoted FOB Singapore Prices will be applicable until the effective date of implementation of the proposed emission related standards in respect of Auto Diesel and thereafter. "Gas Oil 0.25% S" Price will be applicable. For premium grade as defined in Sri Lanka Specifications "Super Diesel" – Quality Premium of SLR 3/- litre over MRP will be applicable to arrive at the Retail Price.

2. Prices of the products at different regional slabs will be adjusted upward form Colombo price as per the prevailing formula, and the slab income will accrue to the relevant storage Company.

3. Prices will be revised on a monthly basis to reflect changes of Singapore Platts average FOB prices, exchange rates and other variations, subject to a maximum revision (up or down) of Rs. 2/lt.

4. The conversion factor for conversion of barrels to KL shall be 6.2898 barrels/KL. The conversion factor converting barrels to MT (for converting freight) shall be as per PLATTS guide to petroleum specifications.

5. The following fixed margins (approximately 2% of wholesale cost based on June 2003 MOP Singapore prices) will accrue to the CUF.

	Rs. Per Litre
Fuel for power generation (Auto diesel, Naphtha etc)	0.35
Jet Al and Aviation Gas	0.40
Kerosene	0.45
Diesel for industrial and automotive use	0.55
Furnace oil for industrial use and power generation	0.55
Petrol	0.85

6. If and when there is an abnormal change of any parameter all players all players to jointly review in consultation with the Government.

7. No player shall sell products at prices less than 05% of the MRP. However, price differential between RPPs and PPPs as per 1. above will be maintained when providing so as to ensure the Premium Petroleum Products will not be priced below formula process for non premium products.

8. Marketing and distribution cost (listed under 18 of the pricing formula) includes cost of delivery from the depot to the retail dealer.

9. Landed Cost shall be determined as per the definition in items 10 of the formula.

10. MRP shall be determined as per the definition in item 28 of the formula.

OPTIONS FOR SRI LANKA (OIL AND GAS)*

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Introduction

Man needs energy for day to day activities, and over the ages, has depended on primary energy available from biomass, wind and sun to provide these basic energy requirements. Coal and gas were first used by Chinese over 3000 years ago, before oil was discovered and commercially harnessed commencing with the first well drilled in Pennsylvania in the United States in 1854.
As development proceeded and with the advent of the internal combustion engine, the use of petroleum came to prominence. More and more oil fields had to be located and oil extracted to satisfy some of the energy needs.

Sri Lanka being a small country with moderate energy resources of its own and with no proven reserves of fossil fuels, hydro-energy and biomass (mainly fuel wood) are Sri Lanka's only indigenous energy resources. All of the country's fossil fuel needs are imported mainly as crude oil and finished petroleum products, and a very small amount of coal as of today.

To satisfy the growing demand for energy, the option available for a developing country like Sri Lanka is to import its primary energy requirements as petroleum, coal and natural gas/liquefied natural gas (LNG) until such time we could locate some of these resources within our territorial boundaries.

Use of Imported Petroleum in the Past

In the past, the country has imported coal and used as a source of fuel in the railways, in marine transport, industry, and in households (to produce town gas). The use of coal has almost ceased today except for a small amount used in the cement industry. By the turn of the centaury, the country began to import petroleum for lighting and later for motor vehicles, followed by industrial fuels like diesel oil and fuel oil to provide motive power and industrial heat. Today hydro electricity and petroleum are the main sources of primary energy in the country.

The petroleum imports and use in the country as from 1950 is given in Table 1. Between 1990 and 2000 the growth in demand accelerated and the demand for petroleum grew at a rate in excess of 11% per annum on average, while between 2000 and 2005 the growth rate declined to around 8% on average per annum. The decline in growth rate in this decade is partly due to high prices of petroleum. During the decade, growth in demand for transport fuels shifted to gasoline or petrol from auto diesel, while growth in demand for petroleum fuels for power generation shifted from heavy diesel to furnace oils. These are some of the fundamental changes that will affect the future supply options if no ad-hoc changes are made in the near future.

Forecasting Future Demand for Petroleum Products

Forecasting future demand is a difficult task requiring many inputs from a number of agencies and some of the parameters taken into consideration may not behave in the manner expected.

The famous physicist Niels Bohr once said "Prediction is very difficult specially if its about the future".

Forecasting demand for petroleum has become difficult as the uncertainties that exist in respect to the fuel requirements for the power sector. The coal based thermal power plants planned consistently failed to materialize. This

* This paper was presented at the SLEMA Annual Sessions 2007, held in Colombo on 28th July 2007

has meant installing gas turbines based on heavy diesel or diesel plants. In such circumstances, the cost of supply goes up and at times even with a breakdown of one of the links of the supply chain, shortages and disruptions in supply of petroleum can occur resulting in accusations and allegation of inefficiencies.

Table 2 gives actual demand in first half of this decade while in Table 3, the forecast demand computed with the information available for the next 10 years. It is projected based on both historical demand growth patterns and some information available from the power generating sector. In forecasting this demand, it is assumed that there will not be any heavy reliance on distillate diesel fuel for power generation except what has been committed so far. Due to the high price of heavy diesel, thermal generation has shifted to cheaper furnace oils. It is assumed that new power plants would be based on furnace oil in the next 10 years as there is no firm decision on the future of the coal based power plants. Based on these assumptions, the aggregate demand for petroleum products would reach 5.5 million metric tons by 2015. If the coal based plants fail to materialise in the next 3-4 years, further addition of thermal plants based on fuel oil would be inevitable.

What Options has Sri Lanka got in Terms of Oil in the near Future?

The options available for Sri Lanka in the short term are very limited. There is no upstream oil industry in Sri Lanka and consequently there are no oil and gas fields located. Hence what can Sri Lanka do? The option available is to import oil and or gas (natural gas). Right now we have to leave out gas as there are no infrastructure facilities to import gas in whatever form. So we have to continue to import oil either in the form of crude oil or refined products.

a) Importing Crude Oil

We import crude oil from Middle East or the Far East. Getting crude oil from other regions is not very practical. Crude oil imported can be put to limited use only before refining. The capacity of existing refinery is 2.1 million tons per annum while the demand in the country as of 2007 is in excess of 4.1 million tons of products. Therefore, Sri Lanka has a shortfall in capacity and needs to import more than 50% as refined products from the international market. By 2015, our imports of refined products would reach 80% of our requirements if there is no addition to capacity. So what are the options for expanding the refining capacity?

i) Between 1995 and 1997 there were two proposals made to establish export oriented refineries in Sri Lanka and both failed to materialize due to various reasons.

ii) The Ceylon Petroleum Corporation’s own proposal to expand capacity of the Sapugaskanda refinery was finally studied in 1998/1999 and was kept in abeyance due to non-viability of the investment following the Far East economic crisis. The project was reactivated in 2001 when the investment became viable, but the government failed to act. A private sector proposal to invest on a expansion scheme for the refinery did not find favor in 2005. Expanding the capacity is being studied again.

iii) With the change in demand pattern for products in the last two years and the increase in demand for fuel oil, there may be opportunity to phase out the investment if the required product quality can be met for power plants. See Table 3 in Appendix for the expected production from an expanded refinery by doubling the capacity and the different options available. Any hydro-skimming option will need to give way for a conversion facility if demand for fuel oil drop with installation of coal based power plants or gas replaces fuel oil.

Impact of a Future Discovery of Oil and or Gas within Sri Lanka Territory.

Sri Lanka is just on the verge of embarking on a exploration program in the Gulf Mannar where potential hydrocarbon bearing structures have been identified. It is expected that in the next few years, international companies or foreign state entities would explore in the Gulf of Mannar. Exploration is expected to be carried under a Production Sharing concept. One can safely postulate that even if the exploration programs run smoothly without any delays and commercial oil is discovered, oil or gas may not come ashore in the next 5 years.

Then comes the quality of oil that is discovered and whether it is suitable for processing at the local refinery or refineries under construction. Then there will be two options available.

a) To modify the refinery to enable “Mannar crude” to be processed.

b) To sell off the crude and continue to import the crude oil to which the refinery is designed.

What if gas or natural gas is discovered instead of oil? Then obviously gas would come ashore using underwater pipelines, to the West coast of Sri Lanka. Distribution pipelines constructed will distribute to where gas can be utilised. The gas could initially be used in the combined cycle power plants already in place and a minimum of 600 MW capacity will be available by 2012. Next conversions to gas would be the Diesel power plants using fuel oil located close to the west coast and here we would have about 250 MW of capacity available by 2012. Further, the cement plant at Puttlam and other industries along the coast line also can be converted to use gas, and all new thermal power plants would be based on gas. Public transport in the urban areas can be converted to use compressed natural gas (CNG) and with the reduction in the use of liquid petroleum and a positive impact on ambient air in urban areas. In the next stage, fertilizer plants such as ammonia/urea can be established and later a petrochemical industry would also be viable.

Options for Importing Gas either in Gaseous State or as Liquefied Natural Gas (LNG)

a) In the absence of indigenous gas, the option of getting gas in the gaseous state is less likely until exportable surplus is available in neighboring India. India is also looking at the possibility of importing gas from Iran via a pipeline traversing Pakistan, or failing that, from Oman with an undersea pipeline. India has also recently discovered new gas fields off-shore.

(b) Importing LNG is a another option that has been studied to a limited extent. For this purpose, its necessary to establish a receiving terminal with pipeline and berthing for dedicated tankers, storage and re-gasification facility, and a cross-country pipe line to demand centers. Often it is also necessary to tie up with a supplier to ensure that the necessary capacity to produce the gas and liquefaction is available. Sufficient land and adequate water depth near shore for a terminal is a necessity. The transfer pipeline from ship to shore has to be kept as short as possible as it is very costly. The minimum capacity required for a terminal to be economical has been estimated at 1.0 million tons per annum. A proposal has been received for establishing a facility that could handle 2.5 million tons per annum at an estimated cost of around US$400 million. Delivered cost of gas was estimated around US$ 8 per million BTU if the gas was available at US$5 per million BTU from the delivery terminal. The delivered cost of gas to power plants and the price of crude oil will determine viability.

Conclusion

The most probable viable option available for Sri Lanka is to continue importing crude oil from the Middle East and possibly Far East, and refine locally to supply the refined products required for transport, power generation, industry, agriculture and fisheries. If viable, the refining capacity could be expanded to satisfy the demand. If under the proposed offshore exploration program, gas is found off-shore Sri Lanka, most of the existing thermal power plants could be converted to use the available gas and displace naphtha, distillate diesel and furnace oils that are in use in the power plants in operation. Gas can also be used to displace transport fuels used in urban areas. All new thermal power plants would be based on gas. If sufficient gas was available, a viable petrochemical industry would become a reality.

APPENDIX -1

Table-1
PERTROLEUM USE IN THE PAST

In' 000 MT						
Year	**1950**	**1960**	**1970**	**1980**	**1990**	**2000**
Total Consumption	206	525	893	900	1150	3300

Table-2
PETROLEUM PRODUCTS CONSUMTION IN THE FIRST HALF OF THE DECADE

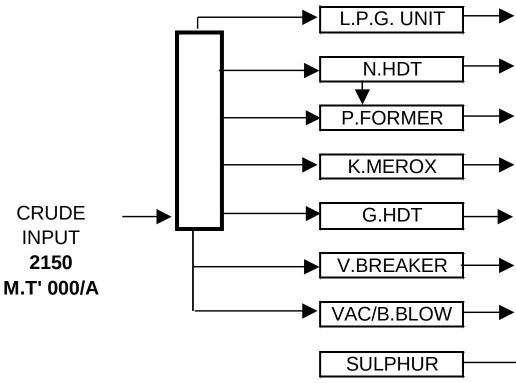
In '000 MT				
Year	**2000**	**2002**	**2004**	**2006**
LPG	115	137	148	152
Petrol	224	285	437	584
Kero/Jet	478	439	504	512
Diesel Transport/Industry	1258	1345	1443	1479
Diesel Power Gen.	431	429	483	269
Naphtha Power Gen	0	56	96	124
Furnace Oil Industry	269	253	207	239
Furnace Oil Power Gen.	467	503	530	733
Total	**3300**	**3452**	**3883**	**4184**

Table-3
PROJECTED FUTURE CONSUMPTION OF PETROLEUM PRODUTS

In ' 000 MT					
Year	**2008**	**2010**	**2012**	**2014**	**2016**
LPG	158	164	171	178	185
Petrol	665	736	828	930	1045
Kero/Jet.	527	542	559	578	590
Diesel Transport/Ind.	1568	1663	1764	1817	1983
Diesel Power Gen	300	300	300	300	300
Naphtha Power Gen.	120	120	120	120	120
Furnace Oil Industry	257	273	289	307	326
Furnace Oil Power Gen.	830	1030	1030	1030	1030
Total	**4218**	**4419**	**4833**	**5065**	**5317**

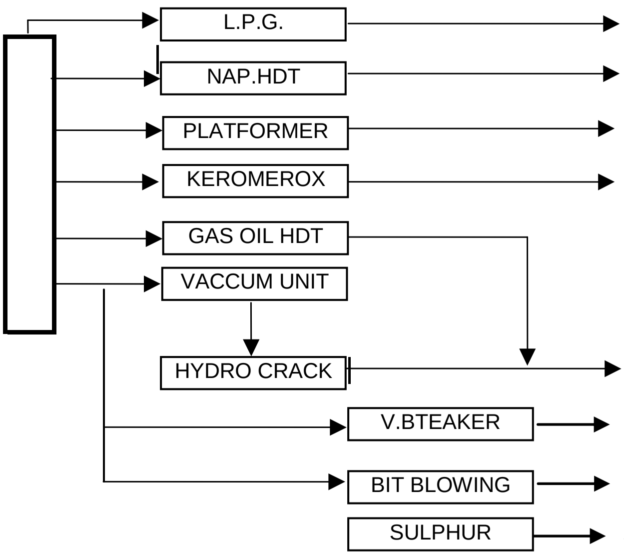
APPENDIX -2

Doubling Capacity With Hydro Skimming Option



	EXISTING HYDRO SKIMMING **OUTPUT M.T' 000/ ANNUM**	*DOUBLING CAPACITY HYDRO SKIMMING WITH MINOR PROCESS CHANGE* **OUTPUT M.T' 000/ ANNUM**	**VOL IN BBLS' 000 ANNUM**
L.P.G	**15**	**60**	664.2
NAPHTHA	**90**	**160**	1449.6
PETROL	**195**	**410**	3427.6
KERO/JET	**355**	**635**	5048.25
A.DIESEL	**560**	**1170**	8541
F.OIL	**765**	**1520**	9880
ASPHALT	**60**	**120**	753.6
SULPHUR		11	44
OUTPUT	**2040**	**4086**	**29808.25**
YIELD	94.88%	95.02%	94.96%
IRANIAN LIGHT CRUDE IN	2150	4300	31390

Doubling Capacity With Hydro Cracking Option



	OUTPUT M.T' 000/ ANNUM	**VOL IN BBLS' 000 ANNUM**
L.P.G	**136**	1505.52
NAPHTHA	**372**	3370.32
PETROL	**487**	4042.1
KERO/JET	**590**	4690.5
A.DIESEL	**1500**	10950
FUEL OIL	**795**	5167.5
ASPHALT	**100**	628
SULPHUR	**42**	168
IRANIAN LIGHT CRUDE IN	**4355**	31791.5
OUTPUT	**4022**	30521.94
YIELD	92.36%	96.01%

SOLAR AIR HEATING SYSTEMS FOR THE INDUSTRY: A NEW APPROACH FOR THEIR DESIGN AND DEVELOPMENT

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Abstract:

Many local industries seem to have the potential to replace a significant fraction of their conventional thermal energy with solar energy from air heating collectors as indicated by studies on tea industry. The few experimental or pilot level solar air-heating systems established in the country have suffered due to inadequate engineering design and defects in their installations. This paper presents a new engineering design approach based on factory built standardized collector cells aimed at achieving better performance and cost effectiveness. Generation of better design data and development of low-cost solar collector cell fabrication methods are needed in order to develop this approach further. The approaches and methodologies suggested here can contribute to the goal of developing the local capacity for utilization of solar energy in the industry

Introduction

Simple technologies have been successfully used world over for many decades to utilize solar energy for air heating applications such as building heating, drying, and chemical process industry. However, no significant utilization of solar air heating is evidenced in Sri Lanka as yet. Our tropical climate with abundant sunshine and a multitude of industries utilizing low to medium grade heat energy provide vast opportunities for the utilization of this benign source of energy. Typical industrial use of hot air in Sri Lanka include; drying/withering of tea, rubber drying, drying of agricultural crops including spices, food drying, curing of ceramic ware, drying of paint work, and drying of timber. Most of these applications require hot air within the temperature range of 35 to 100 C. A study on the tea sector has shown that the technical potential of replacing conventional energy in drying with solar energy is in the range of 30–55 % in most of the tea growing regions (Weeratunga Arachchi, K.). Solar air pre-heating collectors operating at 50% thermal efficiency have been shown to deliver this performance. A study by Laing Design and Development Centre, UK considered a combined solar heat collection and a modified energy efficient tea drying process and concluded that 480m^2 air collector system was adequate in supplying 80% of the heat requirements of a factory processing 800 kg of green leaf per day over 8 hours. A similar potential for conventional energy replacement can be expected from most other industries utilizing low to medium temperature process air.

Solar air heating is known to have been applied in local industries, including tea industry, at experimental or pilot level with a lower degree of success. The largest of these systems known to the author is the 400 m^2 of air pre-heating collectors installed at the tea factory at the low country tea research station at Ratnapura under a SAREC funded project titled “Solar Wood Gasifier Energy in Tea Processing” during 1994–1999 (Ziad Mohamed). It was based on the conventional design consisting of an array of small-area (2m^2) collectors connected in parallel by a network of air ducts. The collectors were also custom-designed for the particular application. The system showed a saving of 25–34% of the fuel oil during the preliminary trials. The capital cost of the system was reported to be high due to the large number of collectors and the associated ductwork. Project investigators suggested that larger collectors and less ductwork would be more economical. This project was expected to demonstrate the technical and economic feasibility of solar air heating systems in tea industry and to encourage similar installations in other industries such as rubber. This objective has not been achieved.

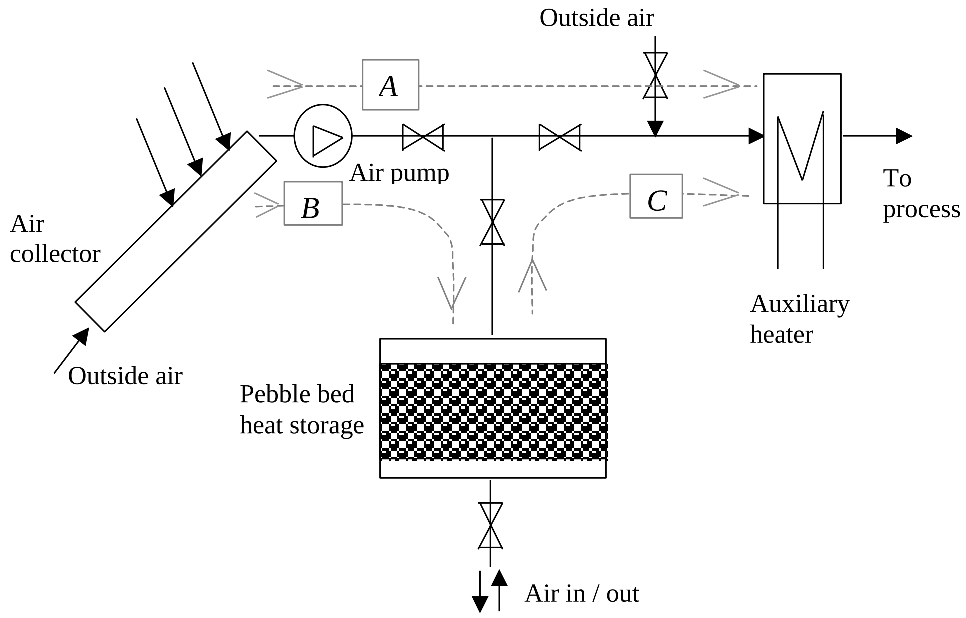
Although the performance of industrial solar air heating systems has not been well documented, one very likely reason for the failure or poor performance of these industrial systems seem to be their inadequate engineering design. Another reason is poor collector fabrication and installation resulting in low reliability (Attalage, R.A.). The present work aims at developing a new methodology for the design of solar air heating systems that would ensure better performance both technically and economically.

Industrial Solar Air Heating Systems (SAHS)

Basic elements of a SAHS are the solar collector, pebble bed storage, auxiliary heater, air pump, and a control mechanism (Figure 1). A majority of potential systems would be in retrofit applications where partial replacement of conventional energy used by existing systems is achieved. Such retrofit systems should be designed to supply hot air at existing process temperatures. The other sector is the new applications where a solar air heating system is included in the design of a new industrial process right from the beginning. Since solar air heating collectors operate more efficiently at lower temperatures, the industrial process itself should be examined in such cases, to see if the temperature of energy delivery could be optimized (Duffie and Beckman).

In retrofit systems, the existing conventional air heater would become the auxiliary heater. This auxiliary heater running on conventional fuel, such as fuel oil, diesel, or fuel wood, would be fitted with a control mechanism so as to maintain a constant temperature of hot air supplied to the process, since the degree of solar preheating would have a variation over the day. In applications that requires heating even outside daylight hours, solar energy storage would be required. Pebble beds are very commonly used for storage of solar energy from air collectors. Air heating collector in Figure 1 always heats outside air and there is no re-circulation of process air back to the air collector. These are known as once-through air collectors or air pre-heating collectors. In this paper, the discussion will be limited to SAHS employing air collectors of this type since a vast majority of potential industrial applications of SAHS in the country would fall into this category.

Figure 1 - General Schematic of Solar Air Heating System



There are three basic modes of operation of these systems. The dashed lines indicate the directions of airflow for each of these modes, *A*, *B*, and *C*.
Mode *A*: Direct delivery of air from the collectors to the process occurs.

Mode *B*: In the absence of process heat loads during daytime, hot air from collectors is diverted to the storage. Heat is stored in the pebble bed.

Mode *C*: Heat stored in the pebble bed is recovered and supplied to the process during nighttime.

In modes A and C, the auxiliary heater would be controlled to keep the temperature of hot air delivery at the required level.

Design of Solar Air Heating Collectors

Solar air collector is the key element in the system. Its design would critically affect the performance of the whole system. The prediction of the performance of an air-heating collector forms the basic approach towards their design. The performance is predicted based on theoretical equations presented in the appendix, which follows the analysis of Niles et.al. and Duffie and Beckman. Back pass type flat plate collectors with a single transparent cover have been considered in the analysis owing to their popular use in industrial applications. Predicted performance depends on the material properties of collector elements, the choice of design solar radiation (*I*), and a few other factors.

Table 1- Solar Collector Design Parameters

Parameter	Value
ρ	1.092 kg/m^3
k	0.0273 W/m.K
μ	1.963 e(-3) Pa.s
C_p	1007. J/kg/C
T_a	30 C
I	700 W/m^2
$(\tau\alpha)$	0.72
U_b	2.0 W/m^2/C
N	1
β	20^o
ε_g	0.88
ε_p	0.95

The term *I* can be taken as the hourly average solar radiation. Since solar radiation varies with time of the day and day of the year in addition to the local weather, selection of a design value for *I* is to be done with caution. *I* is not to be misunderstood as the radiation averaged over a typical day since this value will lead to too low air delivery temperatures. *I* can vary up to about 1000 W/m^2 measured on a horizontal surface at noon on a clear day. A solar air system design handbook, based apparently on European and North American experience, suggests a design radiation value of 600 W/m^2 (S. Robert Hastings and Morck Ove). Being a tropical country with abundant sunshine, solar heating system designs in Sri Lanka may well be based on a radiation value of 700 W/m^2. Parameters used in the prediction of air collector performance in this study, are given in Table 1.

The performance of air heating solar collectors is highly dependent on the airflow rates and air channel dimensions. For instance, the efficiencies of two identical collectors (L = 20 m, B = 5 m) except for the depth of the air channel are compared in Figure 2 at various air-flow rates (values marked against radial chain lines are specific mass flow rates of air in kg/h.m^2). Collectors with the shallow channel depth always exhibit greater efficiencies due to the fact that *Re* is greater and convective heat transfer within the air channel is enhanced. However, this improvement in efficiency is obtained at the expense of greater pressure losses in airflow across the collector. This in turn increases the pumping power requirements. Therefore, in the design of air collectors one has to make a compromise between the improved efficiency and increased cost of pumping air.

The pressure loss in the air channel is given by;

$$\Delta p = \rho g \Delta h = \rho g f \frac{L}{d_h}\frac{V^2}{2g} \quad ; \quad d_h = \frac{2Bd}{(B+d)} \approx 2d$$

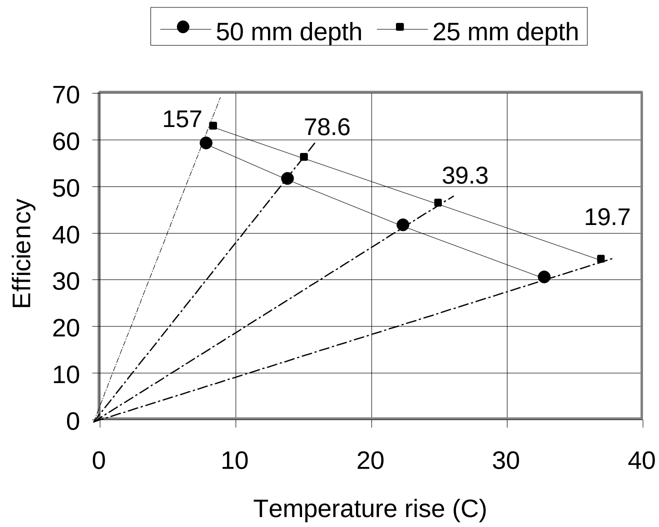
$$f = 0.262\,Re^{-0.2} \quad \text{(Niles et.al.)}$$

Since air velocity $V = \dfrac{\dot{m}}{\rho B d}$,

and *f* is a weak function of *Re* and hence *d* .

$\Delta p \propto (1/d^{2.8}, L)$ for a given air flow rate.

Figure 2 - Comparison of Efficiencies between Collectors of Different Air Channel depths



This means that Δp varies inversely with nearly the cube of air channel depth and proportional to the length. Therefore, sizing of the air collector must consider the pressure loss across the collector and associated fan power.

A judgement has to be made in the design of solar air systems as to what would be a permissible or tolerable pressure loss in air collectors. A handbook on solar air system design suggests, as a rule of thumb for building heating applications, that the pressure drop across each commercial collector of 2 m^2 area must be kept at 8–10 Pa/m^2. This corresponds to a yearly fan energy consumption of less than 4 kWh/m^2 (S. Robert Hastings and Morck Ove).

$$\frac{\text{Fan Power}}{\text{Heat Gain}} = Z\left\{\frac{(\dot{m}/\rho).\Delta P}{\dot{m}C_p\Delta T}\right\} = R$$

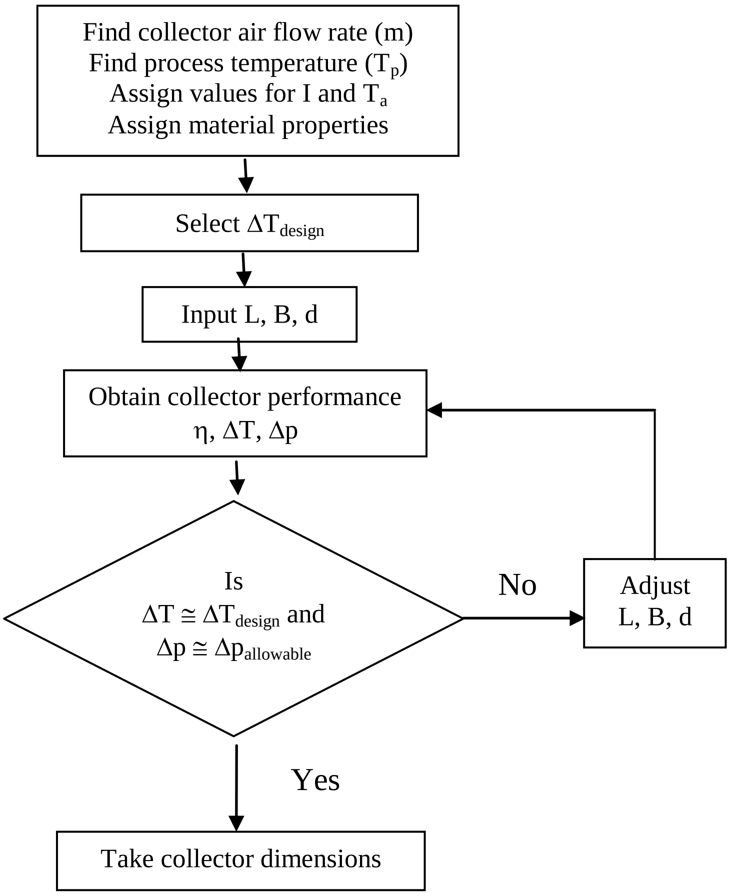
A different approach is suggested here. The allowable collector pressure drop is to be based on the ratio of energy spent for pumping air over the heat energy gained by the collector.

where ΔT is the rise of air temperature across the collector. *Z* is assigned a conservative value of 4.0 in order to account for parasitic pressure losses in air ducts, mechanical efficiency of the fan, and variation of ΔT with solar insolation over an average day. *R* is assigned a somewhat arbitrary value of 2% at this stage. Better values for *Z* and *R* can be assigned at a later stage after adequate local experience with industrial solar air heating systems has been gained. Then,

$\Delta P_{allowable}$ (Pa) = 5 ΔT (C)

This criterion will be taken in the design of air collectors treated in the following sections, to optimize their thermal performance.

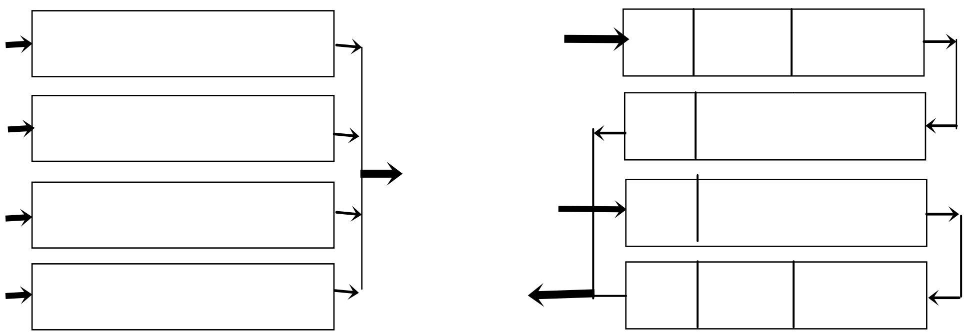
Figure 3 - Industrial Air Heating Collector Sizing Flow Chart



Theoretical equations governing the thermal and hydraulic performance of flat plate collectors can be used in their design for a particular application. The basic design process is outlined in the flow chart in Figure 3. The goal of the design exercise is to determine the dimensions of the solar collector made of selected materials that satisfy the design requirements with regard to the allowable pressure drop ($\Delta P_{allowable}$) and temperature rise (ΔT). This process, however, has not considered the economic performance that forms the primary design criteria of a solar energy system in general (Duffie nad Beckman). Selection of a design value for ΔT must be done so that the outlet temperature will not exceed the process temperature for significant periods of time, leading to energy dumping and hence lowered collector performance. It must also be remembered that the actual incident radiation levels may well exceed the design radiation level of 700 W/m^2 and reach even 1000 W/m^2.

The design engineer can offer many alternative designs that can deliver hot air at the required flow rates and temperatures. These alternatives will concern different collector system configurations – a system made up of a large number of individual small-area collectors connected by a complex network of ducts, or a system made up of a few large-area collectors. The first design alternative based on a large number of small-area collectors is not obviously preferable due to the technical and economic reasons discussed earlier. Systems composed of large-area collectors can be assembled with a number of collector modules connected in parallel combination making an array, or a number of collector modules in parallel combination where each module is in turn made up of a number of smaller collector modules connected in series (Figure 4). Selection of the length and the breadth of large area collectors can be, in most of the cases, constrained by space available for the erection of the collector or the collector construction methods. For instance, if the collector is to be installed on the existing factory roof, the size of the roof will determine the limiting values of collector dimensions. Excessively large breadths may lead to construction flaws and poor flow distribution within the collector. It is, therefore, necessary to keep the breadth of the collector within manageable limits and design for a collector array made up of few collector modules in parallel or series-parallel combination.

Figure 4 - Different Flow Configurations Through Modules of Collector Array



(a) parallel (b) series-parallel

Neglecting the entry length effects in long collector modules, the series-parallel combination essentially works as a parallel combination where the collective thermal performance of modules connected in series is similar to one lengthy module making up the total length.

Table 2 - Various Collector Module Sizes and Configurations Suitable for a Tea Drying Application

Module size L(m)x B(m)x d(mm)	Collector array configuration	Air flow through a collector module (l/s)	Array area (m^2)	Efficiency (%)
150 x 5 x 65	Single module	3700	750	36.2
75 x 10 x 35	Single module	3700	750	36.4
30 x 25 x 15	Single module	3700	750	36.8
75 x 5 x 35	2 parallel modules	1850	750	36.4
30 x 5 x 15	5 parallel modules	740	750	36.8
25 x 3 x 13	10 parallel modules	370	750	36.8
25 x 1 x 13	30 parallel modules	123	750	36.8
20 x 0.75 x 10	50 parallel modules	74	750	37.0

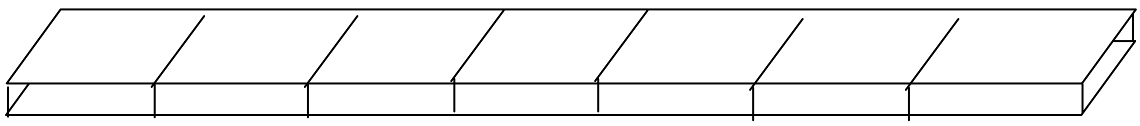
To elaborate on alternative designs, an example of delivering hot air to a tea dryer is considered. The dryer is an endless chain pressure dryer and has a out put capacity of 100 kg of made tea per hour and requires hot air at 90 C. Air flow rate is fixed at 222 m^3/min (3700 l/s) based on recommended operating parameters by Samaraweera. Using the design equation in the appendix, a solar air heating system to heat air by 40 C is designed. The pressure drop across the collector array is set at 200 Pa according to our design criteria. Various collector module sizes and configurations can be considered in this design and Table 2 shows some of the selections. The final choice of the collector configuration will depend on factors such as the space available for erection of collector modules, ducting between the collector array and the dryer, and installation cost.

Air heating collector modules can be fabricated in-situ, at times integrated with the existing structures such as roofs. To ensure the design performance, the collectors have to be;

I. air tight
II. well insulated
III. fitted with water proof covers, and secured to the supports carrying self weight and wind loads.

Building such an air collector could well be a laborious task of fabrication in outdoor conditions, and often at elevated heights, using highly skilled labour. Such fabrications could significantly add to the cost of solar heating systems.

Figure 5 - Flat Plate Collector Module Made up of a Number of Cells Connected in Series



One good alternative to overcome these problems is to assemble collector modules in the field from factory built collector cells (Figure 5) having favourable characteristics such as;

I. light weight enabling easy handling in transport and assembly.
II. made of materials of standard shapes and sizes to avoid wastage
III. manufactured to standard sizes and precise specifications using better techniques and tools
IV. manufactured in large quantities at factory in order to lower the cost.

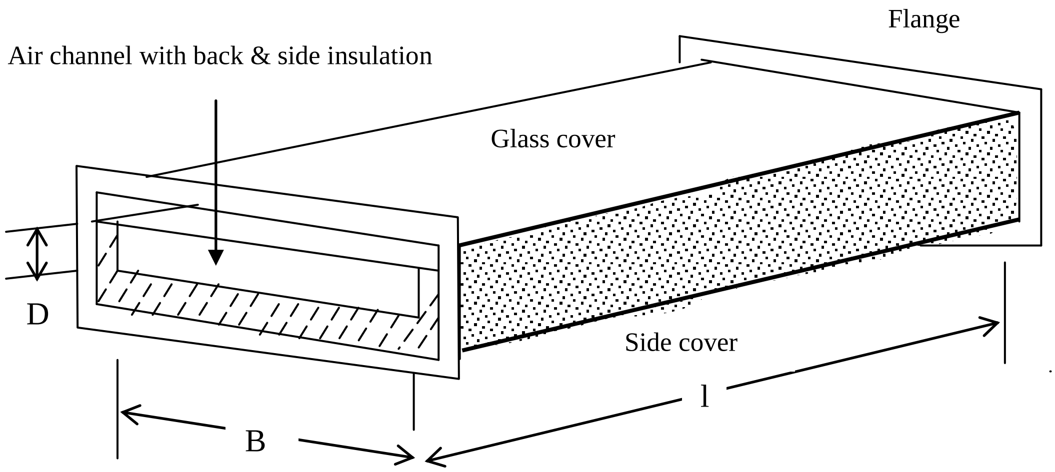
Next section discusses the sizing of a standard collector cell and the performance of collector modules made up of these cells.

Design of SAH Systems Based on Standardized Collector Cells

The major dimensions of the collector cell (Figure 6) are selected such that it gives the favourable characteristics mentioned earlier. Standard sizes of glass panes, iron sheets, insulation materials and other structural materials used in the fabrication of the collector cell are considered in its sizing in order to avoid the wastage of materials. A standard length of l = 2.4 m and breadth of B = 0.85 m has been chosen. The depth of the air channel cannot be set at one standard value because of the wide range of airflow that is encountered in industrial applications. This problem is overcome by manufacturing standardized collector cells that offer a number of channel depths. Based on theoretical performance predictions, a choice of 30 mm, 60 mm, 90 mm, and 120 mm channel depths has been made in order to handle airflows in the range of 260 – 1300 l/s for a range of 10-40 C temperature rise.

These collector cells will then be connected in-situ to form the collector modules of desired lengths. Table 3 indicates the exact airflow for each type of cells at different temperature levels. The design process outlined in Figure 3 is used to obtain the performance of a collector module by setting length L equal to the number of cells times the cell length.

Figure 6 - Geometry of the Standardized Collector Cell of Length *l*



Data in Table 3 can conveniently be used to design solar air collectors without going through the detailed design calculations. First, the required temperature rise is decided. Then, the type and number of cells in each module can be selected form the table. A number of modules have to be connected in parallel combination so that the required airflow rate is obtained. Now the collector array configuration is evaluated with regard to space availability for the array; layout of air ducts and manifolds connecting air collector array with process equipment; and any cost estimates. The best array configuration can be selected, out of the available options, in this manner.

If the previous design example on tea drying application is reconsidered, 15 modules connected in parallel combination, each having 26 cells of D30 type, can deliver 3900 l/s air at 40 C temperature rise. When the airflow is set at 3700 l/s, the delivery temperature will be slightly greater than the design value and the collector array efficiency will also drop slightly. This, however, is well accepted for a design of this nature.

Table 3 - Characteristics of Collector Modules Made up of Different Cell Types for Applications at Various Temperature

Temperature Rise (C) / Δp (Pa)	Number and Type of Cells	Air Flow through Module / a cell (l/s)	Specific Flow Rate (kg/h.m^2)	Efficiency (%)
10 / 50	5 of D30*	315	115	57
	11 of D60*	650		56
	16 of D90*	1000		56
	22 of D120*	1300		55
20 / 100	10 of D30	300	52	52
	22 of D60	600		50
	35 of D90	950		50
	45 of D120	1250		50
30 / 150	17 of D30	275	30	44
	35 of D60	575		44
	55 of D90	875		43
40 / 200	26 of D30	260	19.5	36
	52 of D60	525		36

*type D30 has 30 mm deep air channel, type D60 has 60 mm deep air channel and so on)

Concluding Remarks

The design of solar air heating systems needs careful analysis taking into account technical and economic aspects. This paper presents an analysis of the engineering design procedure aiming at large-area collector modules assembled from factory built standardized collector cells in order to obtain a well-engineered system. Previous local experience indicates that such an approach is likely to lower the cost of industrial scale solar air heating systems while improving the reliability of performance. In addition, this new approach has led to a simple way of sizing a SAH system based on a set of tabulated data such as those shown in Table 3. Actual sizing of the standard collector cells, however, will have to be based on performance measurements as well as economic considerations.

This paper has suggested a solar radiation value of 700 W/m^2 and a design optimization criterion for large-area collectors based on

$$\Delta p = \text{Constant} . \Delta T$$

to be used in the design of SAH systems for industrial use. These criteria have been suggested as an initial step in the development of local design practice for SAH systems for industrial use and the criteria ought to be refined as more local experience is gained with such SAH systems.

A well-planned research and development program is needed now to launch this approach in design of solar industrial air heating systems. First, design data needs to be collected through a series of tests on collector cells made of various locally available materials. Such tests will reveal the real collector performance in relation to pressure losses and efficiencies. Fabrication methods for collector cells need to be developed as well, taking cost factors into consideration. Finally, a pilot-scale industrial solar heating system assembled from such standardized air collector cells, needs to be established.

Such experience is needed, if expanded use of solar energy resource for the industry is to be achieved in the future.

There exists local expertise and skills that can be well utilized for the design, fabrication, and installation of solar air heating systems- a feature that makes the solar air heating technology a most favorable one for developing countries. This expertise has to be pooled and developed through local research, development, training, and pilot scale projects.

Nomenclature

A_c - area of the collector plane receiving insolation (m^2) = L . B
B - width of collector (m)
C_p - specific heat capacity of air (J/kg/C)
F_o - heat removal factor referred to outlet temperature (-)
F' - collector efficiency factor
h_1 - coefficient of convective heat transfer from absorber to air stream ($W/m^2/C$)
I - incident solar radiation normal to the collector plane (W/m^2)
L - length of collector (m)
m - mass flow rate of air through the collector (kg/s)
T_o - outlet air temperature (C)
T_a - ambient air temperature (C)
U_l - overall coefficient of heat loss from heating fluid (air) to surrounding ($W/m^2/C$)
$U_l = U_t + U_b$
U_t - coefficient of top heat loss ($W/m^2/C$)
U_b - coefficient of bottom heat loss ($W/m^2/C$)
η - heat collection efficiency / collector efficiency (-)
$(\tau\alpha)$- combined optical efficiency of transparent cover and absorber surface (approximately solar transmittivity through transparent cover times solar absorptivity of absorber surface) (-)

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APPENDIX I

Theoretical Equations Governing Collector Performance

Theoretical equations that govern the performance of flat plate type collectors are presented in this section.

Figure A1: Schematic of Solar Air-Preheating Collector

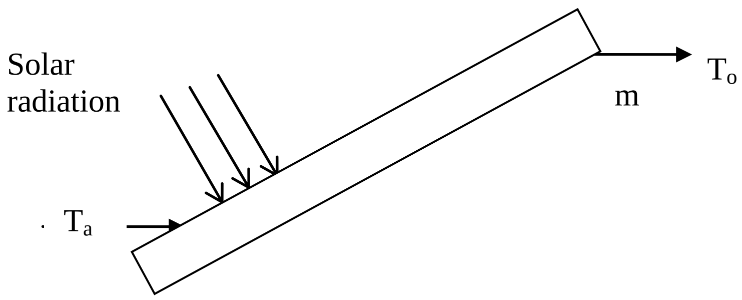
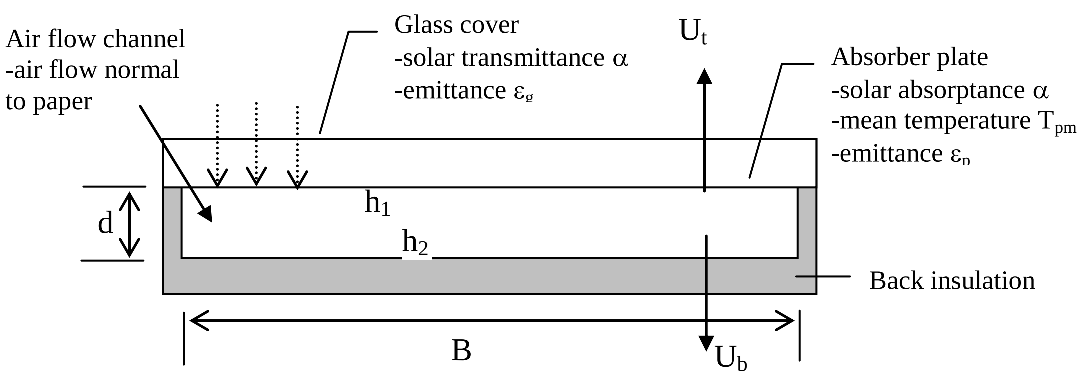


Figure A2: Cross-Section of Solar Flat Plate Collector



Following the analysis of Niles et.al. and Duffie and Beckman, the performance of a solar air-heating collector (Figures A1 and A2) can be given by;

$$\eta = \frac{\dot{m} C_p (T_o - T_a)}{A_c I} = F_o(\tau\alpha) - F_o U_l \frac{(T_o - T_a)}{I} = F_R(\tau\alpha) - F_R U_l \frac{(T_i - T_a)}{I}$$

$$F_o = \gamma\left\{e^{F'/\gamma} - 1\right\} \;;\; F_R = \gamma\left\{1 - e^{-F'/\gamma}\right\} \;;\; \gamma = \frac{\dot{m} C_p}{A_c U_l}$$

$$F' = \frac{1}{1 + \dfrac{U_l}{h_1 + \dfrac{1}{1/h_2 + 1/h_r}}}$$

$$U_l = U_t + U_s$$

U_t can be accurately estimated from correlations such as Klein's (Duffie and Beckman).
U_t, in this case, depends on parameters such as mean collector plate temperature (T_{pm}), number of glass covers (N), collector slope (β), emissivities of glass and collector plate (ε_g and ε_p), ambient temperature, and wind heat transfer coefficient (h_w).

h_1 has been estimated by Niles et.al. using Reynolds analogy with an experimentally determined friction factor based on measurements on 70 feet and 140 feet long collectors.

$$Nu = 0.033\, Re^{0.8}\; Pr^{1/3}$$

$$Re = \frac{2\dot{m}}{\mu(B + d)}$$

h_2 has been assumed equal to h_1.

$$h_r = \frac{4\sigma T_{pm}^3}{2/\varepsilon_p - 1}$$ - coefficient of radiation heat transfer between absorber plate and bottom of air channel ($W/m^2/C$)

When the collector dimensions and material properties, environmental conditions (I and T_a), and airflow rates are specified, above equations can be used to predict the collector efficiency. U_t has to be estimated in an iterative manner starting with a reasonable value for T_{pm} and iterating to meet the condition:

$$T_{pm} = T_a + \eta I\left(\frac{1 - F_R}{F_R U_l}\right)$$

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Digital Thermometer	1	3,000	250
Laser Sighting Infrared Thermometer	1	3,000	750
Data Logger - Grant & Exel	3	12,000	750
Thermo anemometer - Vane type	2	10,500	500
Thermo anemometer - Hot wire type	2	10,500	500
Ultrasonic Doppler flow Meter	1	18,750	1,000
Combustion Analyzer	1	18,750	2,500
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Energy Audit Training Course 2007

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