Green Concept in Engineering Practice

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***Abstract* – In recent time, becoming green is not only a matter of compliance with regulations, however it is a matter of responding to the expectations and demands of our world, country, community, stockholders, customers, employees and competitors. These matters create tremendous pressure for companies to carry out their activities in a more environmental friendly.**

Being green requires the best engineering minds and commitment from the entire organization. Engineering is all about practicality finding solutions to improve the conditions. Excellent understanding of the fundamental engineering is a key to helping industrial activities to become greener and the engineers are in an ideal position to contribute in these activities, in term of development and implementation of technologically sound, as well as cost-effective solutions.

Green initiatives create big business opportunities in the order of trillions of dollars for innovative companies and engineers, in this decade. These business activities are started from research and development, plant design, plant construction and plant operation stage. This paper presents some ideas on how to implement the green concept in engineering activities. The case studies application of green engineering in refinery crude preheat train and cement plant waste heat recovery generation are also presented.

***Keywords* – Green, Engineering, Practice.**

INTRODUCTION

Being green is taking care about sustainablity for the planet and it is not only a compliance matter with regulations but a matter relate to the expectations and demands of community, customers, competitors, employees, and stockholders.

Green practices are frequently considered unaffordable or too expensive, prompting some industries to do just what is required to fulfill the minimum legal requirements. This mindset is obsolete. Today, it is well known that green practices and economic profits have close related. Innovative teams and technical knowledge are required to capitalize on the opportunities to link profitability with environmentally related activities.

It’s commonly acknowledged that improvements such as energy consumption and raw material reduction, waste production minimization and process yields maximization are crucial to increase plant economic and profitability.

There are huge opportunities for technically strong and innovative engineers to bring their knowledge and expertise to allow in green activities, in engineering roles start from Resesearch and Development (R&D), process design and operation. Three key driver for green activities are planet, people and profits.

Nevertheless, setting a goal of zero personal injuries, zero accidents and zero process safety incidents are concerned for some other metrics, incorporate with emissions and other waste streams [1].

This paper will presents some ideas on how to implement the green concept in engineering activities, engineering stage, required tools to achieve green and case study in green engineering.

GREEN ACTIVITIES STAGE

Green activities could be performed for new or existing plant, grass root or retrofit. The activites could be done by performing the one or all stages as follow:

A. Research & Development Stage

Green Research and Development (R&D) deals with making sure that green considerations are taken into account during R&D work. There are two focus of R&D for green, the use of more direct chemistry routes can reduce the number of intermediate stages required and developing innovative processes and products. The ideas related to R&D for green as follow:

- Perform practical solutions that have a large impact to society, ie. air pollution, carbon capture and storage, CO_2 emissions, renewable energy, water supply, food production, and economic mass production of vaccines and drugs
- Develop the new processes that provide higher yields, reduced raw material usage, reduced waste and vent streams, reduced energy consumption, minimized environmental impact, etc.
- Develop safety process system that utilize safe raw materials or intermediates and operate at lower temperatures and/or pressures, etc
- Consider biotechnology [2, 3]
- Develop new biodegradable plastics and develop processes for the commercially viable production of them [1]
- Consider green feeds by find out the products or energy that can be made from green materials and develop processes that use renewable raw materials
- Improved catalyst systems to increase efficiency, reduce byproducts, etc. [4]
- Consider others technology options to reduce process steps
- Consider different process scenarios
- Consider material recycles
- Consider membrane-technology as an alternative to distillation and other energy-intensive separation techniques
- Consider environmental impact in solvents selection and if posibble, replace organic solvents with water [1]

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B. Plant design stage

Some ideas on how to be green in this stage will be pointed as follows:

- Apply the process engineering principles and innovative approach to design the plant, in order increase yields, reduced waste, safer operating conditions, reduced energy and utilities consumption
- Apply inherent safety principles, utilize environment friendly materials, reduce inventories, control of the process conditions, etc
- Find out the most effective processes to accomplish the final result
- Reuse waste streams
- Consider Advanced Process Control (APC) techniques to reduced energy consumption or to increased yields and quality control.
- Consider process intensification to maximize throughput and minimize a unit's plot space
- Perform state of art heat-integration studies by using the most advanced software available in the market.
- Reduce waste by design instead of designing for waste treatment
- Fully understand risks associated with the process technologies
- Consider utilizing more efficientt processes and equipment, for example use of highly efficient heat exchangers, boilers, etc)
- Consider high performance tray and packing and trays to improve distillation, liquid-liquid extraction, scrubbing and others mass transfer operations
- Minimize or remove hazardous materials that are harmful to the people or the environment
- Consider variable-speed drives to minimize energy consumption in motors.
- Consider the use of CO2 streams, either as an inert gas in the process or by binding it in the products
- Utilize divided wall columns and reactive distillation
- Consider fuel gas recovery and recompression in flare systems
- Select adequate flowmeters accuracy to ensure that no waste or inefficiencies are created because of improper flowrates measurement
- Design plants taking into consideration potential changes to product or raw material in the future (plant flexibility)
- Consider automated blowdown for boiler, cooling towers
- Consider fouling in heat and mass transfer equipment design
- Use of local materials of construction [1]

C. Plant operation stage

Some ideas on how to be green in plant operation stage are:

- Continuously find out the opportunities to obtain competitive advantages in terms of reduced waste, reduced energy, reduced utilities consumption, higher yields, lower temperatures, reduced reliance on dangerous raw materials or intermediates, etc.
- Operate the plant in optimum parameters. This may sound simple but it is quite important from environmental viewpoints and profitability that it is not always an easy task
- Always find out the opportunities to reduce, reuse and recycle material and energy. First reduce raw materials and energy consumption and waste, reuse or recycle off specification products and excess energy. If reuse or recycle is not practical, consider combine the excess energy with other energy sources and treating any off specification products to a lower value material instead of sending it to waste treatment
- Take steps to prevent waste formation as early as possible instead of relying on waste treatment
- Find uses for byproducts
- Think outside of the box and challenge the traditional mentality
- Develop, implement and analysis the relevant metrics, such as emissions and Btu (or Kcal) per ton of product
- Build a green culture in which safety and environmental stewardship are top priorities and create stretch goals such as zero personal injuries, zero accidents and zero process safety incidents
- Measure, track and minimize emissions of GHGs, Volatile Organic Compounds (VOC) and regulated substances
- In order to minimize risks, costs and emissions, inventories level of raw materials, intermediates and final products should be minimized
- Fully understand the risks and previous accidents associated with the utilized technology and operate accordingly, hence the operator should be trained well.
- When downsizing, make sure that the remaining employees still have adequate knowledge of the technologies, the processes and understand how to minimize risk and emissions
- Properly inspection of equipment and piping insulation to achive maintain energy efficiency
- Repair steam and utility leaks and replace deficient steam traps and flash tanks [2]
- Maintain or replace dirty disposable filters as required to avoid unnecessary and costly pressure drop
- Properly maintain and calibrate flowmeters hence that no waste or inefficiencies are produced as a result of improper flowrates measurement
- Optimize fuel gas to flares and furnaces by controling air to fuel ratio.
- Look for opportunities to reuse water to minimize waste and flow to the sea.
- Measure and minimize process oxygen demand of waste water
- Optimize compressed-air systems to minimize energy consumption [5]

Use local materials (usually the distant less than radius 1000 km for raw materials and spare parts) to minimize the environmental impact due to excessive transportation.

REQUIRED TOOLS

In order to achive green, the following tools are useful in assessing the plant and evaluate the options that support green-engineering goals. The required tools are as follows:

A. Steady-state simulation

This simulator could be utilized to simulate and accurately analize of mass and energy balances, offline and online energy optimization, compare processes integration and energy consumption, find ways to recycle waste streams, cogeneration, combined heat and power and integrated gasification combined.

B. Dynamic-process simulation

Dynamic response of equipment and control systems could be simulated and analyzed using this software. Configuration of process control strategy and controller tuning that provide more stabilility, energy safe and reliable could be simulated using dynamic process simulation.

C. Advanced process controls

Off line optimization will set the setpoint to achieve maximal yield, minimum quality variation and maximal energy saving. Multivariable control and on line optimization help run the plants at stable and optimal conditions, the stable plants are more energy efficient and more safe.

D. Pinch analysis

Optimization of utilities usage by matching heating and cooling loads of strems ie. steam, cooling water, firing, refrigreation and jeat integration could be perform by considering this method.

E. Separations design

Synthesis of separation equipment could be arranged for new separation or improving existing schemes. It will help to reduce the number of columns in complex separations trains amd energy consumption reduction.

F. Detailed heat exchanger design tools

Sizing, rating and simulation of a heat exchangers can be performed using mechanical software. The dimension, geometry, fluid mechanical, heat transfer, fouling and overal heat transfer coeficient of a heat exchanger are optimized. It include minimizing capital cost of heat-exchanger design. Hence, detailed exchanger performance analysis combined with simulation can improve estimation of the effect of heat-exchanger fouling on energy efficiency.

G. Cost-estimation software

Estimate costs as early as possible in the project will provide the energy efficiency features or saving and reduce investment cost. It is make easier for engineers to do process design in parallel with cost estimation of process alternatives.

H. Computational Fluid Dynamics (CFD)

Analysis of flow patterns, pressure and temperature distribution inside vessels, and other equipments. Better mixing and flow distribution can allow higher heat transfer from hotter process to cooling systems.

CASE STUDY

During conceptual stage, the opportunity to increase energy efficiency is highest. Typically about 98% of operating cost and 80% of capital cost are determined during Front End Engineering Design (FEED). Steady state simulation, pinch analysis tools, and others conceptual design software are very useful during this stage.

In this stage, should be continuously looking for the opportunity to utilize low energy process technology such as adsorption, membrane separators and pervaporation [6]. Identify the best location for a new plant. Use supply chain technologies and services to identify locations that reduce transportation costs and inventories.

Safety and health are more important than profitability. Consider designs that are safer for workers and environmentally benign even if slightly less profitable. Safety and environmental responsibility are justifications for longer pay-back periods; you will save on insurance and avoid fines

Balance the tradeoff between capital and energy costs. Capital is spent once, but you will pay for energy over and over again with near zero chance its cost will decrease in the future. However for existing plant, assess the energy efficiency of your plants and compare it to your industry average and to available technologies first. Train the operators to know the variables that influence energy efficiency. Process training and training simulators are suitable tools for this purpose.

Learn all aspects of the plant process. If the engineers can't run or model your plant process theirself, the engineers probably don't understand it, in which case they should rely on others parties that can provide advise on energy improvements and related technologies.

Seek technologies and knowledge from other industries. Partners from other industries often can help to identify efficiency solutions that it is applicable to your process and consider revamping or retiring old plants, estimate recoverable energy waste, and identify current and future costs.

Also, consider using waste heat from your neighbors, such as power plants, cement plant, refinery, etc. For indirect heating consider to utilize Combined Heat and Power (CHP). CHP delivers steam and electricity for essentially the same fuel cost as steam alone. Although additional capital cost is required, CHP projects typically payback period quickly.

In order to achieve the goal, operation and maintenance should be support with sufficient technologies. Advanced process controls and online optimization are proven technologies that can help save large quantities of energy and raw materials Perform complex-wide optimization because, optimization of individual systems seldom equals a more broadly based analysis of the plant.

Maintenance heat transfer equipment in clean conditions will keep the equipment efficiency in certain conditions. Especially for heat exchangers, it will make the facilities more efficient. Hence, optimization of heat exchanger cleaning schedule is required.

A. Fouling Mitigation in Refinery Crude Preheat Train

Chemical processes convert one or more chemicals or chemical compounds into more valuable products. Energy plays a major role in all chemical processes and contributes significantly to the processing costs. The data on specific energy consumption for some of the major chemical products are shown in Table 1 [7].

Chemical industries constantly strive to reduce the specific energy consumption to a lower level and thereby increase the profit margin and also reduce carbon dioxide emission. Increasing energy cost is also a major concern for the chemical industries. For example, the crude oil price has risen from USD 30/bbl in the year 2000 to USD 100/bbl or above in ten years [8].

Improved process technologies, process operation and heat recovery through heat integration are some of the approaches employed by the chemical industries to reduce the energy consumption. Heat integration involves the use of a network of heat exchangers whereby the heat in the product or intermediate streams is recovered into the feed streams. This approach reduces the heat loss through the product streams while it also reduces the energy required to heat the feed streams.

Heat integration can be applied in heat exchanger networks, reactors, distillation columns, evaporators and dryer, etc., [9]. For example, heat integration study to investigate improving energy efficiency between Crude Distillation Unit (CDU) and Residue Cracking Unit (RCU) was preformed [10]. The results showed that the heat transferred from RCU to CDU reduced the CDU requirements by 40% for a new or grass roots design. RCU retrofit designs were developed to increase steam generation by up to 35% and in line with targeting estimates would appear to have economic potential.

Unfortunately, fouling in heat exchangers is an undesirable process that reduces the realization of the maximum benefits of heat integration. Fouling is the accumulation of unwanted deposits on the surfaces of heat exchangers that represents a resistance to the transfer of heat and, therefore, reduces the efficiency of the particular heat exchanger. The foulant may be crystalline, biological material, products of chemical reactions including corrosion, or particulate matter [11, 12]. The character of the deposit depends on the fluid (liquid or gas) passing through the heat exchanger. The pressure drop across the fouled heat exchanger units increases due to the reduction in the flow area and consequently increases the pumping costs [13].

Fouling occurs in many industrial processes. Several studies have been reported in the literature on fouling in industries such as petrochemical industry [14], dairy plants [15], biomass boilers [16], etc. Optimization of cleaning scheduling in heat exchanger networks subject to fouling in sugar industry has been studied [17]. Macchietto et al. reported that until now, the problem of fouling in crude oil preheat trains still remains unsolved [18.

Crude Preheat Train (CPT) in petroleum refinery represents one of the major heat integration units. In a CPT, crude oil is heated from ambient temperature to about 230 ^{o}C before entering the furnace. The heating mediums in the CPT are the products and pump-around streams from the CDU. The CPT recovers about 70% heat from the products and serves as a product cooler. Without the CPT, 2-3% of product would be used to heat up the crude in the furnace, as shown in Figure 1.

Engineering Sciences Data Unit (ESDU) reported that fouling in CPT is a very serious problem [19]. This problem results in additional energy consumption and affects the plant economy in billions of dollars per annum. The two main impacts of fouling on preheat train operation are (i) reduced heat recovery and (ii) increased pressure drop. For a processing unit of 100,000 bbl/day, a drop in Coil Inlet Temperature (CIT) due to the fouling by 1 K resulted in approximately ₤ 25,000 of additional fuel cost and 750 te of additional carbon dioxide each year [20]. On both economic and environmental basis, there are great motivations to minimize fouling while maximizing heat recovery in the heat exchanger networks.

Increased pressure drops result in reducing throughput in the refinery. It often becomes the most significant cost of fouling in most refineries. For a refinery with a capacity of 100,000 bbl/day and assuming a marginal lost production of £1.2/bbl, every 10% throughput reduction would cost £12,000 per day [20, 21]. In many refinery operations, the pressure drop problem can be more severe [22]. In the USA, fouling in crude distillation units costs went up to US$ 1.3 billion in 1995 [23]. Fouling cannot be avoided, yet it can be mitigated. Therefore, effective fouling mitigation techniques are important [13].

Fouling mitigation techniques include (i) addition of antifoulant chemicals, (ii) design of more efficient heat exchangers and (iii) periodic cleaning of heat exchangers. Each fouling mitigation technique has its own drawbacks. Adding antifoulant increases operating cost. Successful applications of this method have been reported in literature and the annual cost attributable to fouling has been reduced by almost 50%, even by taking into account the cost of the antifoulants [24].

It has also been reported that the use of an antifoulant reduced the decline of the heat-exchanger performance [25]. However, an analysis on the effects of fouling on the overall performance of individual preheat-train heat exchangers using antifoulant chemicals found that two of the commercial antifoulants used were ineffective [26]. Thus, selection of suitable antifoulants is needed which is indeed a very difficult task.

Better design of heat exchangers such as improvements on the mechanical design by designing proper tube and baffles arrangement was able to reduce the fouling tendency [27, 28]. Generally, the designer take into account the industry standard TEMA fouling factors by which heat-transfer surface area is added to make up the lost performance due to fouling. HTRI and TEMA [29] estimated that 11% to 67% more heat-transfer surface area is added in the heat exchangers to compensate for the effects of fouling. Garrett and Price [27] estimated that an additional heat-transfer surface area of 30–40% adds around 25% to the equipment price. Although, retrofitting with more efficient heat exchangers and installing redundant heat exchangers can overcome the problem of fouling, the capital cost of the HEN increases [28, 30].

The other alternative is to perform periodic cleaning of the fouled heat exchangers. Cleaning of heat exchangers involves additional expenditure and possibly, shutting down the plant resulting in the loss of production. Less frequent heat exchanger cleanings may lead to higher costs due to increase in the heat loss and added pressure drop.

The heat-recovery performance of heat exchangers reduces due to fouling, which results in increased heat duty requirement in the furnace. This also raises fuel costs and increases CO_2 emissions from the fired heater. In a refinery with high fouling rate, the loss of heat-recovery performance can require up to 10–15% higher furnace duty [22]. The increase in CO_2 emissions means that a refinery has to pay for more CO_2credits. A CO_2credit is valued at around US$ 20/ton. Using a furnace-fuel cost of US$ 40/bbl, the emission cost ends up at around 25% of the increased fuel cost. In addition, exceeding the CO_2 limits can bring to additional penalties of EUR 100/ton of non-credited CO_2 emitted [20].

It is shown that around 1–5% of the energy consumed by the industrial sector is used to pay for excess fuel burnt and additional electricity consumption due to fouling [27]. Therefore, fouling can cost a refinery up to 5–10% of their production capacity. Conversely, higher costs would be incurred when the heat exchanger is cleaned too frequently. Consequently, an optimization of cleaning schedule is important, to determine an optimal cleaning interval for each heat exchanger in a HEN. The results showed that efficiency of CPT 23% increased which can be translated in IDR 14.1 Billion of fuel saving [31].

B. Waste Heat Recovery Generation (WHRG) in Cement Plant

The cement industry is one of the most energy intensive industries. Basically, in modern portland cement processing consist of quarry, raw meal preparation, preheating of raw meal, kiln, clinker cooling, grinding, storage and dispatch. In preheater tower chemical reaction starts with the decomposition of calcium carbonate ($CaCO_3$) at around 900°C to leave calcium oxide (CaO, lime) and release CO_2; this process is called calcination.

Commonly, in this process, fossil fuels such as coal, petcoke and natural gas is burnt to get the required thermal energy consumption [32]. Cement production plant requires approximately 1.7 tons of limestone as major raw materials per ton of produced clinker and 3.2 to 6.3 GJ of energy consumption [33, 34]. Cost of energy is about 60% of the production costs.

At the end of this process, 20 to 50% of the consumed energy is lost as waste heat that contained in the flow of hot gases, solids and liquids, as product or by product stream. An alternative approach to improve energy efficiency is to recover the waste heat. In some cases, such as industrial furnaces, the efficiency increased about 10% - 50% by utilization of waste heat energy recovery. Regarding to green engineering purpose the study of heat recovery in cement plant is performed as shown in Figure 2.

The results show that a cement plant in Tuban could produced 28 MW electricity in dry season and 20 MW in rainy season. In the other hand, implementation of WHRG resulted in the fuel savings that could be represented as reduction of CO_2 emissions. Hence, for emissions reductions due to the utilization of WHRG is about 20 MW is 14 MT CO_2 per year [35].

CONCLUSION

Some ideas on how to implement the green concept in engineering activities, engineering stage, required tools to achieve green and case study in green engineering have been presented in this paper. In two case study have been shown that application green engineering at design stage of WHRG in cement plant and retrofitting existing CPT in refinery and optimization of cleaning schedule provide improvment in economical and environment result.

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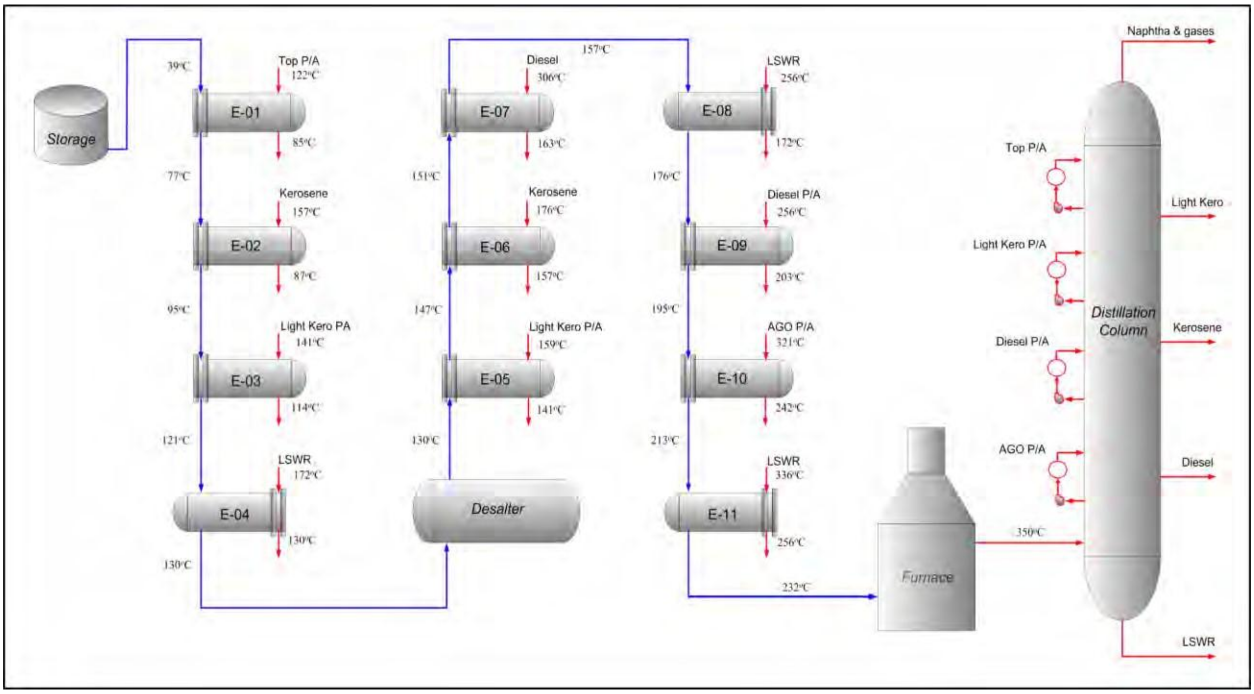

Figure 1. The schematic diagram of the CPT

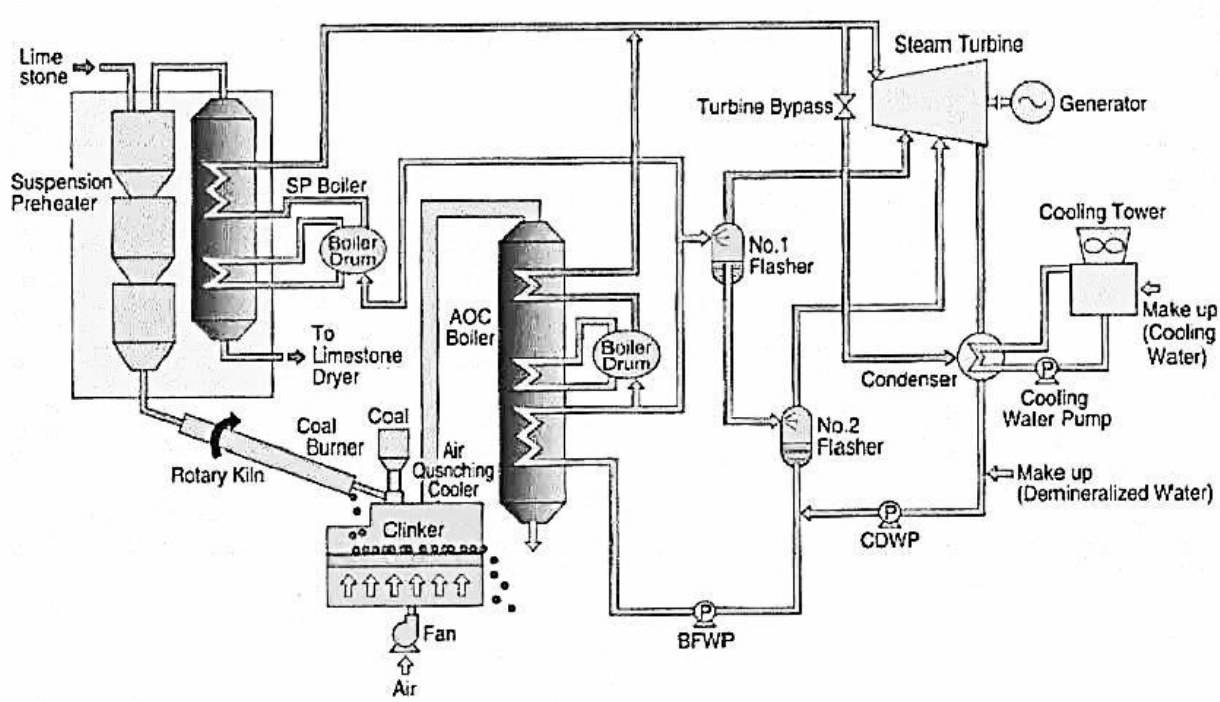

Figure 2. PFD of SP and AQC Boiler in WHRG of Cement Plant

Table 1. Estimated energy consumption for major chemical products

Product name	Volume	Feedstock	Heat	Steam	Energy use including electricity
	ktonnes/yr	GJ/tonne	GJ/tonne	GJ/tonne	GJ/tonne
Benzene steam cracking	14,680	42.60	20.07	7.01	69.68
Ethylene	103,283	47.20	12.80		60.00
Methanol	34,668	20.00		8.50	28.50
Propylene	42,928	46.70	13.30		60.00
Polyethylene, high density	29,969			1.40	1.40
Polypropylene	38,214			1.40	1.40
Polyvinyl chloride	30,042			2.20	2.20
Ammonia	140,000	21.00	7.00		28.00
Sodium Hydroxide& Chlorine	45,000		0.60		0.60