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THE ENERGY STRUCTURE AND INNOVATIVE ENERGY RECOVERY METHODS OF A TYPICAL CHINESE PULP MILL



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Summary :

The pulp and paper industry is a big energy consumer in China. This paper studies the current energy structure and recovery status of the largest pulp mill in China. This paper aims to analyze how the mill reduces the fossil fuel by technological innovations. First, the paper describes the energy structure of the pulp mill from beginning to end; then, the energy saving potential is provided. The results indicate that although the mill has advanced new technologies in the pulping line, there is still some need for improvement in many aspects. Secondly, the paper introduces new energy saving technologies to the pulp mill such as a pulp and paper board dryer section heat recovery integration system and hydrogen burning in the lime kiln. Some of the technologies are only used in this mill while others are widely used in the pulp industry. New technologies also bring great benefits to the mill, and a total of more than 52000 tons of standard coal is saved.

Keywords: *Pulp Mill, Energy Structure, Innovative technology, Heat recovery integration, Hydrogen burning*

1. INTRODUCTION

1.1 Introduction of research on energy consumption in pulp and paper industry

The pulp and paper industry is a very energy intensive industry, especially in China; this industry accounts for2% of the total energy consumption of Chinese industry. As the world's energy problems become more and more serious, the reduction of energy consumption in industries becomes more and more important. The Chinese national policy for papermaking industry development required that by year 2015, the energy intensity per unit production to meet 1.10 tce (tons of standard coal equivalent), a major improvement from the 1.38 tce in 2005. Keeping up with the national standards is a new challenge for the pulp and papermaking workers. Improvement in the energy efficiency of the plant and saving in energy without adversely affecting the product quality is very important to the pulp and paper industry(1).

In order to save energy, first, we should know where the energy comes from and how the energy is used. A study by Chen et al. provides a new energy flow analysis and strategy based on the Taiwanese pulp and paper industry(2), and another, similar paper has been published byHong et al(3). Utlu and Kincay assess the pulp and paper mill through both energy and exergy analyses(4).The primary objective of all energy flow analysis is to identify the energy conservation potential. Energy flow analysis results can serve as benchmarks for current pulp and paper making operations(5,6).Process integration techniques are always used for energy system modeling and analysis in Kraft pulp and paper mills(7).In many pulp and paper mills, technologies for energy recovery or reuse have been well developed, allowing excellent economy of operation. Reusing the secondary heat in pulp mills is a good way to improve energy efficiency. The utilization of low-temperature secondary heat in the drying process may reduce the need for fuels and primary energy use in the mill (8).

Many researchers have done extensive work in optimizing the heat recovery system of the paper machine dryer section(9,10). New models and methods are also described and implemented in different research articles.

One method of improving energy efficiency of a plant is to find new clean fuel sources to use in place of fossil fuels; hydrogen is a good choice(11).Hydrogen is produced in different ways, such as in chemical plant or through the stand-alone production of gasified black liquor from gasified biomass(12). In pulp mills, chip fines, screen rejects, and other solid wastes, which contain lots of wood fiber, are also a source of good fuel(13).Jesús and de Alda focus on the feasibility of recycling pulp and paper mill sludge in the paper and board industries(14). Žarković et al. pay attention to the conservation of resources in the pulp and paper industry derived from using a cleaner production approach(15).

In any case, saving energy and improving energy efficiency is a common concern of both the engineers and researchers. At present, there is great energy-saving potential in the pulp and paper industry that needs to be tapped.

1.2 Introduction of Asia Symbol pulp mill

The Asia Symbol pulp and paper mill (Asia Symbol) is the biggest pulp mill in China. It has two pulp product lines and a paper board product line. One of the pulp product lines is the largest one in the world. It has a pulp capacity as high as 1.75 million tons each year, although the designed annual capacity is only 1.3 million tons. The energy consumption in the mill is extensive. Like other pulp mills, the majority of its energy comes from black liquor, which is a by-product of the pulping process and can be burned in the recovery boilers. Coal is the second most used energy source in the mill, which is all burned int he power boiler (circulating fluidized bed boiler).The recovery boilers and the power boiler supply all the steam which is used for generating electricity, and for heating required in the mill processes. Asia Symbol attaches great importance to energy conservation and cleaner production; indeed, some of its technical specifications exceed the Chinese national standard. Table 1 shows the technical data of Asia Symbol and the current national standard.

Table 1 : Comparison of data between Asia Symbol and National Standard

Item	Unit	Asia Symbol	National Standard [a]
Energy consumption	tce[b]/Adt[c]	0.15	≤0.5
Chip consumption	t/Adt	2.05	≤2.25
Water consumption	m^3/Adt	22	≤50
Waste water discharge	m^3/Adt	20	≤45
Ratio of water reuse	%	93.8	≥85
COD	kg/Adt	25	≤55
BOD_5	kg/Adt	12	≤20
AOX	kg/Adt	0.3	≤1

a. Chinese National Standard: HJ/T 340—2007 Cleaner Production Standard-Production of Kraft Chemical Wood-pulp Paper Industry. b.Ton of Standard Coal Equivalent c. Air Dry Ton Pulp production

1.3 Aims of the paper

As Table 1 shows, Asia Symbol manifests good process data, but the path to achieving such a good standard is not very easy. The aim of this paper is not only to show the energy structure of a large integrated pulp mill, but also to try to emphasize that both the old and the new production lines can save energy through investigation and technological innovation, for example, through the introduction of hydrogen burning in the lime kiln and the process of energy recovery from exhausted air. The paper stresses that technological innovation is as important as theoretical innovation for industrial production.

2.THE ENERGY STRUCTURE OF ASIA SYMBOL

Asia symbol is an integrated pulp and paper mill. It has two pulping lines, one paper board line, two recovery boiler plants, one chemical plant, one power plant, and one effluent treatment plant. Each pulping line consists of four sections: chip preparation, digester cooking, bleaching, and pulp dryer. The recovery plant consists of black liquor evaporation, recovery boiler, steam turbines, and chemical recovery section. All the waste water and sludge is treated in the effluent treatment plant. The electricity and steam at different pressures are supplied from the power plant, which produces steam from the power boilers and recovery boilers. The chemical plant supplies four important chemicals for the whole mill, such as chlorine dioxide, oxygen, sulfur dioxide, and some sodium hydroxide, though the primary source of sodium hydroxide is produced in the recovery plant. Figure 1 is a simplified process flow chart.

The power and recovery boiler provides most of the energy for Asia Symbol, but purchased coal and black liquor alone are not enough to supply the total energy to the mill. Table 2 catalogues all the monthly energy sources of Asia Symbol.

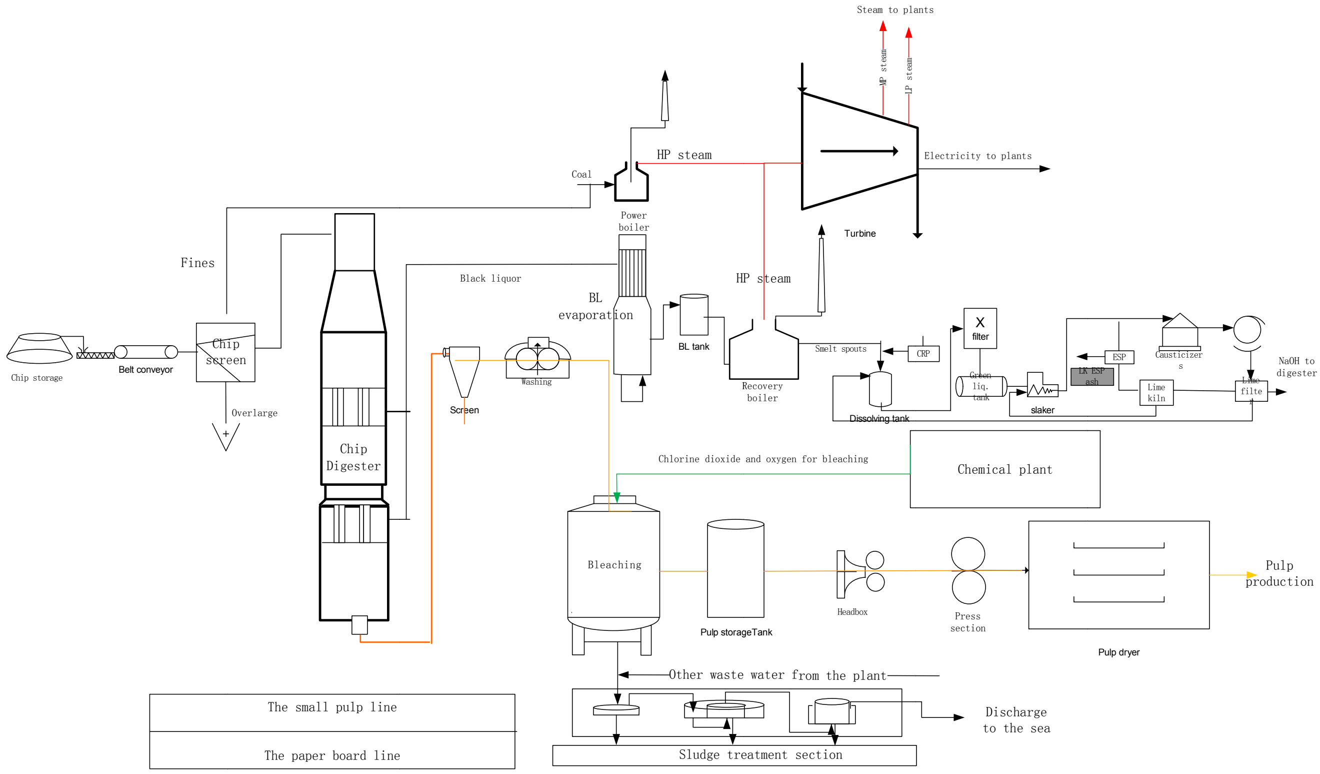

Figure 1 : Process flow chart of Asia Symbol

Table 2 : Energy sources of Asia Symbol

Energy resources		Heat value (kJ/kg)	Total Amount(t)	Equivalent to tec
Purchased	Coal	20935	6074	4340
	Heavy oil	39000	5486	7302
	Diesel	42707	42.4	62
	Purchased electricity	3600[a]	2032600[a]	250
Within mills	Chip fines	7582	798	206
	Black liquor	13500	210710	97506
	Methanol	18164	1959	1215

a. For electricity the unit is kWh

In contrast to tables, figure charts can show the energy structure of the pulp mill better. Figure 2 shows the energy structure of the whole mill and Figure 3 shows the purchased energy structure in a month.

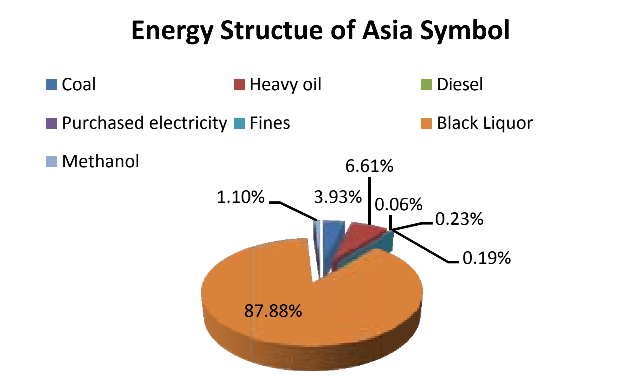

Figure 2 : Energy structure of Asia symbol

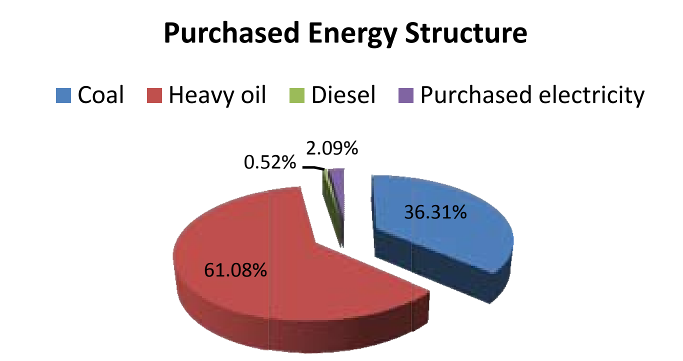

Figure 3 : Purchased energy structure

As we can see from Figure 2, black liquor provides most of the energy for the pulp mill, followed by heavy oil and coal, which are also the greatest purchased energy sources.Beyond that, some potential energy cannot be used before technological improvement; these potential sources are shown in Table 3.

Table 3 : Potential energy in Asia Symbol

Potential energy sources	Heat value (kJ/kg)	Total Amount (t)	Equivalent to tec	Total of tec
Chip fines	7582	13211	3419	
Rejects and Sludge	1972	2458	165	4598
Hydrogen	142000	207	1014	

From Table 3, we can see that the use of chip fines and hydrogen contain lots of energy; if we sufficiently use the potential energy of the paper mill, the mill could theoretically save more than 4598 tons of standard coal in a month. Methods to reuse the potential energy are discussed in the following section.

3. ENERGY SAVING TECHNOLOGIES IN ASIA SYMBOL

From the beginning of the energy flow in the mills to the end, there are always many methods available to save energy. A large number of energy saving technologies are widely applied in the pulp and paper industry, but there are still some innovative technologies currently used only in Asia Symbol.

3.1 General energy saving technologies

The general technologies used in Asia Symbol are similar to those used in other pulp mills. For example, the mill recovers energy from waste water, condensate, and exhaust air from the dryer section. The technique of increasing the level of chip fine burning in the power boiler will be introduced emphatically in this section.

By comparing Table 2 and Table 3, we observe that less than 10% of the total amount of chip fines produced is burned. As we investigated the system, we found that the chip fines feeder is not perfect; the feed speed is very low. So, the workers stopped using the fines burning system. To feed the chip fines to the boiler, we changed the original design of the mill because the system had a feeding blocking problem. We implemented three important improvements. First, we changed the screw feeder to a larger one. Second, the angle of the fines conveyor pipe was adjusted to be higher. Third, although the conveying screw is controlled by a frequency converter, which is easy to adjust, we only know the amount of the rejects from the pulp screen. There is no conveyor system to the power boiler. By altering the design and improving the fines conveyer system, the rejects can be sent directly to the power boiler by the system after mixing with the chip fines. Table 4 shows the results of the improvements.

Table 4 Total chip fines and rejects in power boiler

Item		Get caloric in the power boiler		
	Weight (t/d)	Heat Value (kJ/kg)	Equivalent to standard coal (tec/t)	Total tec
Fines	385.3	7582	0.259	99.8
Screen rejects& sludge	72	4523	0.154	11.1

From Table 4, we estimated that about 38815 tons of standard coal can be saved in per year.

3.2 New innovative energy saving technology in Asia Symbol

Outside of the general energy saving technologies, the unique innovative technologies specific to Asia Symbol are even more attractive as means to improve energy efficiency. The innovative technologies were developed by engineers of Asia Symbol and researchers from several universities. These technologies cannot be found in other pulp and paper mills in China; they are only applied in the Asia Symbol plant.

The first one is a heat integrated recovery system. Recovering the energy from the exhaust air is a very easy process in new paper mills and paper machines. However, the small pulp line and the board line of Asia Symbol were built in the 1990s. The heat recovery technology available in those years was far from perfect. There is only one heat exchanger both in the pulp and paper board dryer section. Figure 4shows the energy recovery system of the pulp dryer section and the supply air heating system before retrofitting. Contrasted with the new pulp line, which utilizes 3 groups of heat exchangers in each exhaust pipe of the dryer section, we infer that a great deal of energy from the pulp and paper board drying sections is wasted. After extensive and comprehensive investigation and research and through measuring the temperature and humidity of the pulp dryer section, we found that the exhaust air from the pulp section in reality contains a great deal of energy. Table 5provides the production capacity of the pulp and paper dryer section. Table 6shows some parameters of the supply and exhaust air of dryer sections.

Table 5 : Production capacity of the pulp and paper dryer section

	Production capacity （t/h）	Dryness after press section(%)	Dryness after dryer section(%)	Vapor from dryer section (t/h)
Paper board	20.24	50	90	16.19
Pulp line	27.38	48	90	23.96

Table 6 : Parameters of air in dryer sections

	Item	Dry air flow (t/h)	Humidity (g/kg)	Temperature(℃)	Enthalpy (kJ/kg)	Energy flow(MJ/h)
Paper board	Supply air	462.63	25	25	88.90	41127.68
	Hood air	462.63	60	92	253.08	117080.56
	Exhaust air	462.63	60	62	219.46	101530.69
Pulp dryer	Supply air	228.17	25	25	88.90	20284.02
	Hood air	228.17	130	98	447.42	102086.70
	Exhaust air	228.17	130	85	431.18	98381.36

Since the old pulp line and paper board line were constructed in a single workshop, the layout of the pulp and paperboard plants provides an easy and feasible way to recover the energy from the exhaust air, particularly from the pulp dryer section. Figure 4depictsthe layouts of the pulp and paper dryer section. We can see that the air supply line of the paper board dryer section is very near the pulp dryer exhaust duct. We shared our idea with the dryer section designers who appreciated it very much.

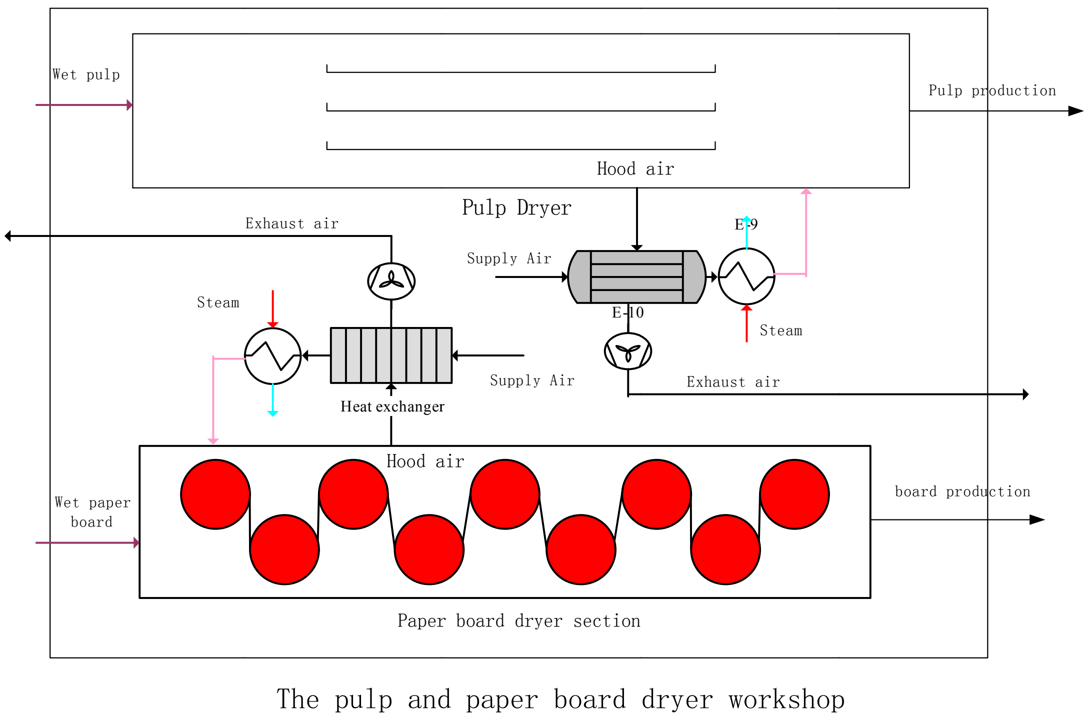

Figure 4 : Layouts of pulp and paper dryer sections

Reforming the integrated heat recovery system took about two weeks. After that, both the temperature and humidity of the exhaust air from the pulp dryer section were decreased. Table 7 shows the changes in the pulp dryer exhaust air. The temperature of the paper board dryer section Supply air temperature increased from 35 0C to about 50 0C.Though the supply air should still be preheated by steam, less steam will be required..Table 7 shows the parameters of the exhaust air after system reforming.

Table 7 Parameters of pulp dryer exhaust air after system reforming

Item	Dry air flow (t/h)	Humidity (g/kg)	Temperature (℃)	Enthalpy (kJ/kg)	Energy flow(MJ/h)
Pulp dryer exhaust air	228.17	130.00	60.00	399.95	91255.71

Figure 5 shows the integrated heat recovery system after system reformation. This reforming brings good economic benefits to the mill; it can save about 3220 tons of standard coal over the course of a year.

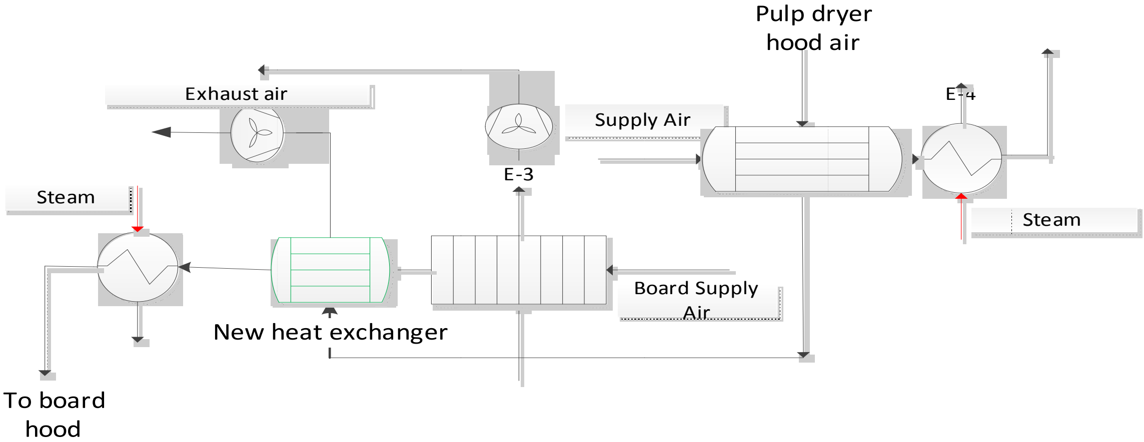

Figure 5 Integrated heat recovery systems

The second new innovative technology is burning hydrogen from the chemical plant in the lime kiln. As we all know, hydrogen is clear and a highly effective energy source. It has the potential to solve not only the mills energy problems, but some of its environmental problems as well. In Asia Symbol, hydrogen is derived from an electrolysis process in the chemical plant. However, the primary function of the chemical plant is to produce chlorine dioxide and oxygen, which are used for bleaching the pulp following the cooking process. The hydrogen produced is only a by-product of the chemical plant. Figure 6 depicts a schematic drawing of the chemical plant.

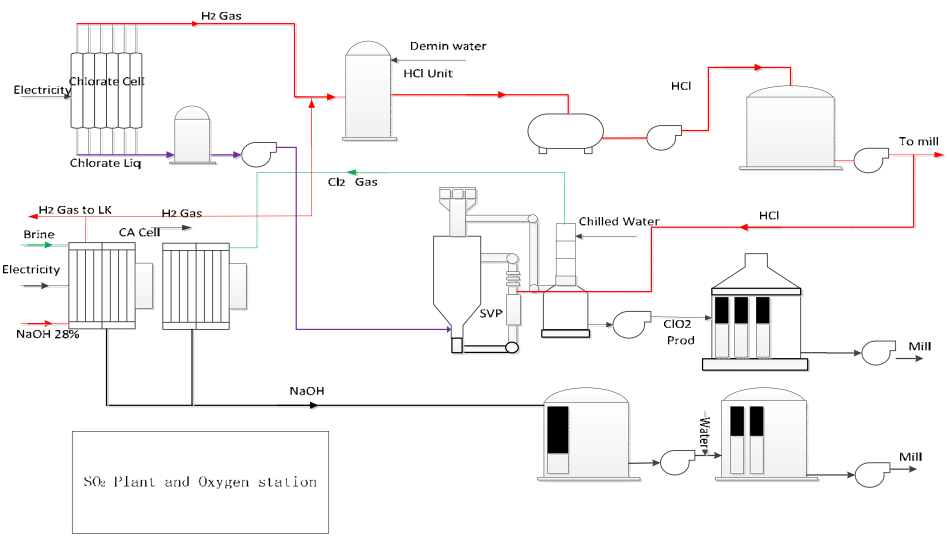

Figure 6 Flow chart of chemical plant

Figure 6 shows that hydrogen is produced in two processes: the chlorate process and the chlor-alkali process.

The calcium oxide is used in the causticization treatment process to produce sodium hydroxide, which is the most important chemical used in pulp cooking. The lime kiln of the pulp mill is used to produce calcium oxide by burning limestone as part of the recovery boiler plant. The lime kiln is fueled by heavy oil.

The demonstration of the project to burn hydrogen in the lime kiln instead of heavy oil is also given by a team of professors from the universities involved and the engineer of the mill. Lots of work needs to be done before hydrogen can really be burned in the lime kiln. First, the hydrogen needs to be pure enough to avoid accident. Second, as the chemical plant is about 300 meters away from the lime kiln, a method to transport the hydrogen needs to be developed. The final design of the hydrogen processing flow is shown in Figure 7.

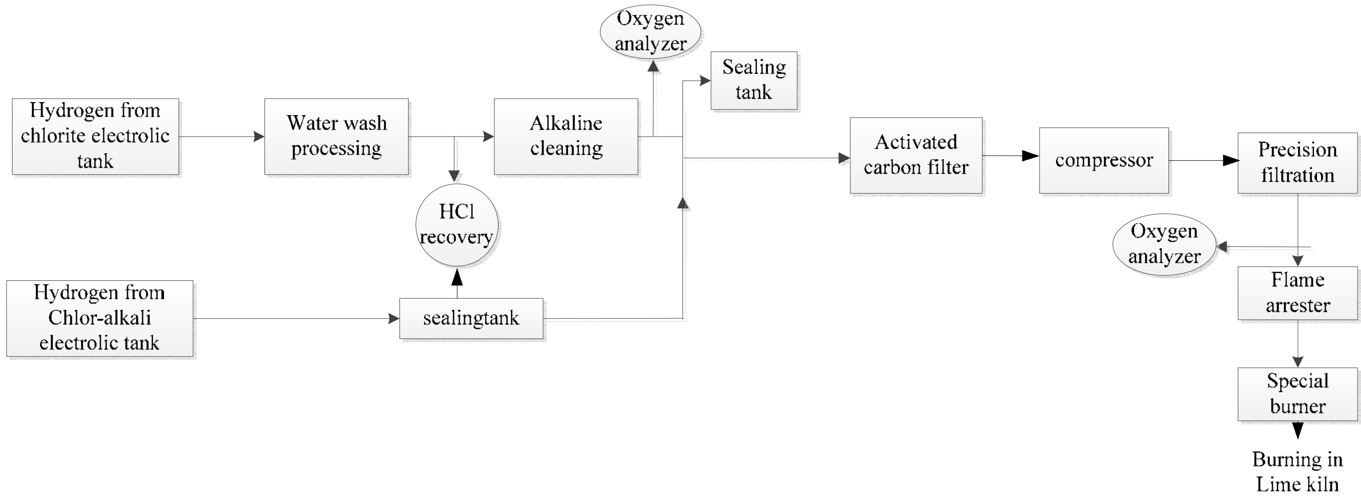

Figure 7 : Hydrogen processing flow chart

As shown in Figure 7, the water wash processing, acid cleaning process, pressurizing apparatus, activated carbon filter, and the cooling dehydrating units are all placed in the chemical plant. The heating and heat-preservation unit, precision filtration, fire retardant-type flame arrester, and special hydrogen burner are placed near the lime kiln. Other support facilities, such as drainage and vapor exhaust devices, are added to the original system. Finally, the hydrogen can be successfully burned in the lime kiln.

The hydrogen burning system retrofit also brings large direct benefits for Asia Symbol. About6.5 tons of hydrogen is burned every day. While the heat value of hydrogen is 142MJ/kg, the heat value of heavy oil is only 39 MJ/kg. It is calculated that, in total, more than 8000 tons of heavy oil is saved every year, which is equivalent to 10800 tons of standard coal.

4. CONCLUSIONS

The pulp mill needs lots of energy to insure proper operation. Energy from black liquor can meet most of the energy demand, but purchased energy, such as coal used in the power boilers and heavy oil burned in the lime kiln, is also very important for the mill, especially for particular plants.

Though the company uses an advanced production process, there is still some potential energy that should be used, and the application of innovative technology achieves good energy saving results.

Chip fines, rejects, and hydrogen are all good fuel sources for the pulp mill that can save a total of approximately 49615 tons of standard coal in a year.

New retrofitting of the heat recovery system can also save 3220 tons of standard coal per year even though it is very easy to improve the integrated system, improvement is very easy and the time and economic cost is very low.

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