TECHNICAL SPECIFICATIONS

PYROLISYS WASTE PLASTICS OIL RECYCLING PLANT (VESTA-10)

Developed, designed and manufactured by Hanchan Green Holdings Co., Ltd.
Seoul, Korea

1. Outline of the Project

The 3R (reduce, recycle and reuse) of waste plastics can be achieved efficiently aiming at improving the environment in general and reduce the public spending appropriated for solid waste processing in particular. The revenue gained by sale of by-products such as diesel fuel, compressed off-gas, and carbon sludge will not only enable a financially self-standing operation of pyrolysis processing plant and make private investment financially viable.

1.1 Outline of Pyrolysis Waste Plastics Oil Recycling Plant

The raw materials targeted for oil recycling though the pyrolysis waste plastics oil recycling technology are the chlorine plastics such as Polyethylene (PE), Polypropylene (PP), Polystyrene (PS) alike that is sorted and compacted at waste sorting center in Yambol and other locations in Bulgaria. When these substances are heated under absence of oxygen or anaerobic condition at around 500°C a thermal decomposition synthetic gas is generated. When such a gas is cooled rapidly it will be liquefied and it turned to pyrolysis oil (recycled oil). During this process synthetic gas that cannot be condensed or non-condensable vapor such as Methane, Butane, and Propane are generated however these are recycled through a artfully designed refining process and returned to melting furnace so as to use it as a heating fuel of rotary furnace (reactor). The oil recycled is further refined through 3 stages high quality refining process and stored in oil tank located outdoor and it is used as a fuel to run the gas turbine or diesel engine driven power generating plant as a form of New Recyclable Energy Project.

1.2 Characteristics of PE, PP, PS and PET

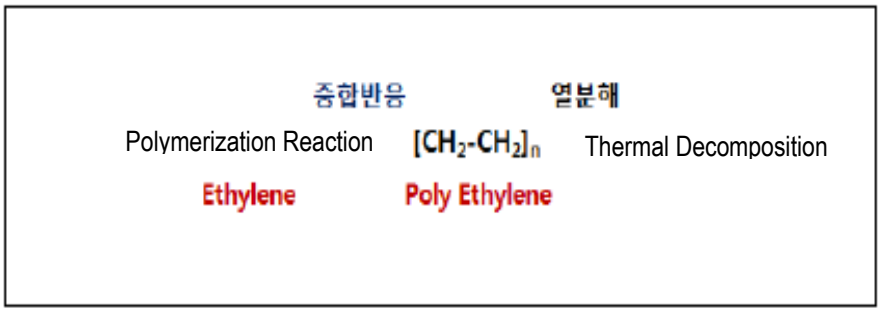
The density of PP, PE and PS used as the raw materials for oil recycling process are approximately PP – 0.91～0.97, PE – 0.90～0.91 and PS – 1.04 ～1.10, respectively. As such the density of these material differ slightly by polymerization degree. The thermal decomposition temperatures of these substances are approximately PP – 220～250°C, PE - 290～360°C, and PS - 330°C, respectively. The characteristics of respective substance is as follow:

1) Characteristics of PE

PE stands for Polyethylene that represents a plastic made through petrochemicals. It is polymerized or produced as "Ethylene" in which carbon and hydrogen are constituted by double bonds. As physical property of PE is lighter than water and its viscosity is high at melting time, process is easy. It is tasteless and odorless; and its electric insulation is superior and chemical resistance property is high.

Most PEs have a linear structure, but in some cases, resins are partially branched due to process changes during the polymerization reaction. Therefore, according to density and crystallinity, PE is classified into HDPE (High-Density PD), LDPE (Low Density PE), VLDPE (Very Low-Density PE), and the like. The melting temperature is 137 ° C, but the temperature decomposed by thermal decomposition is 290 to 360 ° C. As such, this substance can be decomposed with less energy.

Figure below shows the process of conversion of Polyethylene, which is a high molecular substance by polymerization reaction, into a flammable substance by "thermal decomposition" of ethylene, which is a monomer. Here, “m” has a number of about 15 or less that depends on condition of temperature or catalyst.

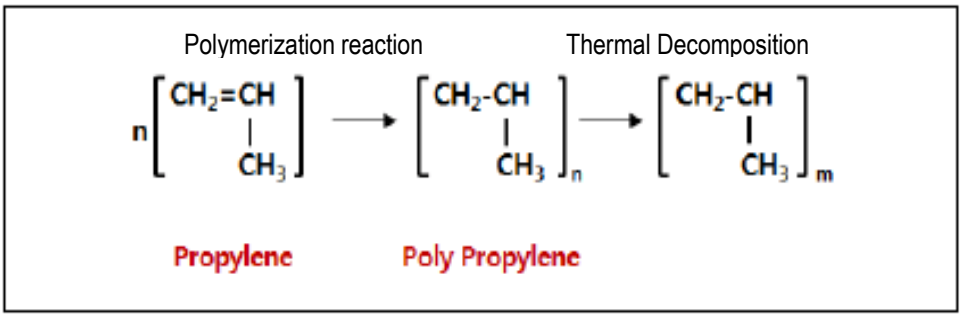


[Ethylene Polymerization and Thermal Decomposition of PE]

2) Characteristics of PP

PP is an abbreviation of Poly Propylene which is produced by polymerizing propylene composed of a double bond of carbon and hydrogen having a methyl group. Since its specific gravity is 0.90, it is lighter than water, its tensile strength and surface strength are high thus strong against friction, while heat resistance is also good among other thermoplastic resins. It has good chemical resistance to acid and alkali, but it tends to swell at 50°C or higher. The melting temperature is 176°C., but the temperature at which pyrolysis is carried out is 220 to 250°C. It is a substance which can be decomposed with less energy volume.

Below figure shows a process in which propylene, which is a monomer, is converted into a substance by thermal decomposition after Polypropylene is formed in the polymerization reaction. Here, “m” has a number of about 15 or less that depends on condition of temperature or catalyst.



[Propylene Polymerization and Thermal Decomposition of PP]

3) Characteristics of PS

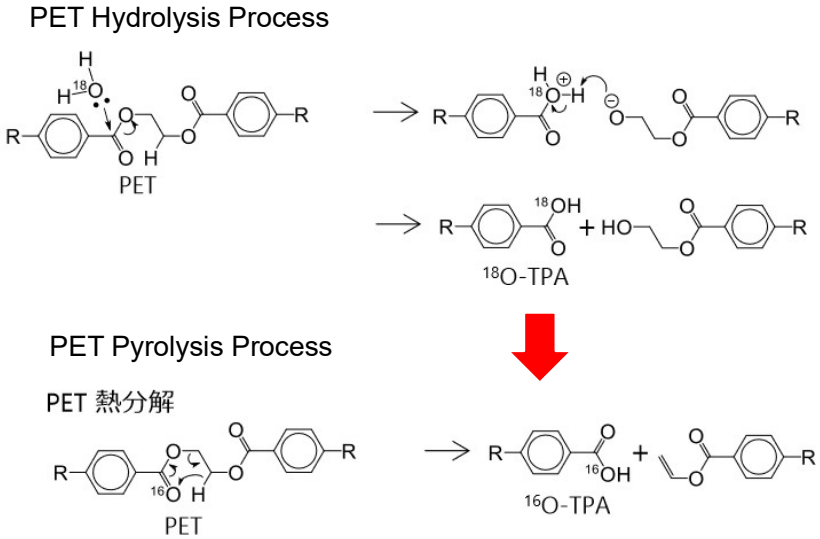
Polystyrene is a homopolymer composed of monomer styrene bonded to itself and it is colorless and transparent, clear coloration is free and specific gravity is lower than polypropylene and polyethylene. Its light stability against radiation is the strongest in plastics group. Its specific gravity is 1.04 to 1.1, which is heavier than water, has acid resistance and alkali resistance, and is thermally decomposed at a temperature of 330 to 400°C.

4) Characteristics of PET

The annual production volume of Polyethylene Terephthalate (PET) is 5th largest among plastic products of general purpose in terms of volume in the world. PET does not generate much useful oil and gas through the pyrolysis process. Moreover, it produces terephthalic acid and benzoic acid of which boiling point is high and is corrosive organic acids. These substances are the causes of corrosion that blocks of piping system of the plant. Therefore, it is necessary to convert these organic acids into useful components.

Hanchan Green Holdings Co., Ltd., the developer of proposed pyrolysis waste plastic oil recycling technology and manufacturer of the pyrolysis plant, examined through the actual operation of thermal decomposition of waste electric wires at pyrolysis plant of RECOMA in Ulsan, Korea that was designed and built by St. Energy Co., Ltd., and found that Terephthalic acid (TPA) and Benzoic acid (BA) can be effectively suppressed by mixing PET with Ca (OH) $_2$ thereby it is possible to recover benzene, which is useful as a petrochemical raw material, through a high quality refining line. Figure below shows that the production flow of Benzene through thermal decomposition of a mixture of PET and $Ca(OH)_2$ which is a metal compound. Chemical formula of Benzene is C_6H_6. The recycled oil yield is 25 to 30% of the raw material input weight. It is recommended to add PP or PE or both with PET so as to increase the volume of recycled oil. Following figures show the hydrolysis step and the pyrolysis step of PET.

1.3 Outline of Oil Recycle Process from Waste Plastics



1.3.1 Outline of Process

1) Waste plastic recycling is the process of producing recycled oil from waste PE, PP, and PS. The target objects for recycling are PE, PP, and PS selected and sorted from municipal wastes at the recycle sorting center, collected by trucks, compressed then stored in warehouse located at pyrolysis waste plastics oil recycling plant within a legal storage volume.

2) Load the raw material into the reactor with a special purpose charging machine, subsequently close the door. Perform preliminary inspections on oil burners and accessories (such as scrubber, blowers, condensers, cleaning tower motors and

pumps). When the inspection is completed, start the operation of the oil burners furnished to the heating furnace, then start thermal decomposition.

3) The syngas pyrolyzed in the reactor of the low temperature thermal decomposition apparatus (Syn Gas) are separated in the primary gas separator into synthetic gas and coarse foreign substances under natural pressure. Further, in the secondary gas separator, the synthesis gas and finer foreign substances are separated again.

4) Synthesis gas separated by the primary and secondary gas separators is liquefied through a jacket type free condenser and a condenser line of the secondary condenser (Shell & Tube Type), resulting in a production of Pyrolyzed oil at about 45% to 75% of the raw material weight (depending on the raw material properties). The so-called non-condensable gas, a synthesis gas having as few as 1 to 5 carbon atoms, is not liquefied and is transfer to the "gas refining line".

5) The non-condensable gas is recycled as a fuel for heating via buffer tank → gas neutralization tower → gas washing tower. In order to prevent secondary air pollution which may occur during combustion, fine dusts and acid gases that may remain in gaseous state are neutralized and recycled as heating fuel. At this time, the remaining gas other than the "purified gas" used as the gas burner fuel is transferred to the "gas compressor", then it is stored in the cylinder and used as fuel.

6) When fuel oil and non-condensable gas are used to supply energy to the low temperature thermal decomposition apparatus, measures against the exhaust gas are necessary when burn them by burner. Exhaust gas is transferred through a water-cooled heat exchanger "Bare Tube" in order to lower its temperature so that the air pollution control facility at the next stage is possible to function properly.

7) At the second stage, the pollutants dissolved in dust and water are removed through a wet scrubber (Wet Scrubber), and a part of the organic substances (VOC) which induces malodor is removed. Subsequently through the deodorizing tower filled with activated carbon, the residual VOC and malodor are removed by the adsorption process. In order to remove dust and acid gas at the same time in the wet type washing tower, alkaline latent (NaOH) is added for maintaining the neutral state of exhaust gas. At this time, waste water is generated and stored in the waste water bin. This waste water is to be entrusted to a special waste water treatment specialist and processed.

1.3.2 Waste Plastics Pyrolysis Process Diagram

Figure-1.1 illustrates the process flow diagram showing respective function of each equipment of Waste Plastics Pyrolysis Oil Recycling process. In addition to this process the recycled oil is further refined by Recycled Pyrolysis Oil Refining Machine (STRM) to make recycled pyrolysis oil complying with the acceptable standards that is to be used as a fuel for power generation and for internal combustion engines.

Figure-1.2 illustrates the process flow of Recycled Process Oil Refining Machine.

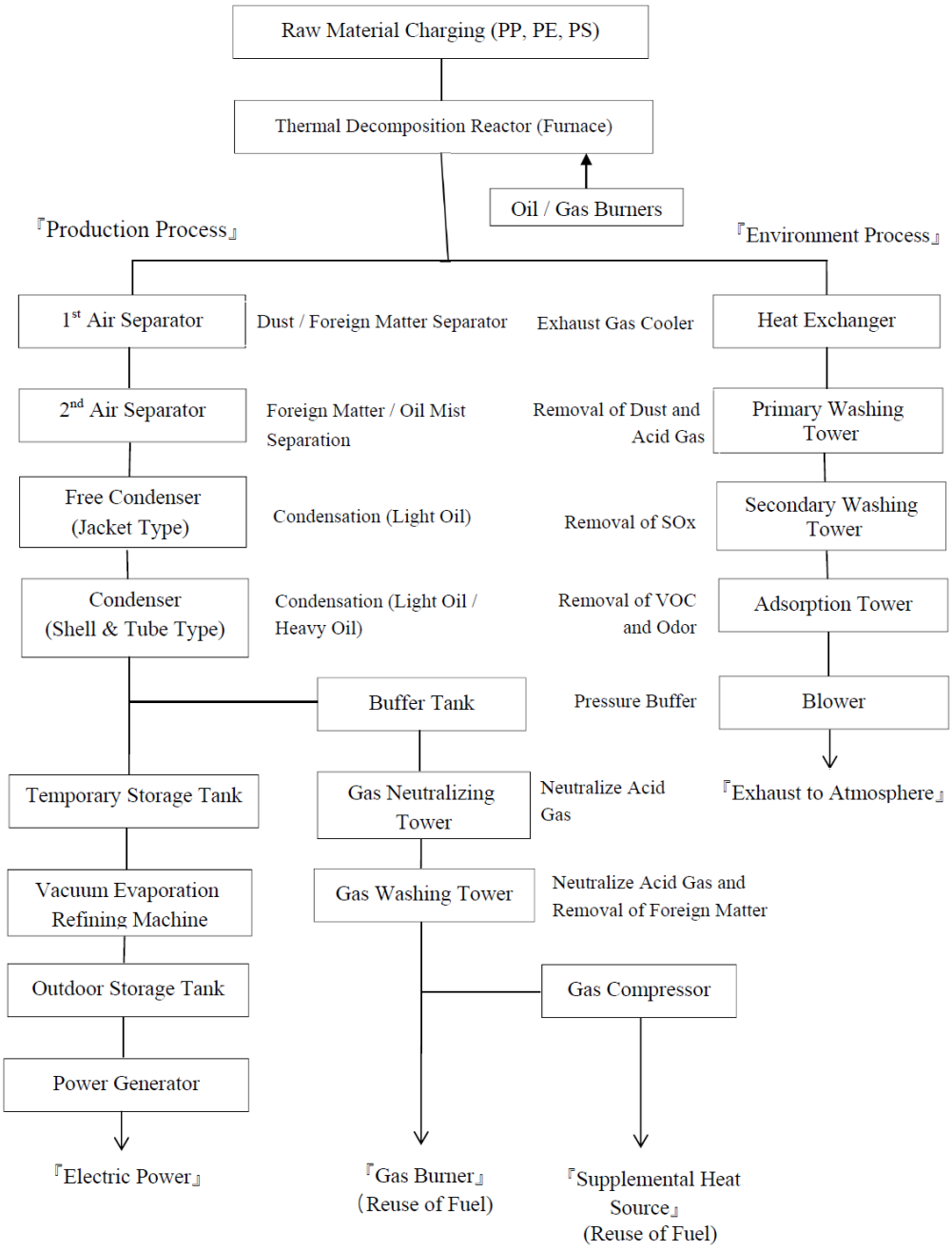


Figure-1.1 Process Diagram of Waste Plastics Pyrolysis Process

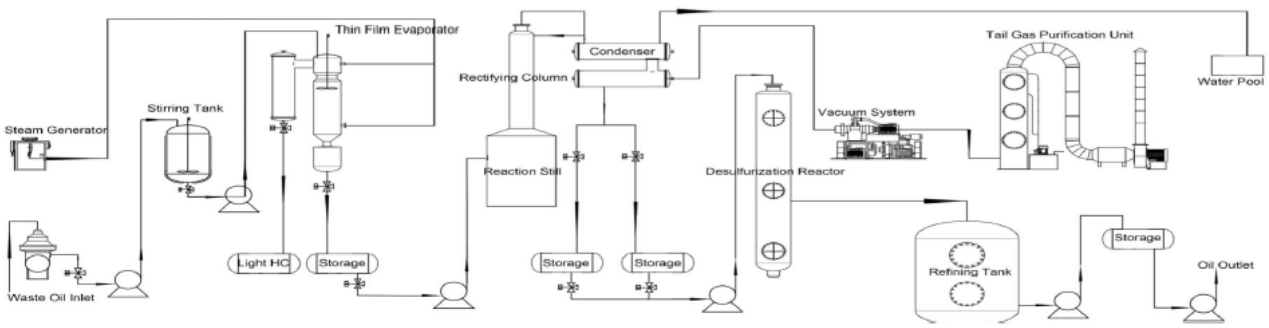


Figure-1.2 Process Diagram of Recycled Pyrolysis Oil Refining Process

Figure-1.3 shows the relative major device and products of Waste Plastics Pyrolysis Oil Pyrolysis Plant.

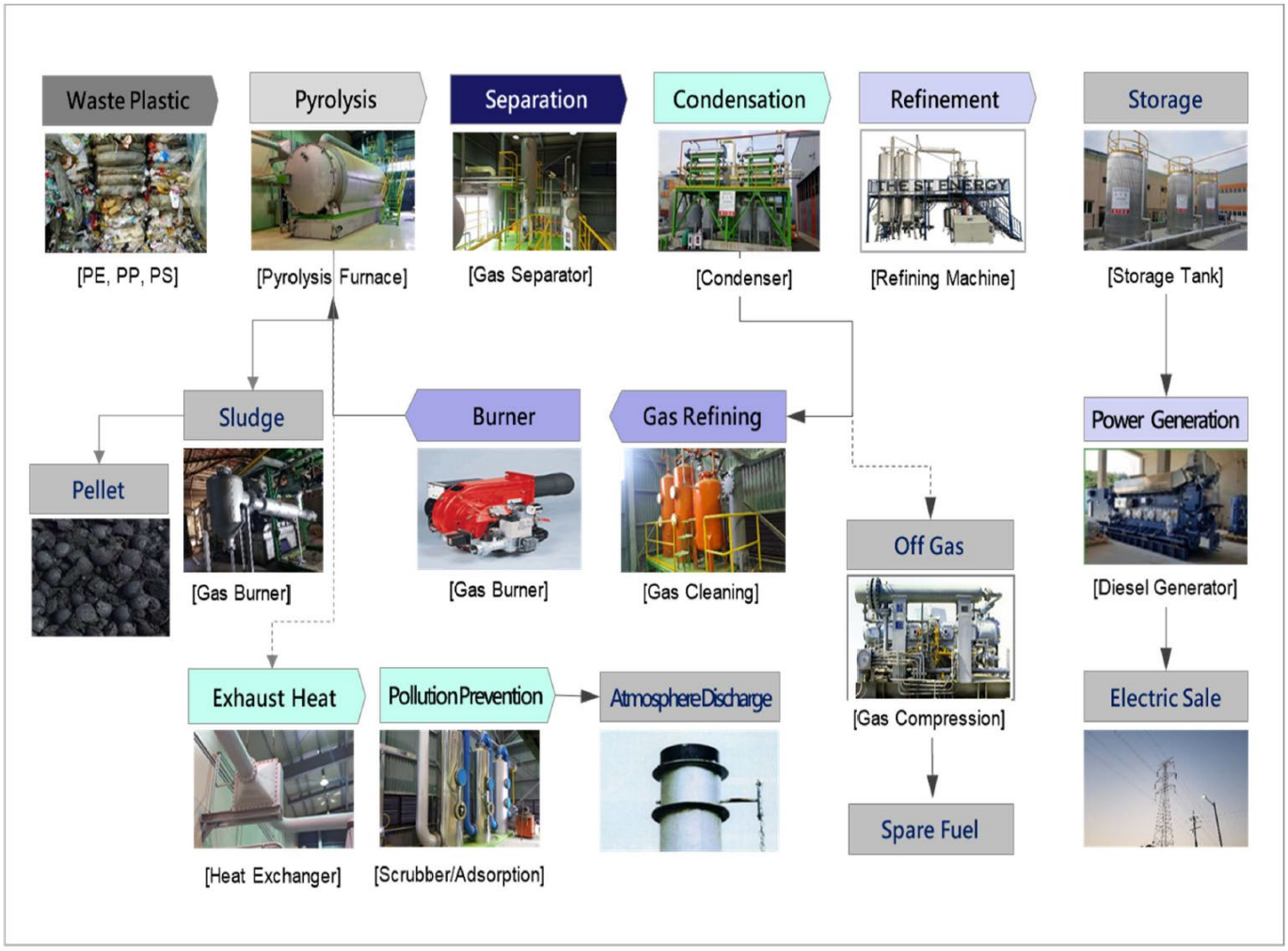


Figure-1.3 Major Devices and Product of Waste Plastics Pyrolysis Plant

Figure-1.4 illustrates the side view of Recycled Pyrolysis Oil Refining Machine.

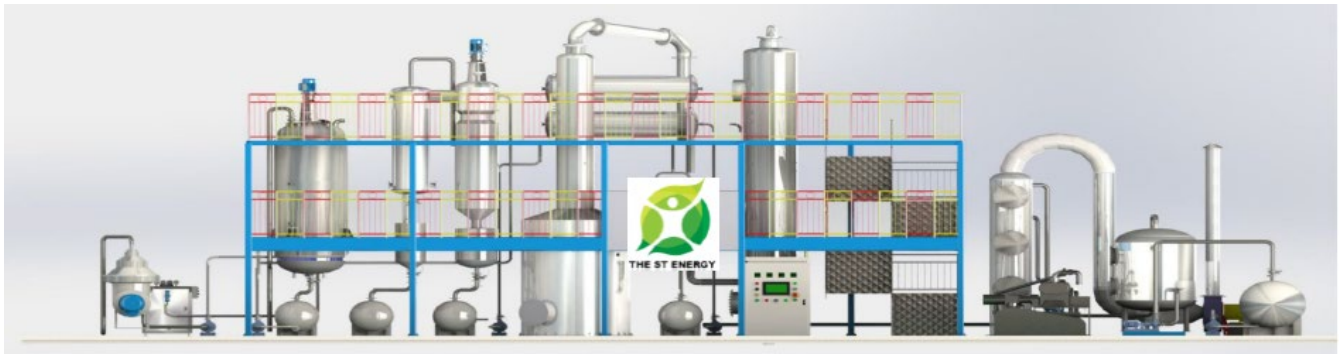


Figure-1.4 Side View of Recycled Pyrolysis Oil Refining Machine

2. Waste Plastics Pyrolysis Technologies by Process

2.1 Low Temperature Thermal Decomposition Furnace (Reactor)

2.1.1 Outline of the Facility

Waste plastics and waste vinyl are loaded into a melting furnace and they are heated by oil and gas burners equipped at a lower part of heating furnace to perform thermal decomposition in a low oxygen and atmospheric pressure. The facility is composed of melting furnace (reactor), cover of reactor, heating furnace, heat resistance bricks, burner (oil / gas), and driving devices.

Low Temperature Melting Furnace (Reactor)	Rotation Driving Mechanism
	

Figure-2.1 Thermal Decomposition Reactor and Rotation Driving Mechanism

2.1.2 Material and Standards

A. Reactor

1) Dimension : 7,700mm (L) x ¢ 2,600 mm x 16mm (T)
2) Material : A51670, boiler steel plate
3) Rotation : 0.4 RPM
4) Weight : Approx. 25 ton
5) Power Consumption : 30HP (22kW)

B. Reactor Cover

1) External Casing: SS400, more than 3.2mm thickness
   Paint : Heat resistant silver paint 2 times (Heat resistant temperature 500℃ or higher)
2) Internal packing: high temperature ceramics thermal insulation Castable.
   (Products with heat resistance more than CT160 is adopted.)

C. Heating Furnace

1) Dimensions: 9,700mm (L) * 2,350mm (W) * 800mm (H)
   - These dimensions may change according to the final dimensions of reactor
2) Composition

① Component : H-150*150*7*10 Channel Steel

② Casing : SS400 thickness more than 6mm

- Heat resistant silver color paint 2 times (heat resistant temperature 600℃ or higher)

D. Heat Resistant Bricks Standards

SK - 34 or higher products with high alumina heat resistance.

Component Composition」Al2O3：70～75％ / CaO:0.01％ / CrO:0.1～0.3％

E. Oil Burner
1) Calorific Value : 279,500 ~ 792,000 (kCal/hr)
2) Type : Rotary and blower integrated type
3) Kind of Fuel : Recycled oil
4) Fuel Consumption : 30 ~ 70 kg/h
5) Air Pressure : 0.25Mpa
6) Driving Motor : 1.1kW × 380V × 60Hz

F. Gas Burner
1) Kind of Fuel : Refined synthetic gas
2) Calorific Value : 150,000 ~ 200,000 (kCal/h)
3) Fuel Consumption : 25 ㎥/h

Item	Oil burner	Gas burner
1) Burning materials	Recycled oil (A grade)	Generated Gas similar LPG)
2) Required Cal(㎉/hr)	500,000/Set	470,000/Set
3) Quantity(㎉)	8,900/ℓ	23,890/N ㎥
4) Consumed Quantity	About 56ℓ/hr	About 20 ㎥/hr
5) Burners (Set)	4EA	4EA
6) Using hours (hr) per day	4 ~ 5	6~7
Actual photos		

Figure-2.2 Oil Burner and Gas Burner

G. Decelerator
1) Type: Cyclone type reduction gear
2) Selected according to the melting furnace rotation speed of 0.4 RPM, lubricating oil injection and maintenance standards follow the manufacturer's design standards.

2.1.3 Design, Manufacturing and Installation

1) The structure of material charging port of melting furnace shall be designed to make charging of raw materials and closing the port easier. Heat resistant packing material shall be applied and the structure shall be explosion resistance.

2) The charging / discharging port of furnace shall be manufactured to prevent air inflow into furnace and synthesis gas leaking from furnace.

3) The structure of the melting furnace must be designed so that heat transfer can be performed evenly by thermally decomposing the raw material in the furnace by

indirect heat supplied by the burners. Since the inside temperature of furnace rises to 450°C, A51670 boiler steel plate shall be used in order to perform heat resistance and long-term operation in stable manner.

4) The interior of melting furnace is structured so as not to adhere clinker due to contact with the raw material for pyrolysis, and a spiral structure is constructed so that sludge can be easily discharged.

5) The cover of melting furnace shall be designed and manufactured using heat resistant ceramics castable filling structure of CT160 or more that can with-stand high temperatures of stored gas heated by burners and prevent leaking such high temperature gas to outside.

2.1.4 Handling and Use of Castable

1) Store the castable in the dry environment where ventilation is good so that rain or water will not be applied before construction, prohibit loading, and keep it on the pallet. Since the storage period is generally about 6 months, long-term storage is prohibited.

2) For mixing, use concrete mixer or paddle type mixer and make one mixing amount in one time shall be appropriate volume that can be used within 20minutes after mixing.

3) Use water compatible to a standard of potable water (pH 6 to 8, 5 to 20 °C) for mixing.

4) The volume of castable shall be obtained by converting it according to specified capacity ratio for refractory use.

5) At the time of mixing, the moisture content shall be in a range of 14 to 16%, adding about 12% in one time, then add 2 to 4% after adding so as to make workability compatible.

6) If the mixing work is left halfway when mixing, it will be cured, so do not stop working on the way. Also, be careful as it would cure and If you leave it halfway when mixing, it will be cured, so do not stop working on the way. Also, be careful as it would cures and over condensation point if the mixing work is done for too long period.

7) Since the heating furnace functions as the foundation of the melting furnace installed on it, it should be structured to have a considerable strength against vertical load. The steel material used shall be H - shaped steel or Channel steel and shall be constructed in a form of a structural frame that can withstand vertical and horizontal loads. Particular attention to be drawn to each corner portion that directly meet with the upper load should be reinforced additionally so as not to deform.

8) The heating furnace casing is toughened steel plate with SS400 thickness 6.0mm or more, heat resistant silver color paint is painted on the surface of casing. This is fixed on the four sides of the heating furnace with anchor bolts to make sure that excessive vibration etc. does not occur during operation.

9) The refractory brick used inside the heating furnace should adopt the refractory degree SK-34 or more according to the Korean Industrial Standards. It shall be made of material that is possible to tolerate extremely high temperature for prevention and deformation of the heating furnace structure due to high temperature.

2.1.5 Refractory Bricks Construction

① Form of Construction
Prior to installing refractory bricks, heat burner and gas burner shall be preliminarily assembled as a preceding process. The gap between heating furnace structure and refractory bricks shall be filled with insulation materials, and high temperature insulation agent (ceramics wool) of 25mm thick shall be filled inside heating furnace. Thereafter, firebricks shall be constructed.

② Construction Method in General

- The volume of refractory bricks needed for construction shall be estimated in accordance with relevant working drawing and located at the place where such work is to be carried out.
- Use mortar mixer to stir well so that it is well dissolved with foreign substances, apply mortar uniformly so that no space is formed on the firebrick surface, set the thickness of the row within 5 mm, and finish cleanly after construction is completed.
- Do not coat with mortar after laying refractory bricks. When adjustment of refractory brick is deemed necessary, use a cutter to cut excessive part of mortar. The minimum thickness of refractory brick shall be 30 mm or more.
- The water used for mortar is to be fresh water within a range of 5 to 20°C. Mortar should not be frozen.

2.2 Primary Gas Separator

2.2.1 Outline of Device

Primary gas separator separates the coarse dust, foreign substances, impurities, etc., which are partially contained in the synthesis gas discharged from the pyrolysis furnace. This device controls the temperature and pressure of the discharged synthesis gas are measured to control the progress of thermal decomposition and the temperature control of the heating furnace. This facility is composed of thermometers, pressure gauges, safety valves, water vapor outlets and sensors.

2.2.2 Material and Dimensions

1) Dimensions	: Ø 630mm x 1,000mm (H)
2) Material	: SS400, thickness 6mm or more
3) Quantity	: 1unit
4) Weight	: 250kg
5) Working pressure	: < 0.04Mpa
6) Working temperature	: < 400℃

2.3 Secondary Gas Separator

2.3.1 Outline of Device

1) Secondary gas separator separates fine dust and oil mist contained in the synthesis gas that has passed through the primary gas separator.

2) Inside the secondary gas separator, a "collision separation plate" is provided so as to collide with the flow of the synthesis gas, to separate heavy material in density such as dust, foreign substances and the like mixed with synthesis gas naturally.

And the light synthetic gas separated passes through the "collision separation plate" and is transferred to the free condenser.

2.3.2 Material and Dimensions

1) Dimensions : Ø 630mm x 3,070mm (H)
2) Quantity : 1 unit
3) Material : SS400, thickness 6.0mm or more
4) Weight : 450kg
5) Working pressure : < 0.04Mpa
6) Working temperature : < 350℃

Primary Gas Separator	Secondary Gas Separator
	

Figure-2.3 Gas Separators

2.4 Cooling Facility

2.4.1 Outline of Facility

The cooling device liquefy syngas passed through primary and secondary gas separators to produce light oil and heavy oil. The cooling device is composed of free condenser (jacket type), cooling condenser (shell and tube type) and cooling tower that is composed of cooling water reservoir, pumps, pipes and valves.

A. Free Condenser (Jacket Type)

1) Dimensions : Ø 630mm x 2,820mm (H) x 1 each
2) Structure : Tube Insert Type
3) Material : STS304, thickness 6.0mm or more
4) Working pressure : < 0.04Mpa
5) Inlet cooling water temperature : < 30℃
6) Exhaust cooling water temperature : < 50℃

B. Cooling Condenser (Shell & Tube Type)

1) Dimensions : Ø 630mm x 2,820mm (H) x 5 each
2) Structure : Shell & Tube Type
3) Material : STS304, thickness 6.0mm or more

4) Working pressure : < 0.04Mpa
5) Inlet water temperature : < 30℃
6) Exhaust water temperature : < 50℃
7) Type : Vertical type

C. Cooling Tower
1) Refrigeration tons : not less than 150RT
2) Quantity : 1 unit
3) Capacity : not less than 585,000 kCal/hr
4) Type : Semi-sealed type

Cooling Condensers	Cooling Tower	Cooling Water Reservoir
		

Note: These photos are of existing plant in Korea and to be used as reference only.

Figure-2.4 Cooling Facility

2.5 Off-gas (non-condensable gas) Refining Equipment

2.5.1 Outline of Facility

Waste plastics are decomposed into hydrocarbons of various carbon numbers (CxHy) during the thermal decomposition process. The carbon number of synthesis gas is mostly 12 to 16, but smaller carbon number of synthesis gas ranging 1 to 5 do not liquefy and remain in a gaseous state. "Gas purification pretreatment" is performed so that this gaseous hydrocarbon can be used as fuel for gas burner after neutralization → adsorption → purification process.

This facility is composed of buffer tank, gas neutralizing tower, and washing tower. The washing tower is equipped with pressure gauge, temperature gauge, pressure adjustment valves. In the gas neutralization tower, sodium hydroxide flip is added in two stages in order to neutralize the synthesis gas. The gas scrubbing tower is of water seal structure and has a sodium hydroxide aqueous solution inside. The foreign substances and chlorine which may be contained in the synthesis gas is neutralized and supplied as a fuel for gas burner.

2.5.2 Material and Dimensions

A. Buffer Tank
1) Purpose : Pressure adjustment tank
2) Dimensions : Ø 630mm x 1,500mm (H)
3) Material : SS400 thickness 6.0mm or more
4) Working pressure : < 0.04Mpa
5) Working temperature : < 40℃
6) Weight : 150kg

B. Gas Neutralizing Tower

1) Purpose : The acidic gas that may be contained in the non-condensable pyrolysis gas is passed through the basic flip for its neutralization.
2) Dimensions : Ø 630mm x 3,000mm (H)
3) Material : SS400 thickness 6.0mm
4) Working pressure : < 0.04Mpa
5) Working temperature : < 40℃
6) Filling material : An aqueous solution of NaOH 5% or less
7) Weight : Approx. 290kg

C. Gas Neutralizing Tower

1) Purpose : The synthesis gas neutralized in the gas neutralization tower is precipitated in the secondary basic aqueous solution for gas washing and removal of impurities.
2) Dimensions : Ø 800mm x 1,500mm (H)
3) Quantity : 1 unit
4) Material : STS304, thickness 6.0mm or more
5) Working pressure : < 0.04Mpa
6) Working temperature : < 40℃
7) Filling material : Basic chloride aqueous solution

Buffer Tank, Gas Neutralizing Tower, Gas Washing Tower	Gas Filter
	

Figure-2.5 Gas Refining Facility

2.6 Exhaust Heat Temperature Reduction Device

2.6.1 Outline of Device

Inside the heating furnace, combustion is performed by oil and gas burners to generate combustion gas. The high temperature (300 ° C) of the exhaust gas is to be lowered primary. This device lowers the exhaust gas temperature thereby lower the load to the air pollution facility at subsequent process.

2.6.2 Material and Dimensions

1) Dimensions : 1,500mm (W) x 1,600mm (L) x 1,000mm (H)
2) Quantity : 1 unit

3) Heat transfer area : 17m^2
4) Tube : Bare tube, Ø 25.4mm, ℓ= 1,200mm (22 rows x 8 lines)

Heat Exchanger

Figure-2.6 Exhaust Heat Reduction Device

2.7 Air Pollution Prevention Facility

2.7.1 Outline of Facility

The air pollution prevention facility treats dust, SOx, NOx, VOC foul odors and the like that may be generated by combustion of oil and gas burners to conform to "Emission Standards of Air Pollutants" specified in the "Atmospheric Environment Conservation Law" of Korea. This facility is composed of primary and secondary washing type adsorption device(Wet Scrubber) and activated carbon adsorption facility which is impregnated with acid and alkaline chemical.

In a two-stage wash type adsorption facility, basic water solution is injected to remove air pollutants such as SOx, dust, etc., that may be contained in the exhaust gas. Odor-causing substances such as hydrogen sulfide, methyl-mercaptan, ammonia and trimethylamine that are not removed by the washing type adsorption facility is removed through charcoal adsorption function in the adsorption tower then exhausted into the atmosphere by sucking exhaust gas using blower.

2.7.2 Technical Description of Device

A. Primary cleaning type adsorption device (Wet Scrubber)
1) Dimension : Ø 1,200mm x 3,000mm (H)
2) Capacity : 4,500 ㎥/h
3) Material : STS316 thickness 6.0mm or more
4) Weight : Approx. 550kg
5) Component : Heat resistant acrylic inspection window, pump, spiral nozzle, water tank, pump, piping, etc.

B. Secondary cleaning type adsorption device (Wet Scrubber)
1) Dimensions : Ø 1,200mm x 3,000mm (H) x 2 unit
2) Capacity : 4,500 ㎥/h (It can be changed by designing of air pollution prevention facility.)
3) Material : STS304 thickness 6.0mm or more

4) Weight : Approx. 550kg
5) Component : Same as (A)

C. Adsorption tower (impregnated activated carbon)
1) Dimension : Ø 1,200mm x 3,000mm (H) x 1unit
2) Capacity : 4,500 ㎥/h
3) Material : SS400 thickness 6.0mm or more
4) Weight : Approx. 540kg
5) Component : Impregnated activated carbon, 2 layers

D. Blower (Draft Fan)
1) Air Volume / Pressure: 185CMM / 300mmAq
2) Revolving: 2,050 RPM

Primary and Secondary Scrubber	Adsorption tower & blower
	

Figure-2.7 Air Pollution Prevention Facility

2.8 Control Panel

The control panel is controlled by programmable logic controller (PLC) communication. It is configured as follows.

1) It consists of indicator lamps that indicates all functional states of facilities such as power on / off push button, sensing temperature gauge, pressure gauge, system error warning and so on.

2) Type: Double door sealed Self-standing type or according to manufacturer's specifications.

3) Structure: The control panel is designed and manufactured for comprehensive operation and operation of the components. Automatic or manual operation is designed to be possible at the control center.

4) Material：Cabinet shall be manufactured by aluminum or galvanized steel plate 1.5 mm thick or more and shock resistance.

5) Structure
- The control panel receives electric power from the low-voltage switchboard.
- Power shall be supplied from primary side as power source for equipment composed for operation, monitoring and control.

- Automatic / manual changeover switch and indicator lamp shall be provided so that manual operation can be performed for the error of automatic interlocking device.
- The control panel shall be equipped with an inscription plate that show the name and voltage of each device. And each operation switch shall be equipped with an inscription plate that shows the purpose of use.

Overall Control Panel


Figure-2.8 Overall Control Panel

3. Measures to Avoid Environmental Pollution

3.1 Atmosphere

3.1.1 Air pollutant generation

Through waste plastics low-temperature pyrolysis process, air pollutants occur at 1) storage and storage facility, 2) low temperature thermal decomposition facility, 3) combustion process of gas, refined oil and refined gas.

1) Storage and storage facility

Waste plastics as a raw material for pyrolysis process shall be stored in a separate warehouse building provided as a storage and storage facility. The roof and wall structure shall be furnished so that raw materials do not get wet by rain and snow. The floor of warehouse shall be of concrete floor that is possible to withstand for the use of forklifts.

2) Low temperature pyrolysis facility

Waste plastics are charged into a pyrolysis reactor and sealed, then they are thermally decomposed from a polymer to a low molecule in an oxygen-free and a low-oxygen state and synthesis gas is produced. Subsequently, the synthesis gas is liquefied through gas separator, condenser and various piping. Since all of these processes are carried out in a sealed state, synthesis gas and other harmful substances do not leak outside.

Since the non-condensable gas is refined through a precise gas refining process and is burned as a fuel of gas burner, there is no fear of occurrence of air pollutants. Some non-condensed gases that still remain even if it is burned as fuel for gas burner are compressed at about 9 kg through a syngas compressor and used as an energy source for other purposes.

Here, air pollutants mean particulate and gaseous substances. Through low temperature thermal decomposition facility, PE, PP and PS are converted into syngas while being decomposed, then synthesis gas is liquefied through four stages of condensers to reduce to be a "recycled oil". Therefore, the condenser plays a role partly of air pollution prevention function.

3) Recycled oil and refined gas (non-condensable gas) burning

Energy is necessary to induce low temperature thermal decomposition reaction of waste plastics. A recycled oil and purified gas generated through the process are used for energy supply. In the initial stage of operation of the pyrolysis furnace, refined oil already produced is used. From the point of time when synthesis gas is generated, purified non-condensable gas is used as an energy needed for operation of pyrolysis furnace.

Air pollutants may be emitted during the combustion process. As shown in Table 4.1, when a light fuel is burned, dust, sulfur oxides (SOx) and nitrogen oxides (NOx) might be generated at concentrations of 16.04 mg / Sm^3, 43.5 ppm, and 85.4 ppm, respectively. When the purified gas is burned dust, sulfur oxide (SOx), nitrogen oxide 78.8 ppm might be generated at a concentration of 4.54 mg / Sm^3, 0.25 ppm, respectively.

3.1.2 Amount of air pollutants generated

For the amount of air pollutants generated by burning of refined gas and refined oil,

the regulated value must be considered at first. Applicable regulatory values stipulated by the Notification of National Institute of Environmental Science Air Pollution Emission Value (No. 2012-10). For purified gas, gases of which main components are C3 or higher are applied, and regenerated oil is applied for other liquid fuel. Table 5.2 shows the content of the notification. And Table-3.1 shows the amount of air pollutants generated in dust, sulfated oxides and nitrogen oxides.

Table-3.1 Air Pollutant Calculation

Fuel	Unit	Light oil	Refined gas	Remarks
Usage Amount	kg/day	766	1,377	
Calorific value Kcal	kCal/kg	7,832	9,556	
Exhaust gas temperature	℃	40		
Air ratio		1:2		
Exhaust gas volume	Sm³/kg	8.66	10.12	Exhaust gas volume
Theoretical exhaust gas volume	Sm³/kg	8.69	10.61	Theoretical exhaust gas volume
Actual wet displacement;	Sm³/kg	10.42	12.63	Actual wet displacement;
Exhaust gas volume	Sm³/day	7,986	17,395	Exhaust gas volume
Theoretical exhaust gas volume	Sm³/kg	8.69	10.61	Theoretical exhaust gas volume
Actual wet displacement;	Sm³/kg	10.42	12.63	Actual wet displacement;
Exhaust gas volume	Sm³/day	7,986	17,395	Exhaust gas volume
Operation time	Time	4	7	Operation time
Hourly emissions	Sm³/hr	1,996	2,485	
Standard state emissions	Sm³/mts	33.28	41.42	
Actual emissions	m³/min	40.59	50.52	@60℃
Everyday dust generation	g/day	156.3	96.4	See < table 4.3 >
Daily SOx generation amount	g/day	1,107	13.8	
Every day NOx emissions	g/day	1,562	3,139	
Dust concentration	mg/Sm³	16.04	4.54	Below 50
SOx concentration	ppm	43.5	0.25	Below 400
NOx concentration	ppm	85.4	78.8	Below 200

Table-3.2 Air pollutant emission count
(National Institute for Environmental Studies)

Appended Table 3. Other Emission Factors of Air Pollutants of Fuels (Article 4)				
Kind of Fuel	Air Pollutant Emission Factor			
	Dust	Sulfurized Nitrogen	Nitrogen Oxide	Unit
Carbon Monoxide	0.03	0.01	3.70	kg/10³m³
Methane				
Ethane				
Acetylene				
Hybrid gases which are C 1 -C 2 main components				
Gases whose main ingredient is C 3 or more	0.07	0.01	2.28	kg/ton
Naphtha	0.24	17.05	2.40	kg/kℓ
Methanol				
Ethanol				
Benzene				

Toluene Other Liquid Fuel				
Wood	31.776		5.24	kg/ton
Wood pellets	0.93		2.42	
Other solid fuel	5.0A	19.5S	5.83	kg/ton
※ C_1 C_2 C_3 refers to the number of carbon atoms. S is the sulfur content (%) in the fuel, and A is the fuel ash content (%).				

Table-3.3 Amount of Air Pollutant Generated by Burner Operation

Burner		Gas Burner	Oil Burner	total
Applicable fuel		LPG similar	A heavy oil	
Usage time /hr		20㎥//hr	191.5kg/hr	
Density at normal pressure		About 2.5g/L	About 0.85kg/L	A
Daily usage time		7 hrs	4 hrs	Maximum criteria
Annual working days usages		300days	300days	
Annual usages		105,000kg/year	270,353L/year	
Dust	Emission	0.07g/kg	0.24g/ L	
	Occurrence	0.0074ton/year	0.0649ton/year	0.0722ton/year/8
Sulfur	Emission coefficient	0.01	1.7	
	Occurrence	0.0011ton/year	0.4596ton/year	0.4607/year
Nitrogen oxides	Emission coefficient	2.28g/kg	2.40g/ L	
	Amount generated	0.2394ton/year	0.6488ton/year	0.8882ton/year

When 4 gas burners and 4 oil burners for 1 pyrolysis facility is operated, the annual emissions of dust, sulfate oxides and nitrogen oxides can be estimated at 3.548 tons. This complies with 4th type business place that is stipulated in the "atmospheric environment conservation law" enforcement order "seal 1 "(The total of the amount of air pollutants generated is at least 2 tons and less than 10 tons per year)"

3.1.3 Air Pollution Control Facility Plan

1) Removal of Dust

Dust can be easily removed with Wet Scrubber. In general, 90% of dust can be removed. The type of liquid to be applied is selected according to the type of contaminants removed at the same time and the type of additional prevention facility in the latter stage. The contaminants to be simultaneously removed are SOx and NOx, these are removed by adding NaOH to circulating water of water scrubber since these are acid gases. This facility is designed as a two-stage system consisting of a scrubber (1) and a scrubber (2) to remove dust and pollutants in order to maintain the pollutant removal efficiency and stability.

2) Removal of SOx

Wet and dry removal methods are used as a method of removing SOx by chemical bonding that use chemicals, but these methods are generally used when discharging of SOx at high concentration rate. However, when burning refined recycled oil, the estimated concentration of SOx is as low as 191.8 mg / s m³ therefore chemical treatment is not necessary. SO_2 in SOx is dissolved at 22.8% of the weight. SO_3 is converted to SO_4 or

$(SO_3)_2$ and forms H_2SO_4 (Refer Perry's Chemical Engineers' Handbook, 17th edition) a wet process for dust removal is applied and a removal rate is conservatively calculated at approximately 20%.

3) Removal of NOx

There exist selective reduction method (SCR) and non-selective reduction method (SNCR) as methods for removing NO_X, but these methods are mainly applied to high concentration of exhaust concentration. In this facility, as the emission concentration is low, these methods are not applied. In NOx, N_2O_5 is dissolved at 130.52 kg per 100 g in weight, 7.34 kg of NO is dissolved and a part of N_2O_3 and N_2O_5 is dissolved. NO_2 is dissolved and converted to NO_3 (Refer Perry's Chemical Engineers' Handbook, 17th edition). Therefore, a wet process is applied for removing NOx, it was conservatively estimated to remove NOx about 40%.

4) Removal of Other Contaminants

The pollutants discharged from the combustion gas are determined by the type of fuel. The refined regenerated oil and refined regeneration gas used as fuel of burners are generated through the low temperature thermal decomposition process. In the case of refined recycled oil, the concentration of sulfur (S) is about 0.001% (refer to the test results table) and the sulfur content is very low compared with the low sulfur oils in the market, therefore it can be said that it is a fuel with a low fear of pollution. The refined regeneration gas is discharged as a combustion gas after neutralization → purification process, therefore it can be said that it is a fuel that is less likely to pollute. When applying the discharge volume estimation 0.1% was applied in consideration of margin.

3.2 Malodor

3.2.1 Malodor substance generation

"Odor" in the "Malodor Countermeasure Law" refers to sulfur hydrogen, mercaptans, amines, and other irritating substances which stimulate the human sense of smell and give a sense of discomfort and disgust, called "designated malodors" . These are substances that cause offensive odors and mean that they are prescribed by the Ordinance of the Ministry of the Environment. "Complex malodor" defines that two or more malodorous substances act together to give an unpleasant feeling and a disgusting odor by stimulating the human sense of smell. The designated malodorous substances and emission allowance criteria of "Enforcement Regulations for Odor Control Law (Mark 1)" are as shown in "Table-3.4" and "Table-3.5".

Table-3.4 Designated malodorous substance

Kind of Designated Malodor Substance	Molecular formula	Solubility in water (%)	Wet process applied
01. Ammonia	NH_3	38	Applied
02. Methyl mercaptan	CH_4S	2.4	Applied
03. Sulfur hydrogen	H_2S	2.58~2.9	Applied
04. Dimethyl Cell Paid	C_2H_6S	slightly dissolved	—
05. Dimethyl sulfide	$C_2H_6S_2$	Not substantially dissolved	—
06. Trim ethylamine	C_3H_9N	41,000mg/100g@19C	Applied
07. Acetaldehyde	C_2H_9O	Applied	—
08. Stylen	C_8H_8	0.02	Applied
09. Propionaldehyde	C_3H_6O	20	Applied
10. Beauxy laldehyde	C_4H_8O	7	Applied
11. n-valeraldehyde	$C_5H_{10}O$	slightly dissolved	—

12. i-Valeraldehyde	$C_5H_{10}O$	—	—
13. Toluene	C_7H_8	0.05	Applied
14. Gyren	C_8H_{10}	insoluble	-
15. Methylethylketon	C_4H_9O	27.5	Applied
16. Methyl isobutyl cateon	$C_6H_{12}O$	1.9	Applied
17. Butyl Acetide	C_4H_8O	Slightly soluble	—
18. n-Butyric acid	$C_3H_5O_2$	g	—
19. Propionic acid	$C_4H_6O_2$	insoluble	—
20. n-valeric acid	$C_5H_{10}O_2$	—	—
21. i-Barrelic acid	$C_5H_{10}O_2$	25g/L	Applied
22. i-Butyl alcohol	$C_4H_{10}O$	slightly dissolved	—

Table-3.5 Specific Offensive Odor Emission Allowance Standards

Kind		Emission allowance standard (ppm)		Strict emissions standards (ppm)
		Industrial Area	Other Area	Industrial Area
1	Ammonia	Less than 2	Less than 1	1 ~ 2
2	Methyl mercaptan	Less than 0.004	Less than 0.002	0.002 ~ 0.004
3	Sulfur hydrogen	Less than 0.06	Less than 0.02	0.02 ~ 0.06
4	Dimethyl Cell Paid	Less than 0.05	Less than 0.01	0.01 ~ 0.05
5	Dimethyl sulfide	Less than 0.03	Less than 0.009	0.009 ~ 0.03
6	Trim ethylamine	Less than 0.02	Less than 0.005	0.005 ~ 0.02
7	Acetaldehyde	Less than 0.1	Less than 0.05	0.05 ~ 0.1
8	Stylen	Less than 0.8	Less than 0.4	0.4 ~ 0.8
9	Propionaldehyde	Less than 0.1	Less than 0.05	0.05 ~ 0.1
10	Beauxyladehyde	Less than 0.1	Less than 0.029	0.029 ~ 0.1
11	*n*-Valeraldehyde	Less than 0.02	Less than 0.009	0.009 ~ 0.02

3.2.2 Odor Control Facility

1) Wet Scrubber

Wet scrubbers for removing air pollutants is possible to remove substances including ammonia, methyl mercaptan, sulfur hydrogen, trimethylamine, styrene, propionaldehyde, butyraldehyde, toluene, methyl ethyl ketone, methyl isobutyl ketone and the like as shown in Table-3.5. The solubility in water (%) means an amount which is dissolved with respect to 100 g.

Tabl-3.6 Removal of Specific Malodorous Substances by Wet Process

Designated malodor type	Molecular Formula	Solubility in Water (%)	Wet Process Applied
01. Ammonia	NH_3	38	Applied
02. Methyl mercaptan	CH_4S	2.4	Applied
03. Sulfur hydrogen	H_2S	2.58~2.9	Applied
04. Dimethyl Cell Paid	C_2H_6S	slightly dissolved	—
05. dimethyl sulfide	$C_2H_6S_2$	Not substantially dissolved	—
06. Trim ethylamine	C_3H_9N	41,000mg/100g@19C	Applied
07. Acetaldehyde	C_2H_9O	Applied	—

08. Styrene	C_8H_8	0.02	Applied
09. Propionaldehyde	C_3H_6O	20	Applied
10 . Beauxylaldehyde	C_4H_8O	7	Applied
11 . n-valeraldehyde	$C_5H_{10}O$	slightly dissolved	—
12 . i-Valeraldehyde	$C_5H_{10}O$	—	—
13 . Toluene	C_7H_8	0.05	Applied
14 . Gyren	C_8H_{10}	insoluble	-
15 . Methylethylketon	C_4H_9O	27.5	Applied
16. Methyl isobutyl Cateon	$C_6H_{12}O$	1.9	Applied
17 . Butyl Acetide	C_4H_8O	Slightly soluble	—
18 . n-Butyric acid	$C_3H_5O_2$	g	—
19 . Propionic acid	$C_4H_6O_2$	insoluble	—
20 . n-valeric acid	$C_5H_{10}O_2$	—	—
21 . i-Barrelic acid	$C_5H_{10}O_2$	25g/L	Applied
22 . i-Butyl alcohol	$C_4H_{10}O$	slightly dissolved	—

3) Deodorizing Tower

Air pollutants and malodorous substances not removed by wet scrubbers are air cell pollutants and malodorous substances such as Dimethyl Cell Paid (C_2H_6S), Dimethyl Sulfide ($C_2H_6S_2$), Acetaldehyde (C_2H_4O), n-Valeraldehyde ($C_5H_{10}O$), i - Valeraldehyde ($C_5H_{10}O$), Gyren (C_8H_{10}), Butylacetide $C_4H_8O_2$), Propionic Acid ($C_3H_5O_2$), n-Butyl Acid ($C_4H_6O_2$), n-Barrel Acid ($C_5H_{10}O_2$), and i-Butyl Alcohol ($C_4H_{10}O$). In order to remove such substances etc., adsorption method is used as its operation is simple and efficiency is proved in general.

Activated carbon is used as the adsorbent. Sulfur hydrogen, methyl mercaptan and the like adsorb 20 to 50 g / kg with ordinary activated carbon. Ten times or more can be removed by impregnated activated carbon containing trivalent iron. "Table 6" shows malodorous substances that can be removed by activated carbon for residual malodorous substances through a wet type scrubber. In Table-3.6, malodorous substances that can be removed by activated carbon acting on residual malodorous substances were indicated by a wet type scrubber.

Table-3.7 Removal of Malodorous Substances by Activated Carbon

Odor Substance	Effectivity of Removal
Dimethyl sulfide	excellent
Acetaldehyde	normal
n-valeraldehyde, i-valeraldehyde	defect
xylene	very good
Butyl Acetate	very good
Propionic acid	very good
n-Butylic acid	very good
n-Valeric acid	very good
I-Buckle alcohol -	very good
<Evaluation Criteria> 1) Very good : 20 ~ 50% or more removed 2) Excellent: 10 ~ 25% 3) Normal: 15% or less	

Impregnated activated carbon is also used in desulfurization applications. Utilizing this, deodorization tower is designed and installed to remove malodorous substances by filling it with impregnated activated carbon at the second stage of wet scrubber.

4. Adjustment of Quality of Recycled Pyrolysis Oil

The recycled pyrolysis oil produced is further refined by Recycled Pyrolysis Oil Refining Machine (STRM) that is added as the final process of Waste Plastics Pyrolysis Oil Recycling process to refine the pyrolysis oil meeting with the standard specifications of diesel fuel for power generation and internal combustion engine. The STRM is composed of following major devices.

1) Recycled pyrolysis oil receiving tank
2) Stirring tank
3) Thin-film Evaporator
4) Reaction Still
5) Condensers
6) Tail gas purification unit
7) Desulfurization reactor
8) Refining tank
9) Product storing tank; and
10) Control panel.

5. Summary of Major Equipment

The function and number of major equipment composed on one VESTA-10 is as follow:

(A) Pyrolysis Waste Plastics Oil Recycling Plant

The kind of equipment, function of each equipment and number of unit is as summarized in Table-5.1.

Table-5.1 Major Equipment Composing VESTA-10 Model and Their Functions

	Equipment	Number of Unit	Function
1	Rotary Furnace	2	40m³ ＜Average weight of waste plastic – 8 tons per batch＞ Reactor is of double structure. An inner part is rotated at 0.4 rpm. The inner temperature goes up to maximum 430°C by burners. The inner temperature is measured by sensor and controlled from control console. When the objects for processing is charged into reactor, an additive made of bio- technology is charged at the same time at a volume of 1/1000 of the total volume of objects. This additive increases the effectivity of oil recycling performance and the quality of oil recycled and produced.

2	Heating Burners	2	The dimensions of heating furnace is around 9,700mm (L) * 2,350mm (W) * 800mm (H) constructed by heat resistance bricks and equipped with a number of oil and gas burners. The flame of burner is scattered by Flame Scattering Apparatus furnished inside of combustion furnace. The heat of flame is transferred to the reactor. This makes possible to increase the inner temperature of reactor evenly. Three (3) oil burners and three (3) gas burners are installed. All these burners use the recovered oil (low quality) generated from the oil recycling process
3	1st Gas Separator	1	Gas generated is accumulated at the upper part of this air separator. Water and wax are eliminated from gas by this apparatus. When the temperature of this reactor goes up to 120℃ a steam will be collected and it is separated through the outlet furnished at the top of air separator. Then the temperature goes up to 160℃, a synthetic gas and wax are generated then the inner pressure of this air separator will increase to 0.01-0.02 Mpa. The wax is dropped to bottom of this air separator by gravity and it is discharged through the outlet furnished at the bottom of this air separator.
4	2nd Gas Separator	1	Subsequently when the temperature of reactor goes up to 300℃, heavy fuel and light fuel are generated. The synthesis gas is moved to Reservoir of Generated Gas
5	Gas Reservoir	1	The inflammable gas generated is reserved and supplied to the burners as a fuel for heating the furnace.
6	Condensor-1		Inside of this condenser is of double structure. The gas generated passes an inner part and the cooling water passes an outer part of the condenser. The gas is cooled and separated from gas as a light oil. The light oil reserved is discharged from the bottom of separator and transferred to Recycled Oil Reserving Tank.
7	Condensor-2	1	- Ditto -
8	Condensor-3	1	- Ditto -
9	Condensor-4	1	- Ditto -
10	Condensor-5	1	- Ditto -
11	Product Tank	1	The tank for receiving and storing the recycled pyrolysis oil.

12	Cooling Chiller (tower)	1	Capacity 150 RT. A circulation water is cooled by this chiller and chilled water is supplied to condensers and other apparatus. The cooling water is circulated thus no waste water is discharged from the plant.
13	Water Tank for Chiller	1	A reservoir tank for circulation water cooled by chiller
14	Buffer Tank	1	Pressure adjustment tank for gas line of off-gas refining unit
15	Gas Neutralization Tank	1	The emitted gas heated by burner is cooled down and connected to processing apparatus for emitted gas
16	Gas Water Seal Tank	1	Remove impurity material and clean syngas by passing pyrolysis gas primary naturalized through sedimentation process in soluble water
17	Heat Exchanger	1	Temperature reducing unit. Lower temperature of exhaust gas heated by oil burner and gas burner by circulated cooling water.
18	1st Scrubber	1	Minutes particles contained in emitted gas is captured and separated by water shower.
19	2nd Scrubber	1	Further more the particles still remained in emitted gas is captured and separated by water shower.
20	Adsorption Tower	1	This cylinder is filled with catalysts to absorb odor of emitted gas.
21	Draft Fan (blower)	1	The exhaust air of burner is sucked and discharged to exhaust port
22	Exhaust Duct	1	Exhaust gas is emitted through this duct.
23	Fuel Oil Tank	1	Fuel for
24	Control Panel	1	

(B) Recycled Oil Refining Unit

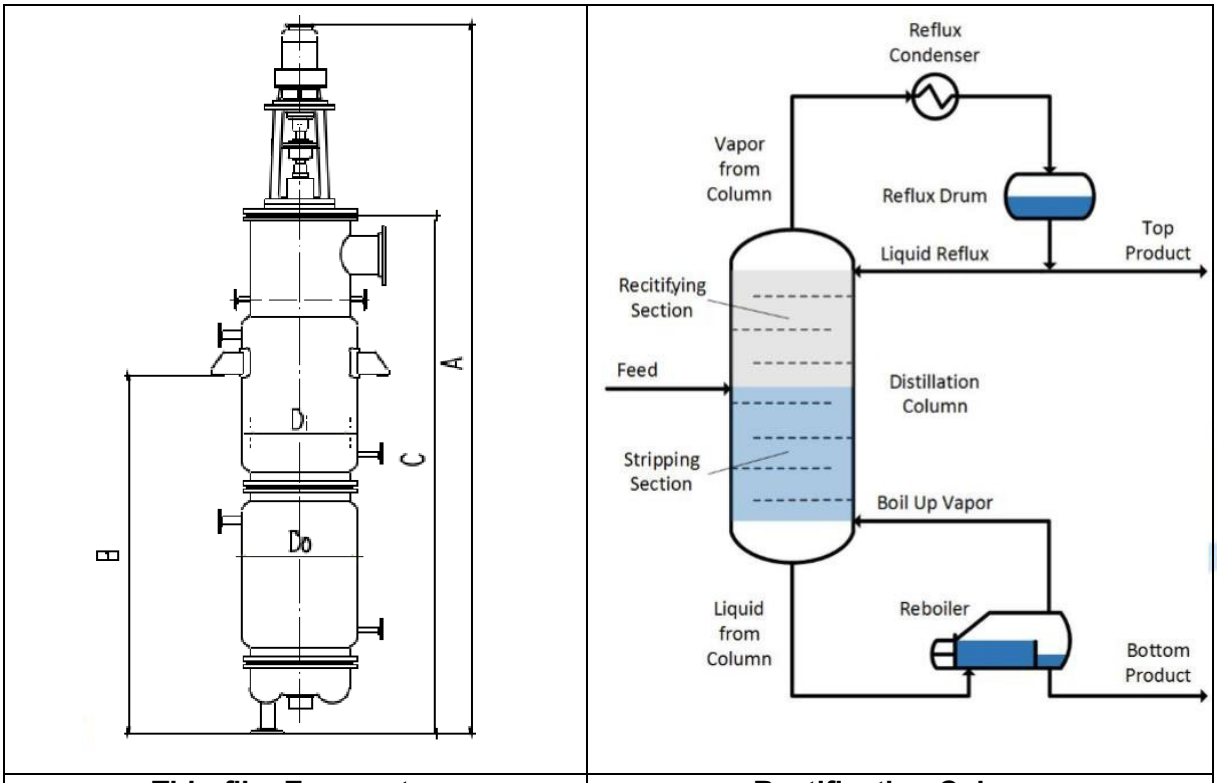
The major equipment composed of one recycled oil refining unit and their respective function is as shown in Table-5.2.

Table-5.2 Major Equipment Composing of Recycled Oil Refining Machine (STRM)

	Equipment	Number of Unit	Function
1	Recycled pyrolysis oil receiving tank with pressure pump	1 set	Recycled pyrolysis oil is received by this tank and pumped to subsequent process.
2	Stirring Tank with pressure pump	1 set	Recycled pyrolysis oil transferred to this tank is stirred and pumped to subsequent process.
3	Thin Film Evaporator with storage tank pressure pump	1 set	This apparatus removes the moisture and light hydrocarbons out of recycled pyrolysis oil transferred to this

			apparatus efficiently without damaging the oil substances by removing the water and light hydrocarbons that are mixed in the processed oil to this stage aiming at increase the flash point of the product.
4	Reaction Still combined with Rectifying Colum	1 set	This apparatus is designed and constructed with precisely calculated numbers and distances of column plates, With PPGT patented column packing, the optimal effect of gas-liquid Mass Transfer Process (the multiple contacts by gas phase and liquid phase on the packings of rectifying column is ensured. A complete separation of light hydrocarbon from recycled pyrolysis oil to get precise cuts of diesel fractions is ensured. High flash point and cetane number are ensured by this process.
5	Condenser-1 with storage tank with pressure pump	1 set	
6	Condenser-2 with storage tank with pressure pump	1 set	
7	Vacuum System	1 set	
8	Tail Gas Purification Unit	1 set	Gas remained in the condenser is transferred to gas purification unit to avoid any environmental adverse effect.
9	Desulfurization Reactor	1 set	Desulfurization by use of catalyst and adsorbent to reduce sulfur contents to less than 100 ppm.
10	Refining Tank with pressure pump	1 set	To remove the particles, suspended materials and damaged additives from waste oil, cracking the waste oil, and thereby improve the coking of distillation column. Through this process the purity, cetane number and flashpoint of produced diesel fuel to meet with the ASTM standards.
11	Product Storage Tank with pressure pump	1 set	Product produced which is equivalent to the character of diesel is stored in this tank for delivery.

Figure-5.3 illustrates the outlook of Thin-film Evaporator and Rectification Column.



Thin-film Evaporator	Rectification Column

Figure-5.3 Thin-film Evaporator and Rectification Column

6. Configuration of Plant and Production Performance

6.1 General

The Pyrolysis Waste Plastics Oil Recycling Plant is composed of (A) Pyrolysis Waste Plastics Oil Recycling Unit, (B) Recycled Oil Refining Unit and (C) Raw Material Loading Machine. The outline of these units and machine are as follows:

(A) Pyrolysis Waste Plastics Oil Recycling Unit

The pyrolysis waste plastics oil recycling unit is designed to convert any solid hydrocarbon waste such as waste plastics; waste vinyl sheet for agriculture and construction use; waste end of life rubber tires; waste industrial electric cables and wires, etc. into diesel equivalent fuel and carbon black at high conversion ratio through pyrolysis technology without releasing any harmful exhaust gas to ambient. The indicative conversion rates against raw material weight by kind of recycled product are as shown in Table-6.1 below.

Table-6.1 Conversion Rate from Row Material to Recycled Product

	Recycled Products	Conversion Rate	
		Waste Plastics	Rubber Tires
1	Diesel equivalent fuel oil	60%	
2	Heavy fuel equivalent fuel oil		60%
2	Carbon Black	20%	20%
3	Steel scrap		10%
4	Residual	10%	10%
5	Off-gas	10%	
	Total	100%	100%

Note:

1) The conversion rate stated above are approximate value and depend on the character of raw materials.

VESTA-10 model is designed to be operated by batch system. The maximum volume of raw materials to be charged into one rotary furnace is 8 tons per batch. The loading of raw material is recommended to be carried out by (C) Raw Material Loading Machine. The list of equipment composing one pyrolysis waste plastics oil recycling unit is as shown in Appendix-1.

(B) Recycled Oil Refining Unit

The recycled oil refining unit is designed to refine recycled oil produced from waste solid hydrocarbon products such as waste plastics and end-of-life rubber tires through pyrolysis waste plastics oil recycling unit described above. The list of equipment composing one recycled oil refining unit is as shown in Appendix-2.

The refining capacity of refined oil is one (1) ton per hour. The specification of refined oil is targeted to meet with the standards of petroleum products for marketing in Bulgaria. The targeted specification of refined oil is as stated in Appendix-3.

(C) Raw Material Loading Machine

The raw material loading machine is recommended to use for charging waste plastics packed appropriately for handling. The base of raw material loading machine is a diesel engine driven front-end loader (forklift) equipped with hydraulic expandable long arm up to 7 m including a clamp. Lifting capacity shall be not less than 1.0 ton at horizontal position.

6.2 Modularization

The configuration of one combined plant as one module is as follow:

A) Pyrolysis Waste Plastics Oil Recycling Plant : 2 sets of Model ST-08/2F
B) Recycled Oil Refining Unit : 1 unit for 2 set of (A)
C) Raw Material Loading Machine : 1 unit for 2 set of (A)

Figure-6.1 below illustrates the floor plan of Pyrolysis Waste Plastics Oil Recycling Plant as one module designed for the Yambol Integrated Power Project.

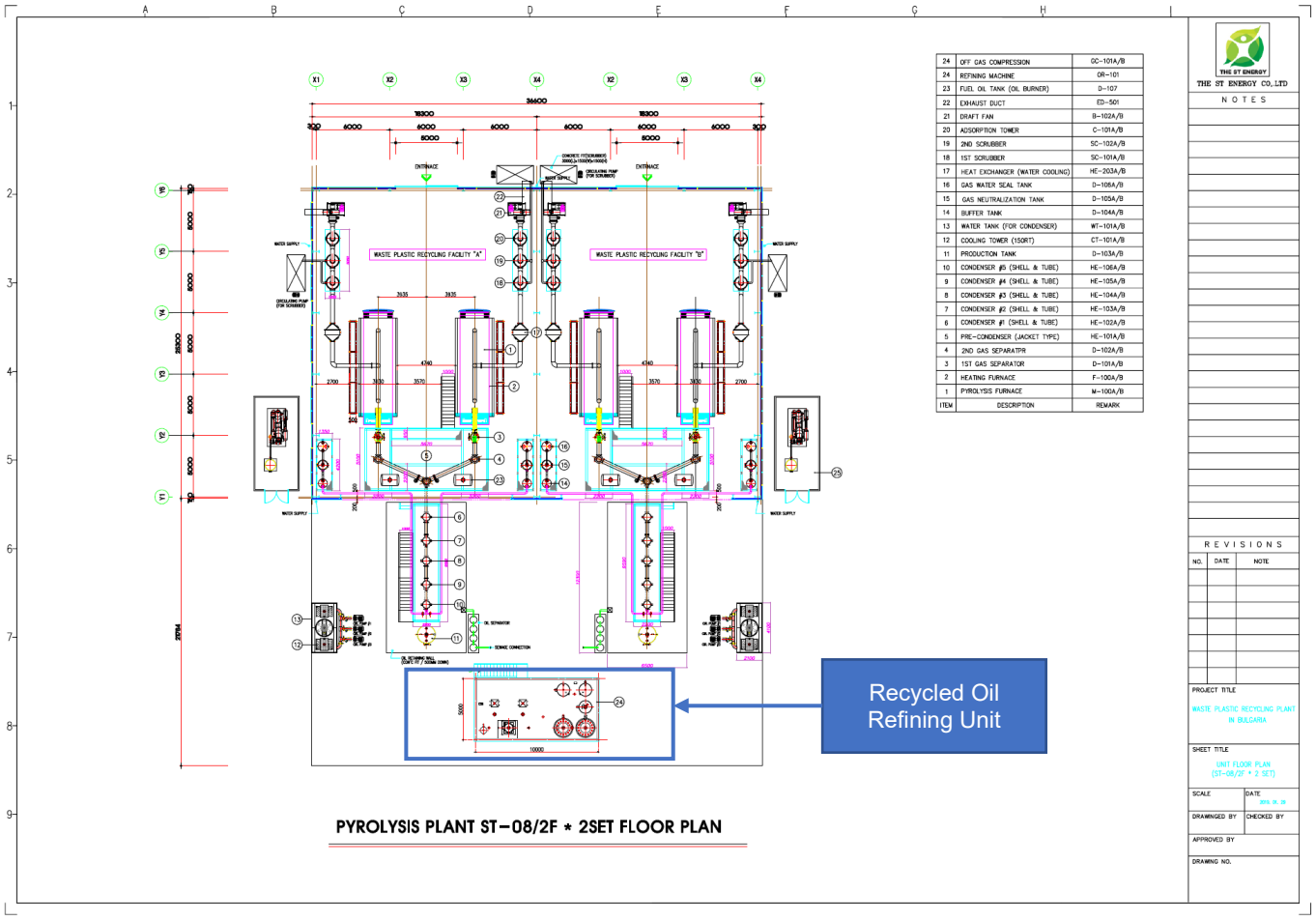


Figure-6.1 Floor Plan of ST-08/2F Model (2 units) as a Module

The location plan of one Recycled Oil Refining Unit is shown in above figure. The floor plan of Recycled Oil Refining Unit is as illustrated in Figure-6.2 below.

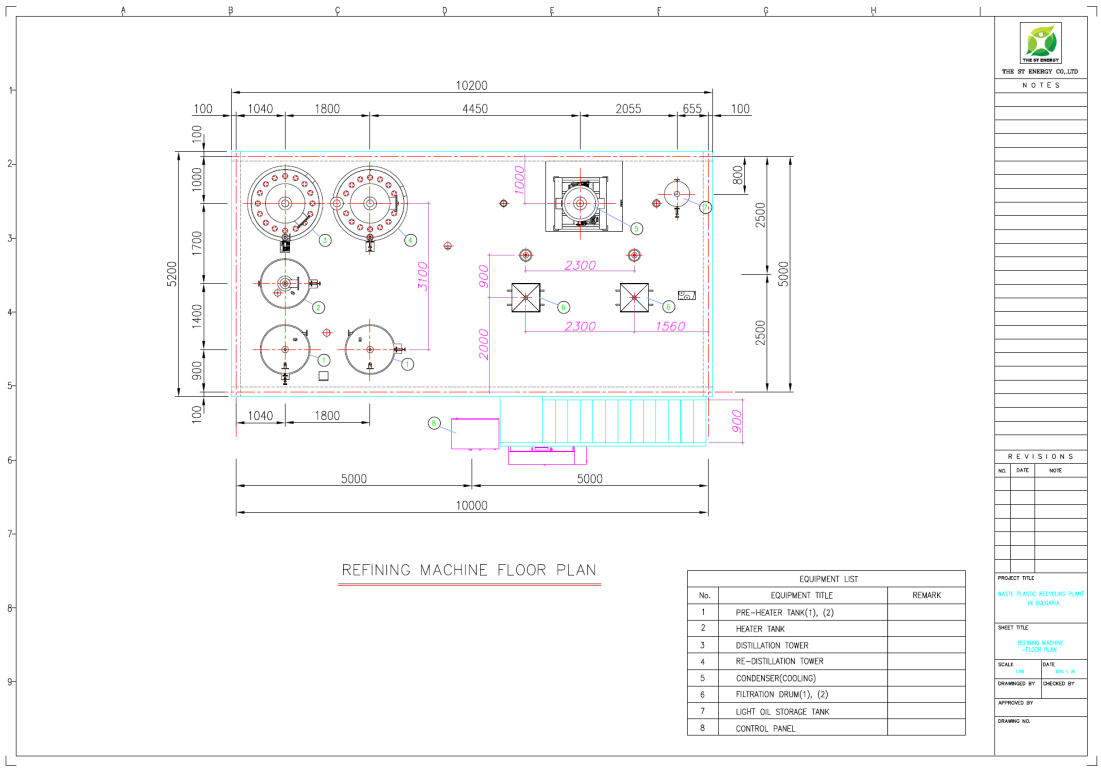


Figure-6.2 Floor Plan of Recycled Oil Refining Unit

It is possible to increase the throughput by arranging the modules side by side. Figure-6.3 illustrates an expanded floor plan with four modules lining up.

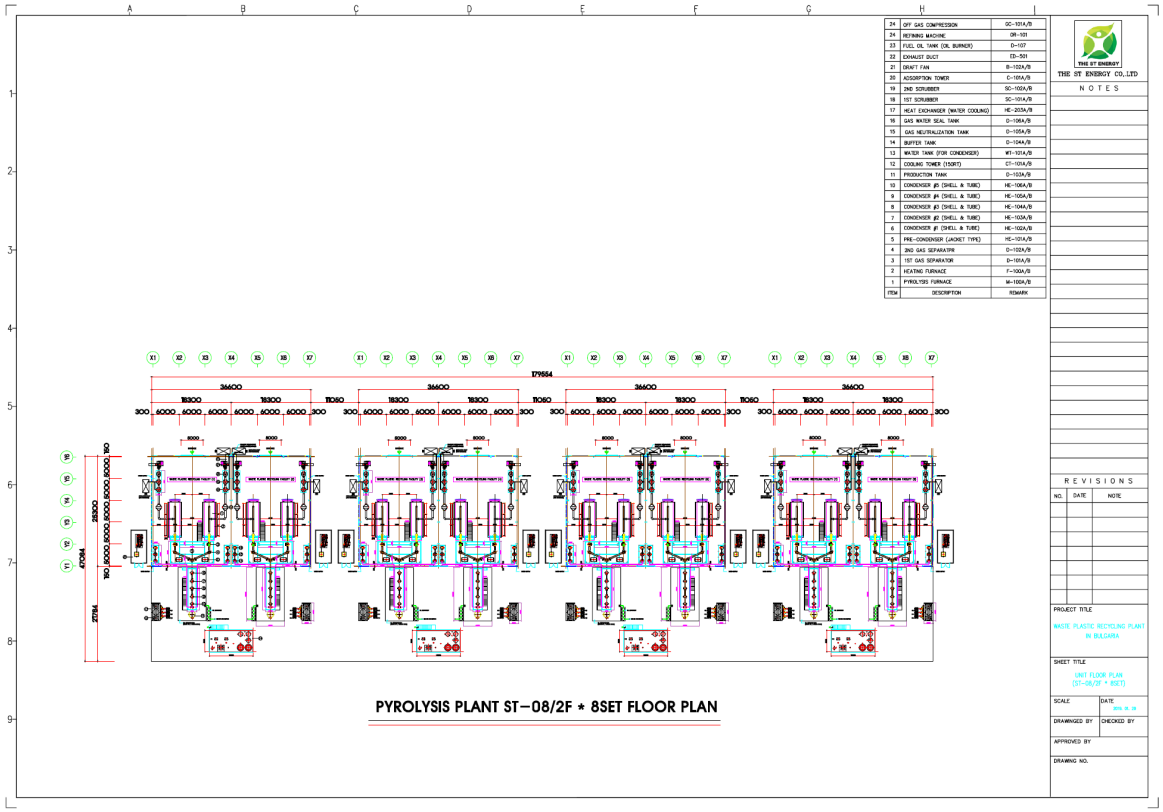


Figure-6.3 Floor Plan of Recycling Oil Refining Unit

7. Operation Mode

The operation mode of pyrolysis oil recycling unit and recycled oil refining unit are as follows:

7.1 Operation Plan of Pyrolysis Waste Plastics Oil Recycling Unit

VESTA-10/2F model is designed to make a tandem or parallel operation of two rotary furnaces possible aiming at maximizing the production capacity. The operation of one rotary furnace is briefly separated in 4 type of operation such as (1) charging raw material to rotary furnace, (2) processing, (3) cooling of rotary furnace and (4) unloading residuals remained inside rotary furnace. A duration of each operation is as shown in Table-7.1 below.

The minimum duration for cooling down the melting furnace is recommended to be not less than 4 hours per one batch operation as shown in below table. This period is very important to follow and it should be strongly followed so as to avoid an explosion of melting furnace, fire accident and injury of operator. The duration of loading and unloading operation is recommended to be one hour for each operation however this can be shortened by mechanical handling of raw material charging and discharging of residual matter.

Table-7.1 Duration of Each Type of Operation

Sequence of Operation	Duration (hour)	Remarks
Loading of raw material	0.5	Recommended to use mechanical loading machine having a hydraulic lifting arm*1
Processing	9.0	Inner part of furnace rotates at 0.4 RPM. Inner temperature and pressure of rotating furnace raise to maximum 430℃ and 0.02 Mpa.
Cooling	4.0	Inner temperature should be lowered at sufficiently low level to avoid explosion when the discharge door is opened.
Unloading of residuals	0.5	By the mechanism provided inside rotary furnace, the residue is automatically collected at the exit by the rotation of furnace.
Total	14.0	Per batch

7.2 Recycled Oil Refining Unit

The operation mode of recycled oil refining unit is continuous and designed to refine around one (1) tons of recycled oil per hour.

7.3 Daily Operation Schedule

Two rotary furnaces are operated in parallel as illustrated in Figure-7.1. As shown in this figure, the processing operation can be carried out in two (2) batches per day.

Day		1 day																							
Hours		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
AM/PM		AM				PM												AM							
Work Shift		1st shift								2nd shift								None							
Time		9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	1	2	3	4	5	6	7	8
No.1	Loading Material		1																						
	Processing			1	2	3	4	5	6	7	8	9													
	Cooling Down												1	2	3	4									
	Unloading	1																							
No.2	Loading Material						1																		
	Processing							1	2	3	4	5	6	7	8	9									
	Cooling Down																1	2	3	4					
	Unloading					1																			

Note:

1) The daily operation schedule proposed above is just a suggestion and it should be fixed by the plant operator.
2) If the duration of one shift is 8 hours and three (3) shifts is possibly adopted; and a raw material volume is sufficient for 3-shifts operation the production volume of recycled oil can be 1.5 times larger than a normal operation by 2-shift operation.

Figure-7.1 Typical Daily Operation Schedule

Appendix-1

Technical Specifications of Pyrolysis Waste Plastics Oil Recycling Unit

NO	ITEM & DESCRIPTION	UNIT	Q'TY
1	**Pyrolysis Oil Plant**		
A	**Melting Equipment**		
	1. Reactor	SET	2
	- Capacity: 40 M^3		
	- Size: 7,700 mm (L) x Ø 2,600 mm x 16 mm (T)		
	- Operating Mode: Horizontal Rotation Mode		
	- RPM of Rotary Furnace: 0.4 RPM		
	- Weight: 25 Ton		
	2. Heating Burner		
	1) Rotary oil burner: 237,000 kcal/hour	EA	3
	- Fuel: Self-produced oil		
	- Special relay for pyrolysis heavy oil pump		
	- Pre-heater		
	- 2 Nozzle High-Low type		
	- Oil piping and electrical wiring		
	2) Gas burner : 200,000 kcal/hour	EA	5
	- Fuel: Recycled off gas		
	- Gas pressure switch & pressure regulator		
	- Gas piping and electrical wiring		
	3. Reactor Base (Heating Furnace)	SET	1
	- Monitoring camera / Control panel monitor link		
	- Check window (heat-resistant glass, air nozzle)		
	- Bearing cooling nozzle		
	- Fire-proof bricks and mortars, castable etc.		
	- Material: SS400 (Flame: H-150 x 150)		
	4. Driving Gear		
	- Motor: 30 HP, 22 kW (Explosion proof type)	EA	1
	- Cyclone speed reducer	EA	1
	5. Exhaust Pipe (Ø300 mm x 6 mm (T)/ Damper)	SET	1
	- Piping from reactor to scrubber		
	6. Sludge Discharger	SET	1
	- Automatic sludge transfer device		
	- Automatic open and close type		
	- Cooling water circulation pump (Jacket type)		
	- Primary terminal hopper		
	- Transport flexible hose / Back filter		
	- Automatic sludge transfer device		
B	**Gas-Dust Separator (I)**	SET	2
	- Size: Ø710 mm x 1,370 mm (H)		
	- Material: SS400, 6T		
	- Operating pressure : < 0.025 Mpa		
C	**Gas Purifying System(Use as fuel after refining)**	EA	5
	- Gas neutralization, deodorization/Buffer tank		
	Size: Ø735 mm x 2,700 mm / STS304, 6T		
	- Gas Cleaning Tank		

	Size: Ø820 mm x 1,630 mm / STS304, 6T		
	- Vacuum pump tank (Ø630 mm x 1,500 mm)		
D	**Heat Exchanger**	SET	1
	- Size: 2,700 mm (L) x 600 mm x 600 mm		
	- Flow speed: < 5 m/s (Tube type)		
	- Material: SS400, 6T		
	- Water-cooled heat exchanger		
E	**Air Pollution Prevention Device**		
	1. Wet Scrubber	EA	1
	- Size: Ø1,200 mm x 3,000 mm / STS304, 4.0T		
	- Capacity: 4,500 ㎥/h		
	2. Deodorization Tower	EA	1
	- Size: Ø1,200 mm x 3,000 mm / STS304, 4.0T		
	- Deodorant (impregnated activated carbon)		
	3. Desulfurization Tower	EA	1
	- Size: Ø1,200 mm x 3,000 mm		
	- Special catalyst		
F	**Cooling System**		
	1. Condenser / Vertical type	SET	4
	- Size: Ø630 mm x 2,820 mm		
	- Operating pressure : < 0.025 Mpa		
	- Type: Shell & Tube / STS304		
	2. Chiller	SET	1
	- Capacity: 20 RT		
	- Operating temperature : < 30℃		
G	**Cooling Tower**	EA	1
	- Size: 80 RT / More than 270,000 kcal/hour		
	- Operating temperature: < 40℃		
H	**Control Panel**	SET	1
	- PLC control method		
	- Load Cell / 60 ton		
	- PLC Monitoring system		
I	**Temporary Storage Tank 1.**	EA	5
	- Size: Ø1,500 mm x 1,500 mm / SS400, 6.0T		
	- Operating pressure : < 0.025 Mpa		
J	**Temporary Storage Tank 2.**	EA	1
	- Size: Ø1,500 mm x 2,000 mm/ SS400, 6.0T		
	- Operating pressure : < 0.025 Mpa		
K	**Fuel Tank**	EA	1
	- Size: Ø1,500 mm x 2,000 mm/ SS400, 6.0T		
	- Material : SS400, 6.0T		
L	**Water Tank**	EA	1
	- Size: 1,500 mm x 1,500 mm x 2,500 mm		
	- Material : STS 304		
M	**Transfer Equipment**	SET	1
	- Air Blower		
	- Flue gas draft fan(Inverter attachment)		
	- Pumps and motors		
N	**Oil pump / Water Pump and Motors**	SET	1
	- Explosion proof type		

0	**Piping & Joint**	SET	1
	- Pipes, Elbow & Tee		
	- STS Bolt & Nut, Pipe clamp		
	- STS Flange (10kg/㎠)		
	- Various valves(Included AOV)		
P	**Other Materials**	SET	1
	- Sight glass, Oil gauge, Sensor		
	- Safety valve, Rupture disc		
	- Catalyst, Gasket, A/C, Demister, etc.		
Q	**Electric Work**	SET	1
R	**Installation Structure**	SET	2
	- Gas-dust separator		
	- Condenser		
	- H-200mm x 200 mm		
S	**Painting**	SET	1
	- Undercoating, Fireproof paint		
Special Notes	1. Basic materials(piping work/instruments) use SUS304, 316 of KS products or JIS standard. High-temperature parts use carbon steel. Basically, speed reducer, various motors / oil and water pumps apply Japanese products.		
	2. The storage tank for recycled oil produced shall be prepared by the client.		

Appendix-2

Technical Specifications

1) Technical Specification of Recycled Pyrolysis Oil Refining Unit

NO	ITEM & DESCRIPTION	UNIT	Q'TY
1	Recycled pyrolysis oil receiving tank;	SET	1
2	Stirring tank;	SET	1
3	Thin-film Evaporator;	SET	1
4	Reaction Still;	SET	1
5	Condenser-1	SET	1
6	Condenser-2	SET	1
7	Tail gas purification unit;	SET	1
8	Desulfurization reactor;	SET	1
9	Refining tank;	SET	1
10	Product storing tank; and	SET	1
11	Control panel.	SET	1
Special Notes			

Appendix-3

Target Specifications of Refined Oil of Recycled Pyrolysis Oil

	Properties	Unit	Value		Test Method	Equivalent Method
1	Total Sulphur content	%(m/m)	>	0.05	KS M ISO 8754	ASTM D4294-10
2	Carbon residue on 10% distillation residue	%(m/m)	>	1.51	KS M ISO 10370	ASTM D4530-11
3	Density at 15℃	kg/m^3	>	0.85	KS M ISO 12185	
4	Water and sediment	(v/v)d %	>	0.01	KS M ISO 3734	
5	Flash point	℃	>	40	KS M ISO 2010	
6	Ash content	% (m/m)	>	0.01	KS M ISO 6245	ASTM D482-12 BDS EN ISO 6245
7	Kinematics viscosity at 40℃	mm^2/s	>	2.612	KS M ISO 3104	ASTM D445-12 BDS EN ISO 3104
8	Distillation (90% recovered)	℃		366.2		ASTM D86-15
9	Cetane index		<	56.2	KS M ISO 4264	ASTM D976
10	Calorific value	kCal/kg		10.500		