Chapter 11
Environmental Management and Technology in Oil Refineries

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1 Purpose of an Oil Refinery

The process of petroleum refining is the physical, thermal and chemical separation of crude oil into marketable products. The primary products are:

- Fuels (e.g. motor gasoline, diesel and distillate fuel oil, liquefied petroleum gas (LPG), jet fuel, residual fuel oil, kerosene);
- Chemical industry feedstock (e.g. naphtha, gasoils and gases);
- Finished non fuel products:

    – Lubricating oils, greases and waxes
    – Bitumen and Asphalt
    – Petroleum Coke
    – Sulphur

- Energy as a by-product in the form of heat (steam) and power (electricity).

Crude oil is a mixture of many different hydrocarbons, other organic compounds and impurities (e.g. oxygen, nitrogen, sulphur, salt and water), with widely ranging properties from gases to substances with very high boiling points. As a result crude oils can vary greatly in their physical and chemical characteristics, depending on their origin. The size, configuration and complexity of a refinery are influenced by the market demand for the type of products, the available crude quality and requirements set by authorities. As these factors vary from location to location, no two refineries are identical.

In 2012 there were 655 refineries worldwide, with a total capacity of around 4400 Mta^{-1} [1]. The world's largest refining region is Asia (25 %), followed by North America and Europe (around 20 % each). In 2013 there were approximately

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120 crude oil refineries in Europe. Due to overcapacity in the European refinery sector, very few refineries have been built in the last 35 years, with 95 % being built before 1981 and 44 % before 1991, i.e. in an era largely before environmental concerns were a major issue for the public, government or industry. Most refineries have since had upgrades and new units built but their overall structure will have remained essentially unchanged.

Refining can be separated into two phases (also sometimes known as simple and complex refineries) and a number of supporting processes.

- **Simple Refinery** which separates the crude oil into its various components or fractions based on different boiling ranges in a distillation column at atmospheric pressure. Vacuum distillation is used to lower the temperature at which the heavier fractions can be separated without thermal decomposition. The desired fractions are collected separately and sent for further processing. This is followed by a further distillation of the lighter components and naphtha to recover methane and ethane to fuel the refinery operations, LPG, gasoline-blending components and petrochemical feedstocks. The yield reflects the crude oil composition. Generally this gives relatively low yields of light products and high yields of residual fuel oil. An increasing number of refineries also have an isomerisation unit to enhance the octane rating of light naphthas. Some simple refineries have bitumen manufacturing facilities involving vacuum distillation and possibly bitumen blowing.
- **Complex refinery** which alters the molecular structure of some of the heavier distillation fractions into lighter molecules, with a higher commercial value, through a range of cracking, coking, reforming, and alkylation processes. This gives higher yields of light products and lower yields of heavy products than in a simple refinery. The majority of refineries worldwide have a fluid catalytic cracking (FCC) unit and an alkylation unit to increase yield and quality of the gasoline pool. In North America, where heavy fuel oil markets are limited, most refineries have a coker. In the European Union (EU), visbreakers are usually installed to reduce the quantity of residual oil produced in the distillation of crude oil and to increase the yield of more valuable middle distillates (heating oil and diesel) by the refinery. A visbreaker thermally cracks large hydrocarbon molecules in the oil by heating in a furnace to reduce its viscosity and to produce small quantities of light hydrocarbons. An Integrated Gasification Combined Cycle (IGCC) unit may also be used to convert the visbreaker residue to power, steam, hydrogen, and some waste streams. Very complex refineries can be designed to produce no residual fuel oil.

   An example of a complex refinery configuration is shown in Fig. 11.1.
- **Supporting operations** may include waste water treatment, energy generation, sulphur recovery, additive production, waste gas treatment, heat exchanger cleaning, blowdown systems, product blending and storage.

A refinery therefore consists of a complex system of stills, crackers, processing and blending units and vessels in which the various reactions take place, bulk storage tanks, and packaging units for products for immediate distribution to the retailer. Bulk storage tanks are usually grouped together in bunded tank farms. These "farms" are used for storage of both crude and refined products.
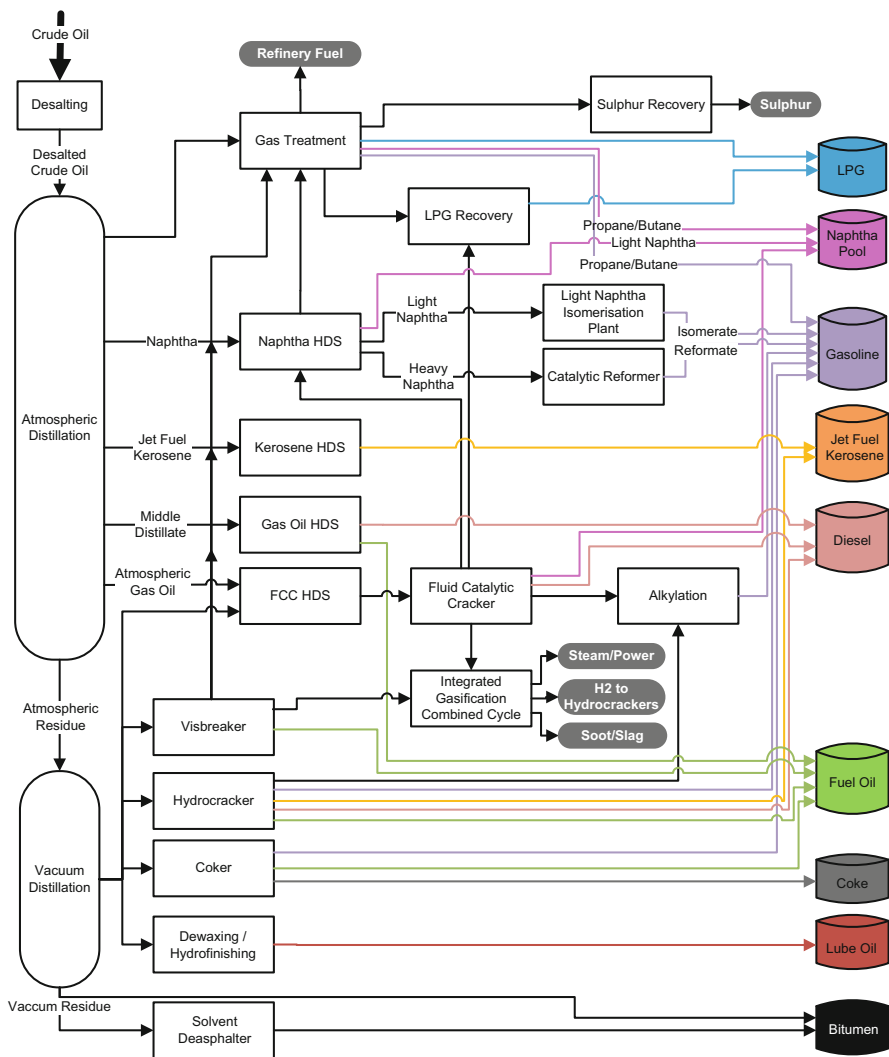
Fig. 11.1 Illustrative complex refinery configuration

Crude oil is transferred into the refinery by a combination of pipeline, roads, rail and marine tanker. Finished products are transferred out of a refinery to smaller distribution terminals by direct pipeline, marine tanker, road or rail.

2 Main Environmental Issues

Crude oil refineries process large amounts of raw materials and consume substantial amounts of energy and water. Emissions to air, water and soil are generated as well as various solid and liquid waste streams.

2.1 *Emissions to Atmosphere*

Oil refining is responsible for a significant proportion of air emissions from industrial activities. Table 11.1 provides an estimation of the contribution to key atmospheric emissions parameters reported for 2007–2012 by EU Member States, Iceland, Liechtenstein, Norway, Serbia and Switzerland in the oil and gas refinery sector.

Typically more than 60 % of refinery air emissions are related to the production of energy for the various processes. Power plants, boilers, heaters and catalytic cracking are the main sources of emissions of carbon monoxide and dioxide, nitrogen oxides (NOx), particulates, and sulphur oxides (SOx) to the atmosphere. Sulphur recovery units and flares also contribute to these emissions. Nitrous oxide (N_2O) is released principally from FCC regenerators. Catalyst changeovers and cokers release particulates. Volatile organic compounds (VOCs) are released from storage, product loading and handling facilities, oil/water separation systems and, as fugitive emissions, from flanges, valves, seals and drains. Other emissions to the atmosphere are H_2S, NH_3, BTX (mixtures of benzene, toluene, and the three xylene isomers), CS_2, COS, HF; heavy metals are also released as particulates.

Refineries will typically have large numbers of permitted routine process release points, which will vary in size and throughput from very small to stacks from large combustion plant. Permits stipulate limits for specific, named pollutants. In order to control these emissions, the facility will be required to monitor emissions and submit findings to the regulatory authorities. In most instances it will be illegal to operate and emit pollutants to the atmosphere without a valid permit. In Europe this is controlled by the Industrial Emissions Directive 2010/75/EU (Integrated Pollution Prevention and Control).

2.1.1 Combustion Related Emissions

NOx Control

Nitrogen oxides are generated in the combustion process from the oxidation of atmospheric nitrogen and nitrogen in the fuel. The primary or process related techniques to prevent NOx emissions to air, as listed in Table 11.2, are: to reduce the nitrogen content in the fuel; to reduce the atmospheric nitrogen oxidised in the combustion process through reduction in oxygen; to reduce the residence time; and to reduce the combustion temperature. Secondary or end-of-pipe techniques serve to reduce or eliminate NOx from the discharges.

Dust and Metal Emissions Control

Particulate emissions are of interest because of their potential adverse impact on health, especially those with a diameter less than 10 μm (PM_{10}) and less than 2.5 μm

Table 11.1 Contribution of oil refining to the European air emissions (2007–2012) [2]

Reporting year	Greenhouse Gases (CO$_2$ Equivalent)		Carbon Monoxide (CO)		Non-Methane Volatile Organic Compounds (NMVOC)		Nitrogen Oxides (NOx)		Sulphur Oxides (SOx)		Heavy Metals		Fine Particulates (PM10)		Chlorinated Organic Substances		Other Organic Substances	
	kt	#sites	kt	#sites	kt	#sites	kt	#sites	kt	#sites	kt	#sites	kt	#sites	kt	#sites	kt	#sites
2007	185,059	217	76	31	206	116	201	126	567	116	0.2	193	7.7	43	0.0	9	2.2	79
2008	191,767	232	86	32	182	117	189	129	504	110	0.2	204	8.4	42	0.1	11	2.0	84
2009	182,638	236	76	30	158	113	172	128	433	110	0.2	199	6.9	41	0.1	10	1.9	80
2010	175,353	231	51	29	135	106	152	120	373	106	0.2	178	6.0	38	0.1	10	1.3	74
2011	172,951	207	56	27	118	96	142	110	353	103	0.1	144	5.2	34	0.1	9	1.2	69
2012	170,134	208	53	29	131	100	139	110	305	101	0.1	134	5.4	33	0.1	10	1.3	62

Table 11.2 Control techniques to prevent or reduce NOx emission from combustion

Approach	Technique
Selection or treatment of fuel	Use of gas to replace liquid fuel
	Use of low nitrogen refinery fuel oil e.g. by selection or by hydrotreatment
Combustion modifications	Staged combustion: air staging and fuel staging
	Optimisation of combustion
	Flue-gas recirculation
	Diluent injection
	Use of low-NO_X burners
Secondary or end-of-pipe techniques	Selective catalytic reduction
	Selective non-catalytic reduction
	Low temperature oxidation
	SNOx combined technique. Dust is removed first using electrostatic precipitation and is followed by catalytic processes to remove sulphur compounds as commercial grade sulphuric acid and NOx as N_2. SOx removal is in the range of 94–96.6 % and NOx removal is in the range of 87–90 % [1]

($PM_{2.5}$). Emitted refinery particulates may range in size from less than a nanometre to the coarse dusts arising from the attrition of catalyst.

The most hazardous refinery particulates contain heavy metals and polycyclic aromatic hydrocarbons, therefore, a reduction in the particle content reduces the metal emissions from the refinery.

Particulate emissions from refineries come from:

- Flue-gas from furnaces, particularly soot when firing liquid refinery fuels if there is sub-optimal combustion;
- Catalyst fines emitted from FCC regeneration units and other catalyst-based processes;
- CO boilers;
- Handling of coke, coke fines and ash generated during the incineration of sludges.

Particulate minimisation techniques include avoidance by replacement or treatment of the fuel, improved combustion and secondary particulate removal as shown in Table 11.3.

Particulate removal techniques are dry, wet, or a combination of the two. The main dry techniques include cyclones, electrostatic precipitators and bag filters. Some wet techniques such as scrubbers may also be used mainly as finishing treatment.

The range of emissions from the majority of European refineries is between 4 and 75 tonnes of particulates per million tonnes of crude oil processed [1]. The lower end of the range being achieved in refineries using substantial amounts of gas combined with effective dust removal.

Table 11.3 Control techniques to prevent or reduce dust and metal emissions

Approach	Technique
Selection or treatment of fuel	Use of gas to replace some or all liquid fuel
	Use of low nitrogen refinery fuel oil e.g. by selection or by hydrotreatment
Selection of catalyst	Higher quality FCC catalyst
	Attrition-resistant catalyst
Combustion modifications	Optimisation of combustion, e.g. improved air-fuel mixing; increase excess air; use of combustion improver additives; increase air pre-heat
	Atomisation of liquid fuel
Secondary or end-of-pipe techniques	Electrostatic precipitator
	Centrifugal separation, i.e. cyclones
	Fabric and solid bundle blowback filter
	Wet scrubbing

Table 11.4 Control techniques to prevent or reduce SOx emissions

Approach	Technique
Selection or treatment of fuel	Use of gas to replace liquid fuel
	Treatment of refinery fuel gas
	Use of low sulphur refinery fuel oil e.g. by selection or by hydrotreatment
Combustion modifications	Optimisation of combustion
	Atomisation of liquid fuel
Secondary or end-of-pipe techniques	Non-regenerative scrubbing
	Regenerative scrubbing
	SNOx combined technique

SOx Emissions Control

The main source of SOx emissions in the refinery is during energy production. During combustion, the sulphur in the fuel is transformed to a mixture of SO_2 and SO_3. As sulphur is a component of crude oil there is a direct relation between the sulphur in the feed to a combustion process and the sulphur oxides in its flue-gas.

SOx emissions also emanate from the catalytic cracking process and sulphur removal and recovery operations. To control SOx emissions, refiners can adopt one or more of the measures in Table 11.4.

In a Sulphur Recovery Unit, the fuel gases (methane and ethane) are separated from the hydrogen sulphide (H_2S) using a solvent (typically amine) to dissolve the H_2S. The fuel gases are removed for use in other refinery processes and the solution is heated and the steam stripped to remove the H_2S gas. The H_2S rich gas streams are then treated in a high efficiency sulphur recovery unit using the Claus process for bulk sulphur removal and a tail gas treatment process to bring sulphur recovery yield to 99 % or more [3].

CO Emissions Control

Carbon monoxide (CO) is an intermediate product of the combustion processes, in particular in understoichiometric combustion conditions. CO emissions may actually be increased with the application of combustion modifications to reduce NOx emissions. This can be limited by careful control of the operational parameters. In addition, the following techniques may also be used:

- Constant delivery of liquid fuel in the secondary heating;
- Good mixing of the exhaust gases;
- Catalytic afterburning;
- Catalysts with oxidation promoters.

CO_2 Emissions Control

A feasible abatement technology for CO_2 is not available. CO_2 separation techniques are available but the problem is the storage and the recycling of the CO_2 and therefore the emphasis must be on emissions reduction. Options to reduce CO_2 emissions are:

- Effective energy management;
- Use of fuels with high hydrogen contents;
- Effective energy production techniques.

2.1.2   Flare-Related Emissions

Flares are used for safety and the environmental control of discharges of undesired or excess combustibles and for surges of gases in emergency situations, upsets, unplanned events or unanticipated equipment failure. Flaring is a source of air emissions and leads to the burning of potential valuable products.

Techniques for the reduction of emissions are given in Table 11.5.

Table 11.5   Control techniques to prevent or reduce flare-related emissions

Approach	Technique
Correct plant design	Sufficient flare gas recovery system capacity.
	Use flaring only as a safety system for other than normal operations (start-up, shut down, emergency).
Plant management	Organizational and control measures to reduce the case of flaring.
Flares design	Efficient combustion of excess gases when flaring from non routine operations.
Monitoring and reporting	Continuous monitoring of gas sent to flaring and associated parameters of combustion.

2.1.3   Non-Methane Volatile Organic Compound (NMVOC) Emissions

NMVOC emissions originate from the evaporation and leakage of hydrocarbon fractions associated with potentially all refining activities, e.g. fugitive emissions from pressurised equipment in process units, storage and distribution losses, and waste water treatment evaporation. Typical sources are control valve stems, flanges, compressor/pump seals, tanks and loading facilities.

The main sources are:

- Fugitive emissions from piping;
- The flare system;
- The waste water treatment plant;
- Storage tanks and refinery dispatch stations.

Techniques to reduce NMVOC emissions focus on prevention and detection of fugitive emissions as shown in Table 11.6.

2.1.4   Odours

The majority of all public complaints regarding refineries are due to odours. Hydrogen sulphide and methyl mercaptan are among the most common odorants from a refinery and are typically generated from storage tanks, sewage systems and oil/water separators. Although they have odour thresholds significantly lower than levels known to cause toxicity, they are nonetheless most often associated with annoyance at levels just exceeding their odour threshold.

The main reduction techniques are covered under atmospheric (see Sect. 2.1) and waste water emissions (see Sect. 2.2).

2.2   Emissions to Water

Potential water contaminants in refinery effluent are:

- Acids, alkalis (pH);
- Oil (free and dissolved);
- Sulphides;
- Ammonia/nitrates;
- Cyanides;
- Heavy metals;
- Heat;
- Other organic materials;
- Nutrients;
- Settleable solids;
- Colour;

Table 11.6 Control techniques to prevent or reduce VOC emissions

Approach		
High integrity equipment		Valves with double packing seals.
		Magnetically driven pumps/compressors/agitators.
		Pumps/compressors/agitators fitted with mechanical seals instead of packing.
		High-integrity gaskets (such as spiral wound, ring joints) for critical applications.
		Floating roof storage tanks equipped with high efficiency seals.
		Fixed roof tank with floating covers connected to a vapour recovery system.
Vapour balancing		The expelled mixture is returned to the liquid supply tank and replaces the pumped-out volume.
Vapour recovery	Absorption	Dissolution in a suitable absorption liquid.
	Adsorption	Retention on the surface of adsorbent solid materials e.g. activated carbon (AC) or zeolite.
	Membrane gas separation	Processed through selective membranes to separate the vapour/air mixture into a hydrocarbon enriched phase (permeate), which is subsequently condensed or absorbed, and a hydrocarbon-depleted phase (retentate).
	Two stage refrigeration/condensation:	Cooling to condense and separate as a liquid.
VOC destruction	Thermal oxidation	Refractory-lined oxidisers equipped with gas burner and a stack.
	Catalytic oxidation	Oxidation accelerated by a catalyst by adsorbing the oxygen and the VOCs on its surface
Leak Detection and Repair (LDAR) programme		An LDAR programme is a structured approach to reduce fugitive VOC emissions by detection (e.g. using sniffing or optical gas imaging methods) and subsequent repair or replacement of leaking components.
VOC diffuse emissions monitoring		Full-screening and quantification of site emissions can be undertaken with an appropriate combination of complementary methods,

- Taste and odour producers;
- Toxic compounds.

Table 11.7 shows the contribution of oil and gas refining to European water emissions 2007–2012.

The largest volume of waste water arises from the distillation, catalytic cracking, and catalytic reforming processes. The waste water from distillation includes condensed steam from the tower (called oily sour water), which contains hydrogen sulphide, ammonia, and oily waste water if barometric condensers are used for vacuum distillation.

Table 11.7 Contribution of oil refining to European water emissions (2007–2012) [2]

Reporting year	Heavy metals		Inorganic substances		Chlorinated organic substances		Other organic substances	
	Tonnes	#sites	Tonnes	Count	Tonnes	Count	Tonnes	Count
2007	66	161	136,040	76	20	13	8015	143
2008	69	193	296,781	79	13	14	7413	175
2009	60	207	263,687	80	28	17	6420	180
2010	47	213	259,635	82	39	15	6521	166
2011	41	203	246,777	77	8	12	5929	128
2012	37	199	225,780	76	24	14	6833	140

Table 11.8 Control techniques for the control of aqueous emissions

Treatment stage	Technique
Cooling water reuse	Closed cooling water circuit where water is cooled.
Waste water pre-treatment	Use of sour water strippers to remove H_2S and NH_3 from process waters prior to reuse/treatment.
	Pre-treatment of other water streams to preserve treatment performance,
Waste water treatment	Oil recovery using gravity separators, plate interceptors and buffer/equalisation tanks.
	Suspended solid and dispersed oil recovery using gas flotation and sand filtration.
	Biological treatment and clarification using fixed bed and suspended systems to reduce the biological oxygen demand and phenolic compounds.
	A polishing step using sand, dual media or multimedia filtration to remove fine particulates.
	External waste water treatment – performed by a plant outside the installation.

Other waste water pollutants include spent potassium hydroxide steam from alkylation, and sour water from visbreaking.

Rainwater falling into process areas may also become contaminated due to entry into production areas, tank systems, secondary containment systems and loading/off loading areas. Good housekeeping practices are required to minimise such contamination.

A refinery site therefore generates a mix of waste water streams containing both soluble and insoluble substances which become pollutants when released. Historically, treatment techniques were directed at reducing the amount of pollutants and the oxygen demand exerted by the waste water prior to release. These end-of-pipe techniques are mature and emphasis is now shifting to prevention and reduction of contaminated waste water streams prior to final treatment units (Table 11.8).

2.3 Soil and Groundwater Contamination

Contamination of soil and groundwater may arise due to the loss of crude, refined products or water containing hydrocarbons as a result of storage, transfer and transport operations. Most refineries have some areas that are contaminated by historical product losses. Current refinery practices are designed to prevent spillages and leaks to the ground. Historically however, the awareness of the potential risks of these contaminated areas was low. The two main issues therefore are the prevention of new spills and the remediation or the remedial control of historic contamination.

2.3.1 Prevention

Measures to control new spills are basically the same as those to control aqueous emissions together with ensuring that areas where oil is regularly handled are covered with an impermeable surface and drain to a dedicated oily water sewer and than tanks are double lined or bunded.

2.3.2 Remediation

Small quantities of contaminated soils or liquids may be managed as hazardous wastes and either treated on site or removed off site for treatment and/or disposal. Larger quantities and gross contamination may require more significant intervention and clean up, especially where it is a hazard or migrating off site. Monitoring regimes are often necessary.

2.4 Waste

The amount of waste generated by refineries is small if it is compared to the amount of raw materials and products that they process. Table 11.9 shows the generation and different waste routes according to the European Pollutant Release and Transfer Register (E-PRTR) declarations.

Waste is classified in Europe according to the European List of Wastes [4] as either hazardous or non-hazardous depending on properties defined in the Waste Framework Directive (WFD) [5] Annex III. It is a requirement under the WFD that wastes are managed according to the proximity principle i.e. as close to the source as possible, but in some cases e.g. where no appropriate facilities exist within the country, it will be necessary to send the wastes outside the country for disposal or recovery.

Table 11.9 Contribution of oil refining to European waste transfers (2007–2012) [2]

Reporting year	Hazardous waste outside country			Hazardous waste within country			Non-hazardous waste			Total waste kt
	Disposal	Recovery	Total	Disposal	Recovery	Total	Disposal	Recovery	Total	
	kt (#sites)	kt (#sites)	kt	kt (#sites)	kt (#sites)	kt	kt (#sites)	kt (#sites)	kt	
2007	3 (5)	37 (44)	40	822 (147)	459 (136)	1282	484 (69)	699 (75)	1183	2505
2008	14 (13)	29 (50)	43	1172 (171)	495 (171)	1667	967 (69)	773 (78)	1740	3450
2009	4 (8)	41 (52)	45	1215 (166)	484 (164)	1699	338 (71)	683 (75)	1021	2765
2010	3 (12)	43 (47)	46	438 (169)	383 (164)	821	231 (75)	476 (89)	708	1575
2011	3 (5)	83 (44)	86	462 (156)	1014 (162)	1476	299 (76)	627 (96)	927	2488
2012	1 (5)	71 (34)	71	324 (154)	542 (157)	866	368 (71)	602 (84)	969	1906

Table 11.10 Control techniques for the management of waste

Technique	Description
Prevention	Good plant operation, materials handling and storage, house-keeping and economy in the use of chemicals.
Sludge pre-treatment	Prior to final treatment the sludge are dewatered and/or de-oiled (by e.g. centrifugal decanters, gravity separators, filtration or steam dryers) to reduce their volume.
Reuse of sludge in process units	Delayed coking technologies can use oily sludges as part of their feedstock.
Segregation of waste streams	According to waste characteristics to enable management via the waste hierarchy.
Spent solid catalyst management	Return to third party (i.e. manufacture or off-site specialist) for recovery or reuse in off-site facilities or correct disposal.
Removal of catalyst from slurry decant oil	Decant oil sludge from process units (e.g. FCC unit) can contain significant concentrations of catalyst fines. These fines need to be separated prior to the reuse of decant oil as a feedstock.

The WFD introduced the concept of the waste hierarchy which states that wastes should be managed in the following order of priority:

- Prevention;
- Preparing for reuse;
- Recycling;
- Other recovery, particularly energy recovery;
- Disposal.

Most oil refinery waste consists of:

- Sludges, both oily (e.g. tanks bottoms) and non-oily (e.g. from waste water treatment facilities);
- Other refinery wastes in liquid, semi-liquid or solid form (e.g. contaminated soil, spent catalysts from conversion processes, oily wastes, incinerator ash, spent caustic, spent clay, spent chemicals, acid tar);
- Non-refining wastes, e.g. domestic, demolition and construction.

Oil retained in sludges or other types of waste represents a loss of product and, where possible, efforts are made to recover such oil. Waste disposal depends very much on its composition and on the local refinery situation. The high operating costs of waste disposal mean that much priority has been given to waste minimisation schemes and management (Table 11.10).

Segregation of waste by its characteristics is fundamental to ensuring efficient management according to the waste hierarchy. Good plant operation, materials handling and storage, housekeeping and economy in the use of chemicals will result in the minimisation of wastes for disposal.

Recycling waste materials for reuse may in many circumstances provide a cost-effective alternative to treatment and disposal. The success of recycling depends on both the ability to segregate recoverable and valuable materials from a waste and the ability to reuse waste materials as a substitute for an input material.

Petroleum sludge wastes are typically water-in-oil emulsions that are stabilised by fine solids. Sludge accumulates in refineries from equipment failure, training and periodic tank cleaning.

Processes for treating petroleum sludge include centrifugation, thermal desorption, solvent extraction, and hydrothermal processing. Electrokinetics is a developing technology that is used for in situ remediation of heavy metals and organic contaminants from saturated or unsaturated soils and sediments.

Process wastes should be tested and classified as hazardous or non-hazardous based on local regulatory requirements and international good practice and disposed of appropriately using authorised and licensed waste disposal operators.

A significant proportion of the non-petroleum outputs can be recovered and sold as by-products, e.g. sulphur, acetic acid, phosphoric acid and recovered metals from catalysts.

Increased use is made of third party waste contractors for off-site treatment, reclamation and disposal. Materials commonly reprocessed off-site by chemical and physical methods include oils, solvents, and recovered metals from catalysts and scrap metal. A strong commitment is required from the recycler not only to upgrade the waste materials for sale or exchange but also in finding suitable markets. The waste producer has a "duty of care" to ensure that the waste is correctly treated and disposed of by any third parties used.

2.5 Energy Consumption

Refineries consume large amounts of energy to generate electricity, heat and steam. Some refineries have installed combined heat and power plants. Typically more than 60 % of refinery air emissions are related to the production of energy [1].

Typical resource and energy consumption of process crude oil for an oil refinery utilising between 200 and 500 ha for land-use would require [6]:

- Total energy between 2100 and 2900 Mjt^{-1} of processed crude oil;
- Electric power between 25 and 48 $kWht^{-1}$ of processed crude oil;
- Fresh make-up water between 0.07 and 014 m^3t^{-1} of processed crude oil.

Good design and management of energy systems are important aspects of minimising the environmental impact of a refinery, bearing in mind the highly integrated and interdependent nature of most processes (Table 11.11).

2.6 Water Consumption

Large volumes of water are used on a continuous basis in a refinery to maintain the water balance in the steam, cooling water, utility service water and emergency fire water supply circuits.

Table 11.11 Control techniques for the management of energy consumption

Technique	Description
Design techniques	
Pinch analysis	Systematic calculation of thermodynamic targets for minimising energy consumption of processes.
Heat integration	Exchanging heat between streams to be heated and streams to be cooled.
Heat and power recovery	Use of energy recovery devices such as waste heat boilers, expanders/power recovery in the FCC unit, use of waste heat in district heating.
Process control and maintenance techniques	
Process optimisation	Automated controlled combustion to lower the fuel consumption combined with heat integration for improving furnace efficiency.
Management and reduction of steam consumption	Mapping of drain valve systems to reduce steam consumption and optimise its use.
Use of energy benchmarking	Participation in ranking and benchmarking activities in order to pursue a continuous improvement by learning from best practice.
Energy efficient production techniques	
Combined heat and power	Production of heat (e.g. steam) and electric power from the same fuel.
Integrated gasification combined cycle (IGCC)	Production of steam, hydrogen and electric power from a variety of fuel types with a high conversion efficiency.

The water usage depends both on purpose and complexity of the refinery. The CONCAWE 2010 survey of 100 refineries [7] reports annual median total fresh water intake of 5.7 Mm^3a^{-1} but these range from 0.14 to 37.8 Mm^3a^{-1} with the annual median fresh water per tonne throughput being 0.70 m^3a^{-1} but similarly ranging from 0.1 to 8.6 m^3a^{-1}.

It is typical for abstraction or water use permits to detail the volumes of water abstraction allowed, as over abstraction can affect local communities and also natural resources.

Drinking water sources, whether public or private, should be protected so that they meet or exceed applicable national standards or in their absence the current edition of World Health Organisation (WHO) Guidelines for Drinking Water Quality [8].

Water requirements for site workers and staff can be met through mains water supply or ground/surface water abstraction which should be properly assessed using testing techniques/lab analysis and water drawdown modelling.

In most refineries, some internal water streams are commonly used as desalter wash water, such as condensate water and steam-stripped sour water. There is scope for increased water reduction and reuse in refineries, which will lead to reduced size and costs of both water make-up and end-of-pipe treatment facilities. This is known as water stream integration where whenever possible steps are taken to prevent, reduce, recycle and reuse process water, rainwater, cooling and even contaminated

groundwater to reduce the amount of fresh water intake and process water for end-of-pipe treatment.

Potential improvements include:

- Reusing unstripped/stripped sour water as wash water;
- Passing sour water from atmospheric and vacuum unit condensates to a stripper in enclosed systems;
- Segregation of non-contaminated water streams to enable reuse as process water;
- Prevention of spillages and leaks;
- Use of vacuum pumps to replace steam ejectors;
- Reuse of waste water generated by the overhead reflux drum, e.g. as a desalter wash water;
- Optimising water reuse by application of side-stream softening to blowdown streams.

3   Environmental Management Systems (EMS)

Environmental management is an integral part of the management process in most oil refineries and in Europe it is a permit requirement to demonstrate the application of Best Available Techniques (BAT). This includes that an EMS is implemented and adhered to that incorporates the following features [1]:

1. Commitment of the management, including senior management.
2. Definition of an environmental policy that includes the continuous improvement for the installation by the management.
3. Planning and establishing the necessary procedures, objectives and targets, in conjunction with financial planning and investment.
4. Implementation of the procedures paying particular attention to:

    (a) Structure and responsibility
    (b) Training, awareness and competence
    (c) Communication
    (d) Employee involvement
    (e) Documentation
    (f) Efficient process control
    (g) Maintenance programmes
    (h) Emergency preparedness and response
    (i) Safeguarding compliance with environmental legislation

5. Checking performance and taking corrective action, paying particular attention to:

    (a) Monitoring and measurement
    (b) Corrective and preventive action

(c) Maintenance of records

(d) Independent internal and external auditing in order to determine whether or not the EMS conforms to planned arrangements and has been properly implemented and maintained.

6. Review of the EMS and its continuing suitability, adequacy and effectiveness by senior management.
7. Following the development of cleaner technologies.
8. Consideration for the environmental impacts from the eventual decommissioning of the installation at the stage of designing a new plant, and throughout its operating life.
9. Application of sectoral benchmarking on a regular basis.

The level of detail and nature of the EMS will generally be related to the nature, scale and complexity of the installation, and the range of environmental impacts identified. Many refineries have EMS certified against ISO 14001:2004 [9] or EMAS [10] which require continuous improvement in performance.

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