MANUAL

FUEL SYSTEMS

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DESIGN AND ENGINEERING PRACTICE

PREFACE

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1. INTRODUCTION

1.1 SCOPE

This new DEP replaces the Standard Specification A-4-1 (October 1973) entitled "Fuel Systems". It specifies requirements and gives recommendations for the design of liquid and gaseous fuel systems as applied on oil refineries, petrochemical complexes and gas plants.

Particularly for refineries, these fuel systems are designed to accommodate process by-product streams which must be consumed on site. Such streams generally have low commercial value and it is required to dispose of these products in a manner which conserves energy and limits environmental impact, e.g. by avoiding flaring. These systems require specific design considerations to cater for variations in fuel flow, composition, physical properties and heating value which are not encountered with commercially available fuels.

Fuel systems which are based on commercial grade liquid fuels and natural gas will not necessarily require such specific design features and a simplification may then be possible. However, many of the design principles are common to all fuel systems regardless of whether they are designed to handle the fuel variations typical of refinery systems or not, so the basic design principles and considerations described in this DEP may be applied to these systems.

Also covered by this DEP are specific fuel system considerations for industrial gas turbines as applied on refineries and particular arrangements for fuelling industrial gas turbines used for power generation and mechanical drives for compressors in LNG trains.

The use of figures in this DEP is intended to illustrate process design concepts only. Details such as safety relief valves, heat tracing and insulation are not included. Equipment required for achieving the desired fuel condition may vary, e.g. the requirement for gas heating to compensate for expansion cooling or the use of a dedicated gas superheater to ensure dryness.

Recognising that there can be significant variations in fuel system requirements from one location to another where operational and environmental priorities may differ, this DEP cannot cover every system specifically. Nevertheless, the design principles described in this DEP shall be considered in all designs and applied as relevant to the particular circumstances.

1.2 DISTRIBUTION, INTENDED USE AND REGULATORY CONSIDERATIONS

Unless otherwise authorised by SIOP and SIEP, the distribution of this DEP is confined to companies forming part of or managed by the Royal Dutch/Shell Group, and to Contractors nominated by them (i.e. the distribution code "C" as defined in DEP 00.00.05.05-Gen.).

This DEP is intended for use in oil refineries, gas plants, chemical plants and, where applicable, in oil and gas production facilities, and supply/marketing installations.

If national and/or local regulations exist in which some of the requirements may be more stringent than in this DEP, the Contractor shall determine by careful scrutiny which of the requirements are the more stringent and which combination of requirements will be acceptable as regards safety, environmental, economic and legal aspects. In all cases the Contractor shall inform the Principal of any deviation from the requirements of this DEP which is considered to be necessary in order to comply with national and/or local regulations. The Principal may then negotiate with the Authorities concerned with the object of obtaining agreement to follow this DEP as closely as possible.

1.3 DEFINITIONS

1.3.1 General definitions

The **Contractor** is the party which carries out all or part of the design, engineering, procurement, construction, commissioning or management of a project, or operation or maintenance of a facility. The Principal may undertake all or part of the duties of the Contractor.

The **Manufacturer/Supplier** is the party which manufactures or supplies equipment and services to perform the duties specified by the Contractor.

The **Principal** is the party which initiates the project and ultimately pays for its design and construction. The Principal will generally specify the technical requirements. The Principal may also include an agent or consultant, authorised to act for, and on behalf of, the Principal.

The word **shall** indicates a requirement.

The word **should** indicates a recommendation.

1.3.2 Specific definitions

Calorific value is synonymous with **heating value** and is the heat liberated by combustion of a fuel. It is expressed in heat units per unit mass for liquid fuels but for gaseous fuels it may be expressed on a mass, molar or volume basis.

- **Gross calorific value (GCV)** or higher heating value (HHV) is the total heat produced by combustion of the fuel.
- **Net calorific value (NCV)** or lower heating value (LHV) is the total heat produced by combustion of the fuel less the latent heat contained in the water vapour (produced by combustion) discharged as flue gas. As this latent heat is not normally recovered, NCV represents the available heat.

The **consumer** is the process or utility unit which will burn the fuel supplied.

The **combustion system** is the system within the consumer's plot which controls, safeguards and burns the fuel in the fired application.

Fuel is a substance which can provide self-sustaining combustion in air and provide a source of useful heat. In this DEP, fuel is in a form which can be measured and controlled, otherwise it is classed as a waste stream.

Fuel gas refers to gaseous fuel which is generated on site, generally containing hydrocarbons and hydrogen but few inerts, and may be of variable composition/calorific value.

Fuel oil is a term used to describe oil-based liquid fuels generally, but excluding low boiling point fuels such as liquid butane or naphtha.

The term **light** refers to fuel oil having a relatively high proportion of volatile components and low viscosity.

The term **heavy** refers to fuel oil having a relatively high proportion of high boiling point residues and high viscosity.

Fuel supply from the fuel system to the consumer refers to the conditions at the consumer's battery limit.

The **fuel system** is the system which receives a fuel or a number of fuel component streams, stores the fuel as required, conditions the fuel such that it is suitable for use in the consumer's combustion system(s), and distributes the fuel to the consumer(s) at these required conditions.

Low pressure gas or vent gas refers to gas which has a calorific value similar to fuel gas but which is available only at a pressure below that of the main fuel gas system. It may be considered as a fuel when the pressure is still sufficiently high for it to be measured and controlled in a dedicated low pressure combustion system.

Natural gas refers to natural gas supplied by the national grid and, as such, has a closely controlled composition/calorific value and is normally available at high pressure (i.e. above 25 bar (ga)).

A **refinery fuel gas system** is a system which is typical of, but not restricted to, oil refineries in which gas is collected from various sources, mixed and supplied to process furnaces and utility boilers which use burners operating with a fuel gas pressure up to 1.5 bar (ga).

Syngas refers to gas produced from the gasification process (of either gas, oil or coal) and from which a major proportion of the hydrogen has been removed (for process feedstock), leaving a gaseous fuel of relatively low calorific value but available at high pressure. Hydrogen content of the gas may vary as process hydrogen demand fluctuates.

V_{50} viscosity is a viscosity characteristic used in fuel oil blending. It is based on the kinematic viscosity of the fuel oil, ν, in the units of mm^2/s (centistokes), measured at temperature, t (°C), and corrected to 50 °C according to the formula:

$$V_{50} = 19.2 + 118 * \log [(t+273)/323] + 33.5 * \log \log (\nu+0.85).$$

NOTE: log is to base 10.

Waste gas/offgas refers to gaseous product streams which can be combusted/incinerated but require the support of a fuel to provide sufficient heat to sustain combustion, and may be available only at a pressure near to atmospheric. Therefore, these gases are not considered as fuels.

1.4 CROSS-REFERENCES

Where cross-references to other parts of this DEP are made, the referenced section number is shown in brackets. Other documents referenced in this DEP are listed in (5.).

2. GENERAL DESIGN CONSIDERATIONS

2.1 AVAILABILITY

Refinery fuel systems are designed to supply fuel to the consumer's combustion system at conditions which allow safe, reliable and uninterrupted combustion as required by the process or utility unit. Unless specified otherwise, fuel systems shall be designed for continuous operation and an appropriate philosophy of components sparing shall be applied to achieve this availability. Particular consideration shall be given to the need to keep vital utility services in operation during major plant emergencies. For vital rotating equipment, a sparing philosophy of N+2 together with independent drives (using different energy source) should be applied, where N is the number in service during normal operation. For stationary equipment which may be expected to require regular maintenance (fired heater, heat exchanger, filter), spare equipment shall be provided such that 100% duty can be maintained with one of these equipment items shut down.

In some cases, a second independent fuel system based on a different fuel type or grade may be used as a back-up and this can influence the equipment sparing for each system. The provision of a second fuel system may be considered necessary for other reasons, such as the need to provide a lighter fuel oil to the consumer during plant start-up before switching to a much heavier fuel oil. Such a second system can also serve as a source of suitable flushing medium for the primary heavy fuel oil system.

2.2 FUEL BALANCING

Refinery fuel systems are designed to dispose of low value by-product streams in an efficient and environmentally acceptable manner. The aim is to match the fuel consumption with production of the fuel component streams. Priority shall be given to keeping plant-generated gaseous fuel in balance with consumption to avoid excess flaring whilst also minimising the need to provide higher cost make-up gas (normally by LPG vaporisation). Storage of liquid fuels is possible and, therefore, fuel oil is normally used as the balancing medium for satisfying the refinery fuel demand. Many refinery furnaces and boilers are equipped to burn liquid and gaseous fuels simultaneously, thus providing the means of balancing fuel consumption with demand as variations in production/consumption occur.

2.3 COMBUSTION SYSTEM REQUIREMENTS

Not only must fuel systems satisfy the demand of the consumer in terms of quantity, the fuel delivered must also be of the correct quality in terms of pressure, temperature, density and composition as indicated below.

In the case of **gaseous fuels**, variations in density and heating value shall be minimised by appropriate mixing and buffering of gaseous fuel streams. Also the fuel gas shall be delivered to the consumer at a constant pressure, the header pressure being controlled by buffering and/or by make-up from a higher pressure supply.

Fuel gas system design shall exclude the risk of condensation of liquids, if necessary by applying heat tracing and insulation. Water or hydrocarbon liquid formation may arise, for example, from expansion cooling, water saturation due to scrubbing and significant concentration of butane (and higher paraffins). Protection against the carry-over of liquids in the fuel gas supply to the consumer shall be provided by the provision of a central mixing and knock-out vessel before distribution regardless of whether the consumer's combustion system also has its own knock-out provision. Care shall be exercised to avoid mixing fuel gas streams which may be contaminated with compounds which may react chemically to form solids or gums which may foul the system. If dry solids contamination is likely, e.g. scale dust from long pipelines, gas filters shall be applied.

Special constraints apply for gas turbine fuel systems, where variations in Wobbe Index are strictly limited and the gas must be superheated to ensure that it is moisture-free. Gas turbines require a gas supply pressure of at least 18 bar (ga) and the associated fuel supply systems are described as HP (high pressure).

In the case of **fuel oil systems**, the supply pressure and temperature to the consumer's combustion system is a primary concern. For fuel oil burners, regardless of the atomisation method, the viscosity of the fuel oil entering the burner shall be not higher than 20 mm^2/s. Good fuel oil atomisation is achievable at 20 mm^2/s viscosity and below. Therefore, the fuel oil temperature, as delivered to the consumer, shall be sufficient to achieve this objective. There is also a lower temperature limit, regardless of viscosity, for fuel oil supplied to combustion systems which use steam-atomised burners. This is because if the fuel cools the atomising steam causing it to condense in the burner barrel and atomiser, it has a detrimental effect on the burner performance which can prejudice safety. Thus, for steam-atomised burners, the fuel oil temperature should be at least 120 °C to avoid this effect. As gas oil is normally supplied at ambient temperature, it should not be applied on steam-atomised burner systems for start-up purposes, rather a fuel oil of viscosity V_{50} of around 32 mm^2/s is preferred (to give 20 mm^2/s at 120 °C). Unless specified otherwise, the fuel oil supply system shall be suitable for combustion systems using steam atomisation as this is generally produces more efficient and cleaner combustion. These systems require a ring main pressure of around 18 bar (ga). The fuel supplied to the consumer shall be adequately filtered to ensure that oil borne particles cannot block the atomisers. **Waste gas** disposal systems are generally at low pressure (slightly above atmospheric pressure), have variable heating value and flows are uncontrolled. These gases are supplied to special burners where the main fuel provides support for combustion. The waste gas disposal system design is outside the scope of this DEP. **Low boiling fuel** (LBF) is also considered as a waste liquid for disposal and it has a high heating value. It has to be delivered to the consumer by a separate system suitable for pressure-atomised combustion systems, similar to normal fuels. As there is a strong incentive for re-processing off-spec. products, these systems are becoming less common.

For off-spec. LPG (i.e. C_3/C_4), vaporisation and disposal via the refinery fuel gas system is strongly preferred to flaring. If a continuous supply of butane is available as fuel, then this shall be vaporised and supplied to the refinery fuel gas system, making adequate design provisions to avoid liquid drop-out. Alternatively, if this would require heating of the whole fuel gas system, it can be considered more economical to supply gaseous butane to dedicated consumers via a heated system, using refinery fuel gas as a back-up supply.

2.4 FUEL STRATEGY

Taking into account the factors described in (2.1 - 2.3), it shall be decided which types of fuel systems are required and which consumers need to be served by each system in order that system capacities and requirements for safeguarding the supply can be established. In addition, the fuel package will be influenced by present and future atmospheric emission legislation together with the design crude diet and the resulting polluting contaminants in the fuel products. Those units which are not able to fire fuel oil due to design limitations or are not equipped with suitable flue gas cleaning facilities for meeting the required atmospheric emission limits, become priority gas consumers.

Apart from priority gas consumers, it may not be necessary to provide dual fuel firing on all units. The refinery fuel balance under foreseeable operating modes shall be carefully scrutinised to determine the most economical installation, providing dual fuel supply only where necessary to satisfy balancing needs or security of equipment availability.

Due consideration shall be given to the fuel available for plant start-up (before the plant produces its own fuel). Provision shall be made for importing and storing this fuel as necessary, maximising the use of the fuel system facilities provided for normal operation. The facilities provided shall ensure that the plant start-up sequence can be accomplished smoothly and without interruption as a transition to own-produced fuel is achieved.

Utility steam and power generators are often required to operate in 'boxed in' mode if the rest of the plant is shut down and there is no fuel supply from outside the battery limits. In this case, the fuel oil or LPG storage capacity shall be sufficient to maintain the supply of fuel to these priority units over this period. If a back-up liquid fuel system is needed to maintain continuity of operation during an emergency when the main fuel supply is lost, this fuel system shall be on continuous stand-by (i.e. circulating). Alternatively, it may be possible to arrange a natural gas supply from the national grid to provide this back-up.

All of these factors shall be established in order to determine the required capacity of each fuel system and the sparing philosophy to be applied to meet the required availability.

2.5 FUEL SYSTEM GENERAL DESIGN

The fuel system piping shall be designed according to DEP 31.38.01.10-Gen., DEP 31.38.01.11-Gen. and DEP 31.38.01.12-Gen.

Thermal insulation shall comply with DEP 30.46.00.31-Gen.

Electrical heat tracing shall comply with DEP 33.68.30.32-Gen.

For pressure reliefs and connections to the flare system refer to DEP 80.45.10.10-Gen.

Shell and tube heat exchangers shall be in accordance with DEP 31.21.01.30-Gen. Heat transfer fluid systems shall be in accordance with DEP 20.05.50.10-Gen. Electric heaters may be used for fuel gas heating on gas plants, particularly where other heating mediums are not available (e.g. plant start-up). These heaters shall be approved by the Principal.

Fired heaters shall be in accordance with DEP 31.24.00.30-Gen.

3. GASEOUS FUEL SYSTEMS

3.1 REFINERY FUEL GAS SYSTEMS

This term shall be understood primarily as LP fuel gas systems applicable on refineries where process gas streams are collected, combined and distributed at a controlled pressure to the combustion control systems of refinery furnaces and boilers. The design rules may be applicable also to fuel gas systems in similar non-refinery plant provided that the distributed gas composition is acceptable to the consumers.

In refinery fuel gas systems, variations in gas composition can be considerable (e.g. molecular weight variation >100%) and combustion systems are provided with appropriate instrumentation to adjust the air/fuel ratio automatically to compensate for these changes. Accepting that composition changes can occur, the aim of the system design shall be to minimise the change and, in particular, the rate of change. In other fuel gas systems, large variations in gas composition may not be allowed and, therefore, the system design shall be adapted accordingly. For example, restrictions on gas composition variation apply for fixed air fuel ratio burners where a constant Wobbe Index is required.

Unless specified otherwise, refinery fuel gas systems shall be designed for continuous availability.

Reference is made to Figures 1, 2 and 3 for conceptual designs. More details are provided on Standard Drawing S 01.001.

NOTE: The previously applied specific arrangement of LPG vaporiser controls for off-spec. LPG vaporisation and disposal to flare are no longer included. Nowadays, LPG reprocessing reduces the requirement for disposal, and flaring for purposes other than safety relief should be avoided in line with Group environmental policy. Therefore, if LPG disposal is necessary, this should be consumed as fuel gas via the standard arrangement, if necessary providing intermediate storage for the off-spec. LPG.

3.1.1 System pressure and balancing

Refinery fuel gas systems are designed to provide a constant gas supply pressure to the consumers whilst allowing gas production and consumption to vary independently from each other within specified ranges. The supply pressure to the consumers is normally set at a level of 4.0 bar (ga), aiming for economy of size in the distribution linework and providing adequate allowance for pressure drop across the combustion systems for obtaining maximum fuel gas pressure at the burners of 1.5 bar (ga). Fluctuations imposed on the system by producers or consumers shall not cause the supply pressure at the battery limit of the consumer to vary by more than + 0.5 bar.

The pressure drop over the fuel gas system should not be higher than 0.5 bar in order avoid unnecessarily high pressures in the collection header which could prevent some gas streams from low pressure producers from entering the system. Higher fuel gas system pressures are undesirable also because this will increase the tendency of condensation of heavier components. The system shall be adequately buffered such that pressure fluctuations can be contained within the system under normal operating conditions thus avoiding flaring (over-pressure control) and unplanned injection of vaporised LPG or natural gas (under-pressure control) in order to minimise environmental pollution and fuel cost respectively. The provision of dual fuel firing facilities shall allow fuel gas production to be balanced by consumption by appropriate increase or decrease of the oil/gas ratio in such a way that firing symmetry on individual consumer units is maintained. An automatic balancing system can be used on a large fuel consumer (e.g. boiler plant) whereby fuel gas header pressure is controlled by increasing or decreasing fuel gas consumption on the unit as required and automatically adjusting the fuel oil firing to make up the total fuel demand of the unit.

Another means of automatic fuel gas header pressure control may be applied when there is a fuel gas source available at high pressure (e.g. 25 bar (ga)). In this case, a high pressure buffer vessel can be installed (Figure 2) which operates in a pressure range between the source gas pressure and the system pressure, thus absorbing the pressure swings caused by variations in production and consumption. For further guidelines for design, see (3.1.3).

3.1.2 Fuel gas collection

All potential fuel gas producers which are being considered shall be examined from a safety and integrity viewpoint. Factors such as high upstream pressures, cooling on pressure reduction, hydrate formation, water content, butane content, inerts content, low source temperature and chemical reactivity (e.g. forming fouling compounds) shall be considered in terms of the effect on the mixed fuel gas.

In refinery and chemical plant operations, most gas streams entering the fuel gas system comprise paraffinic and olefinic hydrocarbons in the range C_1 to C_4, hydrogen and only a minor quantity of inerts. Within this limited composition range, the variation in heating value is related to the gas density and the stoichiometric combustion air requirement per unit heat input is approximately constant. Therefore, the combustion systems of the consumers can accommodate changes in composition of this type by using gas density measurement for correcting the set point for air fuel ratio control. When inert gases or other types of gas such as carbon monoxide are added, the relationship between density and heating value no longer holds and the stoichiometric combustion air requirement per unit heat input will change and it is then necessary to measure the Wobbe Index of the gas as a basis for air fuel ratio control. Due account of these factors shall be taken in ensuring that the variation in the composition of fuel gas supplied by the system will be acceptable to the consumers. Although the system shall be protected against liquid contamination of the fuel gas supplied to the consumer by provision of liquid knock-out facilities, the system shall be designed to avoid liquid formation during normal operation. Fuel gas heaters shall be used on those collection header supply lines where necessary. For clean service, compact heat exchangers may be considered. Normally, the heating medium will be steam but, if steam is not available (e.g. on gas plants), electrical heaters may be applied.

3.1.3 Buffer, mixing and KO vessels

Depending on specific requirements a vessel may be used effectively to serve a combination of functions. For example, a vessel designed for liquid knock-out may be suitably sized for buffering and to provide adequate mixing, particularly where a number of streams of similar composition are being combined. On the other hand, the mixing of two dissimilar streams may require a specific mixer design.

For fuel gas systems based on gas of constant composition and no risk of liquid contamination/formation (e.g. certain gas processing plants) the mixing and KO vessel is not required.

Vessel relief valves shall be sized according to DEP 80.45.10.10-Gen. and connected upstream of demister mats, if applied.

Demister mats shall not be applied in the vessel if the gas is potentially fouling unless two parallel vessels are installed which will enable maintenance of one vessel whilst the fuel gas system remains in service.

To facilitate inspection, the vessel shall be provided with a manhole and utility connection for nitrogen purging and steaming out. Block valves and blind flanges shall be provided on all nozzle connections which are not used during normal operation. Block valves and spectacle blinds shall be provided in all connection lines to the fuel gas system for use when the vessel is taken out of operation. If there are two vessels in parallel, it shall be possible to isolate either one whilst the second remains in operation.

Where fuel gas is available to the system at a high pressure, such as from a de-ethaniser operating at around 25 bar (ga) and feeding into a LP fuel gas system, consideration should be given to the provision of an HP buffer vessel whereby the buffer of HP gas is used to control the gas system pressure during normal swings in production/demand. The arrangement, requiring pressure control upstream and downstream of the vessel, is shown in Figure 2. Vessel sizing depends on the mass flow capacity of the system and the estimated variations in flow resulting from, for example, trips of individual gas producers or consumers. However, for initial design, the vessel should be sized to absorb/liberate 10% of the normal system gas flowrate over a 1 hour period, operating from the middle pressure of the operating range to the maximum/minimum pressure respectively. Thus, for a buffer vessel operating in the pressure range 5 to 25 bar (ga) and serving a gas system handling 5000 kg/h, the vessel should absorb 500 kg gas in 1 hour as the vessel pressure rises from 15 to 25 bar (ga). Similarly, 500 kg gas will be liberated in 1 hour as the pressure falls from 15 to 5 bar (ga). For a typical gas of molecular weight 22, a vessel volume of around 50 m^3 would then suffice.

If there is a possibility of liquid contamination or formation in the gas supply to the vessel or within the vessel, the vessel shall be designed also as a gas/liquid separator.

Vessels designed for gas/liquid separation shall be in accordance with DEP 31.22.05.11-Gen.

In cases where the refinery fuel gas system must be kept in continuous operation, two vessels in parallel shall be provided connected to a common inlet and outlet header. It shall be possible to isolate one vessel for maintenance whilst the fuel gas system remains operational. The sizing of each vessel need not be designed for full system capacity but shall have sufficient capacity to meet the demand of essential gas consumers. If outage of the fuel gas system can be accepted temporarily to allow vessel inspection/maintenance (e.g. where there is a planned total refinery maintenance shut-down), one buffer vessel suffices, provided that the risk of unscheduled outage is acceptable to the Principal.

The vessel shall satisfy the requirements for gas/liquid separation in accordance with DEP 31.22.05.11-Gen. Also, the resultant vessel volume, together with that of associated headers, shall provide sufficient hold-up of gas for absorbing flow variations expected in the various gas producer streams during normal operation without causing gas venting or injection for pressure control. Generally, mixing of the gas streams in the collection header combined with the gas hold-up in the vessel is sufficient to reduce the rate of gas composition change in the distributed fuel gas to a tolerable level following a step change in the producer gas streams. A sudden loss of an input gas stream and consequential input of vaporised LPG make-up is a typical example. A tolerable change in gas composition shall be judged by the ability of the consumer units handle composition change (e.g. response of density measurement for air fuel ratio correction). Where this is not satisfied, additional measures shall be applied to improve gas mixing, e.g. by a specific mixing device upstream the LP mixing/knock-out vessel.

The **overpressure vent control** to flare shall be designed to maintain the pressure within 0.5 bar of the set control pressure, taking account of the fluctuations in production and consumption possible during normal operation. In some cases, this may require the provision of two control valves in parallel, one small and one large, the latter acting when production is significantly higher than consumption (e.g. following trips of one or more consumers). Control valves shall have tight shut-off. Block valves shall be provided upstream/downstream of the control valve(s). A bypass of the control valve and its isolation valves shall be provided with a hand control valve plus block valve. Instrumentation shall be in accordance with Standard Drawing S 01.001.

3.1.4 LPG vaporiser

LPG evaporator design shall ensure a rapid response capability such that the fuel gas system pressure is maintained within 0.5 bar of the system set control pressure when a sudden demand occurs. This condition shall be defined as the sudden loss of the largest fuel gas producer feeding into the system or, alternatively, the largest step change in demand which can occur from a consumer unit. Cases to be considered in determining the latter shall include but not necessarily limited to:

- a trip of liquid fuel supply to dual fired unit with auto-control on fuel gas;
- a trip of a liquid fuel fired utility boiler and resultant increase in load on gas fired steam generation.

The vaporiser hold-up between normal and low liquid level alarm shall be sufficient for supplementing the fuel gas flow of the largest fuel gas producer or meeting the step change demand as defined above, for a period of 1 hour.

The vaporisation capacity shall satisfy the largest demand as determined by the following:

- the equivalent flow of the largest fuel gas producer;
- the required fuel gas demand of essential fuel gas consumers, e.g. utilities;
- the required fuel gas demand for plant start-up, i.e. prior to other gas producers being available.

Vaporisers shall be designed to avoid film boiling by appropriate selection of heating medium and LPG vaporisation pressure to avoid too high a temperature difference. The conditions under which film boiling may be expected shall be determined for the particular grade (or range) of LPG to be used. LP steam is frequently used as heating medium.

The number of vaporisers shall be chosen such that shut-down inspection of one vessel can be done without affecting system reliability. When the LPG is supplied from storage, the transfer pumps should be spared and provided with separate power sources.

For clean service, compact heat exchanger types may be considered as an alternative to kettle type vaporisers.

In order to prevent unnecessary LPG vaporisation when in stand-by, the heating medium control equipment shall be designed for minimum leakage when closed. Dual range control valves (one small, one large for high range control with upstream tight shut-off valve) achieve this objective.

If LP steam is used as heating medium, a non-return valve shall be provided in the steam supply line in order to prevent backflow of LPG into the steam system should there be a rupture of the heating coil. In addition, detection of high pressure on the steam side (indicative of tube rupture) shall initiate isolation of the steam supply and condensate collection to avoid contamination of these systems by hydrocarbons. The coil shall be maintained drained of condensate so that the vaporiser can respond rapidly on demand. A condensate drain vessel shall be provided fitted with a pressure balancing line (connected to the coil inlet) to permit free drainage of condensate to the vessel.

LPG with high propane content is preferred since butane (or heavier hydrocarbons) can lead to liquid condensation in the fuel gas at normal system pressure and ambient temperature. For example, when the N-butane (having a vapour pressure of 1 bar at 0 °C) proportion in fuel gas reaches 20% molar, it will start to condense from fuel gas at 5.0 bar (abs) system pressure and at a gas temperature of 0 °C. The maximum butane (and heavier hydrocarbon) concentration in fuel gas shall be calculated for the worst case scenario and the corresponding dewpoint of the gas determined. If butane (or heavier hydrocarbon) condensation is predicted, then the fuel gas shall be heated to at least 5 °C above the fuel gas dewpoint and heat tracing/insulation applied to downstream linework to maintain this temperature. The vaporised LPG pressure reduction valve (i.e. fuel gas system pressure control) and the vaporiser safety relief valve shall be arranged such that no liquid accumulation due to cooling can occur in the line.

3.1.7 Flare gas recovery

Flaring is an environmental nuisance and a loss of energy. The flare gas recovery system is a means of recovering those gases produced at low pressure, which are sent to flare because they cannot be sent directly to the refinery fuel gas system. A typical flare gas recovery system incorporating a two-stage compressor is shown in Figure 4.

The system takes suction from the plant main flare gas header upstream of the water seal vessels.

The compressor shall be under suction pressure control to maintain a positive pressure in the flare gas header and thus avoid the risk of air ingress. This shall be further protected by a low suction pressure trip of the compressor.

The compressed, dry gas is then supplied to the LP collection header of the refinery fuel gas system. Consideration shall be given to the fact that recovered flare gas may contain significant quantities of inerts and the possible effects on the final mixed fuel composition shall be assessed.

3.1.8 Natural gas

In certain cases, natural gas may be available as a fuel back-up. Such an arrangement, as shown in Figure 3, replaces the LPG vaporiser.

Normally, natural gas is available at a pressure above 25 bar (ga). When the pressure is reduced to 4.5 bar (ga) significant expansion cooling will occur and this may be accompanied by the formation of hydrates which can foul the let-down valve. Where hydrate formation is possible, a gas heater shall installed in the gas supply line prior to expansion.

The temperature of the let down natural gas supplied for mixing with other gas streams shall not be significantly lower than the ambient temperature in order to avoid unnecessary condensation of liquids from the other gas streams.

3.2 FUEL GAS SYSTEMS FOR GAS TURBINE APPLICATIONS

3.2.1 General

Fuel gas systems for supplying gas turbines operate at a higher pressure than refinery fuel gas systems. The required **supply pressure** for the gas turbine is dependent on the gas turbine type and on the heating value of the gas but is generally at least 18 bar (ga). It is important to establish during the design whether dry low-NOx combustors will be used initially or later as a retrofit before finalising the design pressure of the system. It is essential that **no liquid entrainment** (either water or hydrocarbons) can occur and so efficient liquid knock-out followed by gas **superheating** to a minimum of 20 °C above the gas dewpoint is required.

In order to maintain stable operation and maximise lifetime of the combustors, it is also necessary to minimise variations in combustion dynamics by supplying a fuel which provides a constant release of heat at a given pressure drop over the combustor fuel nozzle and, also, which produces a constant flame type. Therefore, it is preferable to use a fuel at a constant composition and temperature which will thus produce a consistent flame characteristic. When fuel gas composition does vary, temperature adjustment of the gas supply offers a degree of density adjustment to maintain a constant combustor pressure drop/heat release relationship, but this does not necessarily maintain the same combustion characteristics. The fuel shall also be free of contaminants which could prejudice the lifetime of the gas turbine blades by either corrosion or erosion. Allowable contaminants shall be verified with the gas turbine manufacturer. Natural gas is a fuel which satisfies these requirements and is the gas most commonly used in industrial gas turbines. It is also the gaseous fuel upon which gas turbine design is most commonly based. However, other gaseous fuels can be used provided that the variations in calorific value, density and composition are restricted and that the gas turbine combustor design is suitably matched to the fuel type. Particularly where some variation in fuel gas composition/temperature is possible, or where more than one fuel gas type may be supplied to the gas turbine (e.g. a different fuel as back-up), due attention shall be given to the manufacturer's limitations on the **Wobbe Index (WI)** of the fuel.

The **Wobbe Index** relates the heating value of a gas to its density and is important for combustor design. The basic relation is

$$WI = CV / (SG)^{0.5}$$

where WI = Wobbe Index
CV = calorific value on volumetric basis
SG = specific gravity (with respect to air)

However, there are a number of variations possible using different units for calorific value, expressing heating value on a Gross or Net basis, or on a mass basis instead of volume basis, and relating to standard conditions, which then requires inclusion of absolute temperature in the formula. As an example the WI used by gas turbine manufacturers is defined as follows:

$$WI = 37256\ NCV/((1.8 * Tg + 491.61) *SG)^{0.5}$$

where:

NCV = Net calorific value in J/m^3 at ISO conditions (15 °C and 1.013 bar (a))
Tg = Gas temperature in degrees Celcius
SG = Specific gravity to air at ISO conditions.

The Wobbe Index is not dimensionless and so the calculated value is dependent on the units and formula used. Therefore, the Manufacturer/Supplier of the gas turbine shall state clearly the definition of Wobbe Index used and specify the variations in Wobbe Index acceptable both as an absolute variation and also as a rate of change. This is of particular importance where the design includes the possibility to switch from one fuel gas type to another (e.g. a back-up supply).

Note that a constant Wobbe Index provides a constant heat input for a given burner pressure but does not necessarily provide a constant flame type. The latter is dependent on the gas composition. In particular, the proportion of hydrogen will affect the resulting flame characteristics. **Therefore, the gas turbine Manufacturer/Supplier shall always be consulted as to the suitability of the machine for the range of fuel gas compositions envisaged.**

The fuel system design shall meet the requirements for the gas turbine installation as described in DEP 31.29.70.11-Gen.

3.2.2 Fuel gas selection

Fuel gas selected for gas turbines shall be such that it meets the requirements in terms of Wobbe Index and composition control (3.2.1) and, ideally, is available at a sufficiently high pressure without the need for compression. Compression of low pressure fuel gas is also possible, however, provided that it does not contain a significant proportion of components which will liquefy on compression. If gas compression is applied, compressors shall be according to DEP 31.29.40.30-Gen. (centrifugal) or DEP 31.29.40.31-Gen. (reciprocating).

Natural gas from the grid is a traditional fuel for gas turbine applications. Gas composition and heating value are virtually constant and reliability of supply is normally high. **Refinery fuel gas** composition may vary considerably and is not normally considered as a suitable gas turbine fuel. However, gas produced by a particular unit (and which would otherwise go to the refinery fuel gas system), may well satisfy the criteria in terms of constant Wobbe Index and sufficient quantity. Preferred gas streams are those available from high pressure units. Careful consideration shall be given to the possible contamination of LPG by sulphur, caustic soda or H_2S, which would have a detrimental effect on the gas turbine. A low calorific value gas stream which is available in bulk, clean and of constant Wobbe Index can be economically attractive as fuel for a gas turbine even when compression is required.

Syngas, produced by the gasification of residue or coal, is available dry and at high pressure from the gasification unit and is a suitable gas turbine fuel. It has a heating value in the order of 15 MJ/kg, compared to that of refinery fuel gas of 45 - 50 MJ/kg. The adiabatic flame temperature, however, is high and thermal NOx production from syngas-fired gas turbines is higher than the equivalent natural gas fired installation. Depending on the environmental requirements, therefore, the syngas may have to be diluted further with inert gases to reduce flame temperature and subsequent NOx production. **Whenever such gaseous fuels are considered for use in gas turbines, careful scrutiny shall be exercised in checking the suitability for use in the gas turbine selected, particularly in respect of combustor design**. The gas turbine Supplier should provide references of satisfactory industrial operation on a similar fuel. As a minimum, the Manufacturer shall produce evidence of successful tests of the combustors using this type of fuel. Note that the optimum gas supply pressure may differ from that required for natural gas.

LNG Plants

Modern LNG plant design is based on gas turbine powered compressor drives on the LNG trains and gas turbine generators for electrical power production. The make-up of the HP fuel system is dependent on the composition of the raw gas being processed. If there is a significant quantity of end-flash which must be injected into the fuel gas system, there may not be a need to take demethaniser overheads into the system to maintain the balance. However, account shall be taken of the possibility that end-flash may contain a significant quantity of nitrogen which lowers the calorific value and may cause undesirable fluctuations in the mixed gas Wobbe Index being supplied to the gas turbines.

Raw gas let-down into fuel gas often provides a back-up fuel supply. Pressure control is normally achieved by let-down of demethaniser overheads or raw gas into the system. Only during upsets and start-up will gas be diverted to flare. The streams which make up the HP fuel gas system may differ in composition sufficiently to cause problems in Wobbe Index variation. The system design shall be checked for Wobbe Index variations resulting from all operating cases where quantity and composition of the input streams change. Examples are LNG storage boil-off gas increase during loading operations, injection of fractionated streams and raw gas use during start-up.

Demethaniser overheads, if used in the fuel gas system, are of suitable quality and pressure for directly fuelling the gas turbines which drive the refrigerant compressors. Provided that the overall fuel balance requires the use of demethaniser overheads as fuel in quantity greater than the fuel demand of these gas turbines, it is possible to use a common collection/distribution fuel main in this area to achieve a simple low cost arrangement. However, the designer shall confirm that such an arrangement does not result in unacceptable variations in Wobbe Index in the remaining gas supply to other users, e.g. power generation gas turbines.

3.2.3 Back-up fuel supply

Unless there is an adequate back-up electrical supply to the plant from the national grid, a back-up fuel supply shall be provided to enable continued gas turbine power generation during operational upsets on the refinery process units. This may be achieved by delivering a back-up gaseous fuel to the system such that the same combustors are used or, when the same combustors cannot be used, it will involve a switch-over from one fuel manifold to the other. Although dual fuel machines generally refer to the two fuels being either gas or liquid, the liquid fuel combustors can be replaced by gas combustors suitable for burning the back-up fuel gas. Unless specified otherwise, the overall system shall be designed such that the switch-over to back-up fuel supply can be made whilst the gas turbine continues to generate power at base load. This may require specific a design of mixer/buffer to reduce the rate of change of WI during the switch-over period. There may be conditions, however, where this is not possible and a ramping down of load is required to enable the switch-over of fuel (e.g. when the normal fuel is gas and the back-up fuel is gas having a significantly different composition). In this case, agreement with the Principal that this is acceptable shall be obtained. If it is not acceptable, a different back-up fuel shall be chosen

3.2.4 Gas turbine fuel system schemes

The fuel system design will vary according to the type and source of the fuel gas supplied. The principal parameters and design considerations are:

- Gas composition (mixing) and supply control - attention shall be given to the suitability and reliability of streams for maintaining the required quantity and Wobbe Index of supply.
- Achieving required supply pressure (expansion or compression) - attention shall be given to expansion cooling and compression heating effects. Reliability of compression equipment shall be taken into account particularly with respect to required response time for back-up fuel supply and mixing/buffering capacity.
- Primary liquid knock-out (KO) facilities after compression or mixing - if compression may produce liquids, KO facilities shall be provided immediately downstream of the compressor (or aftercooler if applied). Any liquid drop-out shall be removed from the fuel gas, never re-vaporised in the gas by heating.
- Gas buffering/mixing - in order to maintain sufficient supply of fuel gas within the Wobbe Index variation limits during supply upsets, particularly during change-over to back-up fuel supply, gas mixing and buffering equipment shall be provided to maintain base load operation, unless stated otherwise by the Principal.

- Dual gas manifold - to cater for gas of variable composition and Wobbe Index, some gas turbines may be designed with a dual manifold and automatic control for switching the second manifold into service as required to maintain a constant heat input. However, when the dual gas manifold is used, the option for liquid fuel firing is no longer available.

- Inert gas addition for Wobbe Index control or NOx control - if inert gas such as nitrogen or carbon dioxide is available on a continuous basis at sufficient pressure, this may be mixed into the fuel gas at the buffer/mixing vessel. However, this technique shall be applied only after careful examination of the consequences of loss (trip) of inert gas on Wobbe Index of the gas and after verification by the gas turbine Manufacturer of the suitability of the gas composition, with or without inert gas, for firing in the proposed gas turbine.

- Gas heating for density/Wobbe Index control - if gas composition changes produce Wobbe Index variations greater than the acceptable range advised by the gas turbine Manufacturer, sufficient compensation may be possible by heating the fuel gas to produce a gas of lower density. This may find application, for example, where vaporised LPG is used as a back-up fuel, in which case a higher vaporisation pressure as well as direct superheating may provide the optimum arrangement. In all cases the downstream fuel supply linework and equipment shall be confirmed to be suitable for operation at this temperature, and shall be insulated and heat-traced to maintain this temperature.

- Dry gas superheating - gas supply shall be at a temperature which is at least 20 °C above the dewpoint of the gas. Superheating shall be applied as required, using steam, heat transfer fluid or electricity as heating medium. The choice of heating medium is dependent on the required gas temperature, duty and availability of heating medium. The heating medium shall be at a pressure lower than the gas to avoid contamination of the gas in the event of cross-leakage. In addition, the safety aspects of cross-leakage of gas into the heating medium shall be evaluated.

- Fast response back-up fuel system - unless otherwise advised by the Principal, the system shall allow a fuel change-over whilst maintaining base load operation of the gas turbine. As well as ensuring adequate gas buffering, attention shall be given to the design of LPG vaporisers with respect to response time when used as the back-up system. When heating by steam, the design shall ensure that condensate does not accumulate in the heating coil and thereby inhibit heat transfer when a demand occurs. An alternative design of vaporiser (e.g. compact heat exchanger) may be applied to achieve the required response subject to approval by the Principal of the design type.

  As an alternative to gaseous fuel back-up, diesel (distillate) fuel may be used provided that the gas turbine is equipped for dual fuel. Diesel fuel back-up systems are standard systems from the gas turbine Suppliers and incorporate a skid-mounted fuel forwarding system.

- Final knock-out, filtration and firing control - this final section is normally part of the gas turbine package specification and is basically the gas turbine Manufacturer's protection for his equipment. The gas supplied in accordance with the fuel gas system requirements will not contain any liquid and this final KO facility should never experience liquids during operation. Only at start-up, when gas is vented to flare immediately upstream the gas turbine (line warm-up) will there be any likelihood of liquid. This vent connection shall be as close as possible to the fuel control valve. If particulate contamination of the gas is considered to be a possibility, e.g. corrosion deposits in pipelines, parallel 100% capacity filters shall be installed. These filters shall be switchable, have facilities for isolation and cleaning and be equipped with pressure drop monitoring/alarm facilities.

Some examples of typical schemes are shown in Figures 5, 6 and 7 respectively:

- Gas turbine natural gas supply with diesel back-up
- Gas turbine compressed fuel gas supply system with vaporised LPG back-up
- Fuel system for supplying syngas blended with LPG to a dual gas fired gas turbine

3.3 WASTE GAS/OFFGAS AND LOW PRESSURE GAS

3.3.1 Waste gas/offgas

Waste gas/offgas is not covered by this DEP as these are streams which are not suitable for use in fuel gas systems. Examples of sources of these gas streams on refineries are:

- High vacuum and thermal cracking units.
- Sour water strippers.
- Asphalt burning system (see Figure 11).
- Bitumen blowing units.

Reasons for unsuitability for fuel systems may be summarised as follows:

- Available only at low pressure (e.g. just above atmospheric pressure).
- Low calorific value (mainly inert gases).
- Erratic flow-contaminated by pollutant, corrosive or other undesirable compounds such as H_2S.

Even if the gas is available at a sufficiently high pressure for injecting into a refinery fuel gas system, caution shall be exercised before disposing of waste gas via this route because this could have undesirable effects on the fuel gas composition and system reliability.

3.3.2 Low pressure gas system

If low pressure gas is available liquid-free and of similar heating value to that of refinery fuel gas, it is worthwhile to consider the possibility and economic attractiveness of a dedicated low pressure gas system serving one or two furnaces within the same plot. Such a system will operate at a pressure below that of the refinery fuel gas system but the pressure must still be sufficiently high to enable effective control and safeguarding of the consumer's fired equipment. Thus, the envisaged system operating pressure will be in the order of 1.5 to 2.5 bar (ga).

The system shall be designed to operate at a constant pressure, this pressure being dependent on the minimum source gas pressure and the requirements of the burner system. System pressure is controlled by let-down of refinery fuel gas into the system in the case of under-pressure and by venting excess gas to the flare system when production exceeds demand. Figure 8 shows a typical arrangement.

4. LIQUID FUEL SYSTEMS

4.1 REFINERY FUEL OIL SYSTEMS

4.1.1 General

Refinery fuel oil (RFO) is the term given to the main fuel oil system for the refinery. The fuel oil make-up in RFO is not specific as it can vary from one location to another, depending on which by-product streams need to be disposed of via the system. The main property affecting the design of any RFO system is the viscosity of the fuel oil. On this basis, three system types are defined:

- Long residue fuel system, LRFS, V_{50} range 30 to 38 mm^2/s (temperature for 20 mm^2/s viscosity is approximately 100 to 160 °C)
- Short residue fuel system, SRFS, V_{50} range 38 to 44 mm^2/s (temperature for 20 mm^2/s viscosity is approximately 160 to 220 °C)
- Asphalt burning system, ABS, V_{50} range 40 to 50 mm^2/s (temperature for 20 mm^2/s viscosity is approximately 220 to 280 °C)

If a liquid residue fuel generates gas during storage (e.g. by after-cracking of a long or short cracked residue) it shall be handled in an ABS. Hence viscosity is not the only parameter determining the type of fuel system and some overlap of viscosity range handled by each system is possible.

All RFO systems shall be designed to deliver fuel oil to the consumer units at a temperature which ensures that the viscosity at the burner does not exceed 20 mm^2/s (see 4.1.3). In the past, when combustion systems were based on pressure atomisation, gas oil was provided for cold start-up of furnaces and boilers. However, current philosophy is based on steam-atomised burner systems for which a minimum fuel supply temperature of 120 °C is required (see 2.3). **Therefore, it is neither required nor desirable to supply fuel oil lighter than V_{50} of 32 to steam-atomised burner systems.**

The ABS takes the heaviest residues which can be handled by a liquid fuel system based on viscosity reduction by temperature increase. It also takes other residues which have been subjected to thermal cracking and, consequently, have a tendency to produce vapours from after-cracking. The maximum temperature to which the residues can be heated in an ABS is limited to that beyond which significant thermal cracking of the residue will occur and produce unacceptable coking in the system. The high pour point and high viscosity of the fuel have significant importance for the storage and supply section design, particularly in relation to storage temperature and pump selection. All pipework and associated equipment containing the asphalt fuel is heat traced, normally with MP steam at a condensing temperature of 200 °C which serves to keep the fuel fluid in the event that circulation stops. The higher fuel distribution temperature of up to 300 °C is maintained by high circulation rates throughout the system via the heater.

4.1.2 Choice of liquid fuel and blending

The RFO system is the backbone fuel system for the majority of refineries where it will be required for initial start-up and for maintaining essential utilities in operation when other systems have failed (see 2.1). The high availability of RFO is achieved by provision of adequate fuel storage and by equipment sparing within a particular RFO system and /or providing a separate back up system. The latter is a requirement when an ABS is installed.

RFO may serve as a base load fuel, as a start-up fuel, as a back-up to fuel gas and as a means of balancing fuel gas systems. In the ABS, the residue has low commercial value but the system is not suitable for start-up purposes and there are potential difficulties with supply (particularly if fed directly from a process unit) and handling the fuel. Therefore, an ABS shall have a liquid fuel system back-up.

Of increasing importance is the need to limit the emissions of pollutants to the atmosphere. Some heavy residues contain a high concentration of sulphur which, on combustion, produces SO_2 and SO_3. Fuel-bound nitrogen is high in some residues which increases NOx production (i.e. in addition to thermal NOx). In addition, these residues can contain a high proportion of ash and it is generally more difficult to obtain complete burn-out of the fuel than for lighter fuels. Consequently, heavy residue combustion is often associated with high particulates emission. There are exceptions such as ethylene pitch which is relatively ash- and sulphur-free in comparison to cracked residues produced in refineries. Nevertheless, with all residues which contain little volatile matter, it is difficult to obtain complete burn-out of the fuel and there is the risk of particulates emission. In addition, as carbon burn-out is favoured by high flame temperature, the associated thermal NOx production can be high.

In addition to atmospheric emission limitations, there may also be limitations imposed by the equipment in which the fuel is to be fired, e.g. flue gas acid dewpoint, convection bank cleaning provisions. Hence, in the selection of fuel streams for the fuel system, the effect of the supplied fuel on the downstream equipment and the stack emissions shall be evaluated. The resultant fuel selected shall`not prejudice equipment integrity or result in emissions of pollutants in excess of the limits prescribed for the location.

Blending of high viscosity residue (such as from a deasphalting unit) with a low viscosity diluent stream may be necessary to produce a fuel viscosity which can be handled by the system. Care shall be taken to avoid mixing high temperature streams with light product streams which can cause flashing.

Alternatively, blending will be required because of the need to dispose of a number of residue streams via the same system. However, if the streams are not compatible, they can interact and cause the asphaltenes to flocculate leading to fouling of the system. Crude origin and processing history are factors which influence the compatibility of one component (the residue) with another (residue or diluent). In particular, straight run fuels are likely to be incompatible with residues formed by thermal cracking processes. Where there is any doubt as to the compatibility of streams for blending, laboratory blending compatibility tests shall be performed at the operating temperatures. The Shell accelerated Hot Filtration Test is recommended for establishing the suitability of the resultant fuel.

Good mixing of the fuel component streams shall be ensured by in-line blending or application of a mixing vessel. Static in-line mixers shall not be used for blending cracked fuels because of potential blockage problems. The storage tank shall not be used as a mixing vessel.

Account shall also be taken of the fact that the viscosity-temperature relationship and blending rules used for blending of commercial grade fuel oils cannot be applied to the heavier residue grades (e.g. asphalt, flashed cracked residue) with the same degree of confidence. If behaviour of a particular residue is not established, tests shall be performed to establish the viscosity-temperature relationship in the range of proposed use and the stability and blending capability before the fuel system is designed.

4.1.3 Combustion system requirements

There are two principal types of fuel oil combustion systems currently in use. The older installations are generally based on pressure-atomised burners whereas the more recent installations are based on steam atomisation using medium pressure (MP) steam (normally available at 18 bar (ga)).

For pressure-atomised burner systems, the required fuel oil pressure at the battery limit of the consumer is 30 bar (ga) minimum whereas for the steam-atomised burner systems the required minimum pressure is 16 bar (ga).

Due to the superior performance of the steam-atomised burners in terms of turndown and emissions control, pressure-atomised burner systems are being progressively replaced by the steam-atomised type. This means that in the present situation both systems may be in operation, each requiring a different supply pressure.

When a high pressure fuel oil distribution system is used to supply a low pressure loop for a steam-atomised burner system, the design shall ensure that the low pressure loop is protected against over-pressurisation from the high pressure loop. The temperature of the fuel oil supplied to the consumer shall be such that, at the offtake, the fuel has a viscosity not exceeding 20 mm^2/s, which is the established maximum viscosity required for achieving efficient atomisation of the fuel.

4.1.4 Long Residue and Short Residue fuel systems (LRFS & SRFS)

4.1.4.1 General

The system arrangement for both systems are basically the same. The differences relate to the storage and operating temperature, in particular the method of heating.

Fuel is taken from storage, pumped, heated, filtered and distributed to consumers via a circulating loop. The distribution loop pressure is controlled in the return line to the pump suction. The temperature of fuel oil in the loop is maintained at the required value by providing adequate circulation. The flow return to the pump suction should not be less than 20% of the pumped flowrate at design fuel consumption rate but may be higher depending on the length/heat loss from the circulation loop.

Figures 9 and 10 show typical long and short residue burning systems, respectively.

4.1.4.2 Storage tank

The storage tank shall be designed for a storage capacity calculated on the basis of 24 hours maximum fuel oil firing rate on all furnaces served by the system, unless otherwise specified by the Principal. For design and fabrication of storage tanks DEP 34.51.01.31-Gen. shall apply.

The fuel oil storage temperature is dependent on the pour point and viscosity of the fuel oil and may be above the flash point. If the storage temperature is at least 10 °C below the flash point, tank blanketing is not necessary, but if not the storage tank shall be blanketed with steam, nitrogen or fuel gas. If steam blanketing is applied, an atmospheric vent shall be provided. If nitrogen or fuel gas is used, the gas shall be vented to flare or otherwise incinerated.

The fuel oil in the tank shall be maintained above its pour point and at a viscosity which permits gravity flow from the tank to the distribution pumps at the design rate. If required, a suction heater shall be installed to meet the viscosity requirements at the pump suction. Storage tank heating is accomplished by heating coils in the lower part of the storage tank. The fuel oil offtake to the pump suction line shall be located above the top of the heating coil to ensure that the coil is always completely below the fuel oil level. Storage tank heating shall not be accomplished by returning hot fuel from the distribution loop to the tank if this can result in overheating of the contents. This would apply to an LRFS, for example, where the fuel is circulated at 140 °C but stored below 90 °C as water may be present in the tank.

For the long residue type burning system the storage temperature will be less than 90 °C and the heating medium for the heating coil may be low pressure (LP) steam (LP steam pressure is normally around 4.5 bar (ga)) or hot water. Provision shall be made for drainage of water from a position below the heating coil.

For the short residue type burning system, where the storage temperature is required to be above 100 °C, the storage tank heating shall maintain the tank contents above the pour point but at a minimum temperature of 110 °C, specifically to avoid fluctuation around the boiling point of water. The preferred tank heating medium is a heat transfer fluid. If this heating facility is not available, electrical heating may be applied as an alternative provided that appropriate protection against high surface temperature (>300 °C) is incorporated. In order to avoid the risk of water leakage into the fuel, heating by steam or hot water shall not be applied.

4.1.4.3 Fuel oil circulation pumps

Pumps supplying the distribution loops shall be of the centrifugal type.

Three pumps shall be installed in parallel, each pump sized for at least 60% of the design fuel oil consumption. Normal operation will be with two pumps running and one stand-by.

The stand-by pump shall cut in automatically on falling fuel supply pressure such that fuel oil pressure is restored to normal without the system pressure falling to the low pressure trip setting of the consumers. If this cannot be achieved with 60% capacity pumps, then the capacity will have to be increased.

The stand-by pump shall be provided with an electric motor driver of the high starting torque type.

The drives of the two pumps in continuous operation may be electric or steam turbine, the choice being dependent on the outcome of considerations of the required security of fuel oil supply. Electric motor drives are attractive in terms of low maintenance requirement, ease of installation and operation, and for standardisation of the three pumps, but make the system totally dependent on the electric power supply. If an all electric drive option is selected, the two continuously operating pumps shall have independent power supplies (i.e. connected to different bus bars, preferably one to the emergency board). For large capacity fuel oil systems, where insufficient power is available from the emergency board for the drive, a steam turbine shall be applied. Also, when there is a requirement to maintain the fuel system in operation during a major power failure on the site, e.g. to maintain the utilities boilers in operation, a steam turbine drive shall be selected for at least one of the pumps, and for both pumps if the fuel system still has to deliver full capacity under electrical power failure conditions. A steam turbine drive shall not be used for the stand-by pump.

An exception to the three-pump configuration may be made when the security of fuel oil supply is less critical. Such a situation applies when an alternative fuel source is available for maintaining fuel supply to essential consumers. In this case, two pumps each rated at 100% of the design distribution flow (consumption plus return) may be installed to be operated continuously in parallel at 50% load each. For two electric drives, independent power supplies should be used, otherwise use one steam turbine drive and one electric.

Centrifugal pumps shall be according to DEP 31.29.02.30-Gen. and electric motor drives according to DEP 33.66.05.31-Gen. For steam turbine drives, DEP 31.29.60.10-Gen. and DEP 31.29.60.30-Gen. shall apply.

4.1.4.4 Fuel heaters

The temperature of the fuel oil delivered to the most remote customer (in terms of the distribution loop) shall be such that the fuel viscosity does not exceed 20 mm^2/s at the burner (see 4.1.3). Heat loss from the distribution linework shall be estimated in order to determine the required heater outlet temperature. Heating via heat exchangers using steam or HTF is preferred. Direct heating via electric heater or fired heater is applied when indirect heating is not feasible. Fuel oil flow through the heater shall be the total flow, not slip stream heating with partial bypass, with outlet temperature controlled by adjustment of the heating medium.

The fuel heaters shall be adequately spared to enable design heating capacity to be achieved when one heater is taken out of service for cleaning. In most applications, two heaters will be provided, one in operation and one stand-by. However, in large fuel systems, where large heat exchangers would be required for 100% heating capacity, it may be economically attractive to install three 50% capacity heaters in parallel.

For straight run long residue fuel oil systems where the distribution temperature will be less than 180 °C, MP steam (18 bar (ga)), having a condensation temperature of approximately 210 °C, is the preferred heating medium and is available on most sites. If MP steam is not available but a heat transfer fluid (HTF) system is available at a suitable temperature, this may then be used as heating medium. If no such fluid heating medium is available, alternative direct heating via electric heater or fired heater has to be considered. For straight run short residue fuel systems, where the distribution temperature may be up to 240 °C, MP steam is not suitable for heating. It is still preferred to use indirect heating if a suitable heating medium is available. This may be as HTF if available at a suitable temperature e.g. 280 - 300 °C, or as steam at higher pressure, e.g. intermediate pressure (IP) steam at a pressure level of 35 to 40 bar (ga) if available on site. This has a condensing temperature 245 to 251 °C and should only be considered for heating up to 220 °C distribution temperature. Steam at higher pressures becomes increasingly unattractive due to the pressure impact on equipment design versus the small gain in condensing temperature. When no suitable heating medium is available for indirect heating, direct heating via fired heater(s) shall be provided. In any event, the fuel oil film temperature in the heater tubes shall not exceed that above which fuel degradation/cracking can occur, i.e. the heating system shall not cause any flashing of light components or the formation of coke particles. For the purpose of this DEP, this film temperature shall be taken as 330 °C.

Fired heaters shall be designed according to DEP 31.24.00.30-Gen.

Heat exchangers shall be designed according to DEP 31.21.01.30-Gen.

4.1.4.5 Fuel oil filters

Suction filters, normally referred to as strainers, shall be installed in the pump suction line preferably close to the source of supply (e.g. storage tank outlet). Strainers shall be 100% spared with facilities for switching from one to the other to allow cleaning/flushing without interrupting the fuel oil supply. Vent and drain connections shall be provided on the filter body. The strainers shall be provided with differential pressure measurement for indicating when cleaning is necessary. Strainers shall be of the bucket type design with wire mesh screen and designed according to BS 799: Part 4. As this standard relates to commercial fuel oils as classified in BS 2869: Part 2, the fuel oil class which has a viscosity equal to or higher than the RFO shall apply for design.

Pressure or 'hot' filters shall be installed in the common line downstream the heaters. Filters shall be 100% spared with facilities for on-line switching from one to the other and to allow cleaning/flushing without interruption of the distribution fuel flow. Vent and drain connections shall be provided on the filter body. The filters shall be provided with differential pressure measurement for indicating when cleaning is necessary. Strainers shall be of the bucket type with wire mesh screens. Alternatively, the filters may be of the 'Auto-Klean' type which uses a stack of circular filter plates (instead of a mesh screen) with cleaning blades. These blades scrape filtered deposits off the filter plates as the filter assembly is rotated.

The pressure drop across the filter in clean condition at design flow should not exceed 0.15 bar.

Filters/strainers designed with flushing facilities shall be provided with an appropriate collection pot for the flushings with personnel protection against hot fuel oil splashes.

4.1.4.6 Heat tracing and Insulation

All fuel linework and associated equipment shall be heat-traced and insulated to minimise heat loss from the fuel. It is not essential that the heat tracing medium is at the same temperature or at a higher temperature than the circulating fuel oil, but it should be sufficient to maintain fluidity (i.e. pumpable) in stagnant lines. Where the heat tracing is not sufficient to maintain fuel in a stagnant line at the distribution temperature, provision shall be made for flushing with lower viscosity fuel or flushing oil so that combustion systems are not supplied with fuel with a viscosity higher than 20 mm^2/s when flow in the line is re-established.

If the heat-tracing medium temperature is higher than the distribution temperature, the consequences of heating the fuel oil to that temperature in a stagnant line shall be evaluated. In any case, whatever the temperature of the heat tracing, provision shall be made for thermal expansion relief. The associated instrumentation shall have a pressure rating which can tolerate the maximum pressures which can arise from expansion.

The preferred and most common heat-tracing medium is saturated steam for which, at a given pressure, the condensing temperature is fixed and ensures a constant temperature throughout the system, provided that adequate provisions are made for condensate removal to keep the tracing lines clear. LP steam at around 3.5 bar (ga) (condensing temperature 148 °C) is acceptable for long residue fuel oil systems and, when available, should be used in preference to higher pressure steam due to its lower cost. MP steam at around 18 bar (ga) (condensing temperature 210 °C) is acceptable for all systems and shall be applied on short residue fuel systems.

Electrical tracing may be used when steam is not available. The system shall be provided with facilities for monitoring each heating circuit and to give warning when it is not operational. Also, the maximum temperature which can develop in the heating elements shall be limited such that the fuel in a stagnant line cannot be overheated to the point of coking or vaporisation. Electrical trace heating installations shall conform to DEP 33.68.30.32. Heat transfer fluids are not considered suitable for heat tracing due to potential leakage from the numerous connections with consequential fire risk (in combination with insulation) and environmental hazards, as well as being difficult to control flow and temperature throughout the system.

The heat-tracing system shall be designed to allow access to equipment which will require routine maintenance. For example, it shall be possible to remove a control valve without breaking the heat-tracing system.

4.1.4.7 Flushing and steam-out connections

Particularly for short residue systems, flushing connections shall be provided for filling the system with lighter fuel oil or flushing oil prior to system shut-down. Also connections shall be provided on principal equipment which is subject to maintenance on a routine basis such as pumps, heaters and filters. It shall be possible to take such equipment out of service to flush and drain without interruption of the fuel oil system operation.

For high viscosity systems (SRFS), connections shall be provided on consumer supply lines to enable flushing of the downstream system. When an alternative lower viscosity fuel supply is available, this may be introduced into the system prior to a shut down whilst the system continues in normal operation. Then, the fired appliance may be shut down and, later, started up on the light viscosity fuel oil. Note that the flushing fuel oil used in this way shall be compatible with the burner installation see (2.3).

Flushing oil shall not be injected directly into a hot system if this would cause flashing of light components.

Alternatively, MP steam may be used to displace fuel from linework to a suitable disposal point (e.g. slops tank). Steaming out linework via the burners is possible when this can be done safely, i.e. when there is combustion support and when the heat release from the purged oil can be accommodated.

The flushing system or steam-out line-up shall be designed such that a back-flow of RFO into the flushing or steam system cannot occur.

Steaming-out connections to appropriate reception facilities (slops, fuel oil pool) shall also be provided for the above equipment, at strategic points for emptying the system or individual branches of the system.

4.1.5 Asphalt burning system (ABS)

4.1.5.1 General

As stated in 4.1.1 the ABS handles the very heavy residues up to a maximum viscosity of approximately V_{50} = 50 mm^2/s and those residues which may generate gas during storage (see 4.1.1). This maximum V_{50} value is approximate because the viscosity/temperature relationship for residues varies depending on crude origin, the process by which the residue has been formed and its history, i.e. storage period and cracking severity. Similarly, the temperature at which cracking becomes significant also varies with type of residue. Therefore, in designing an ABS, the characteristics of the residue, including the viscosity temperature relationship, shall be determined first in order to establish the temperature required for 20 mm^2/s viscosity and to verify that this temperature plus an allowance for system heat losses can be tolerated by the residue without significant cracking/coke formation taking place.

In addition to the above, it shall be recognised that heavy residues derived from crude oil refining processes contain a concentration of the impurities present in the original crude. Of particular concern are sulphur, nitrogen, metals, asphaltenes, coke and ash. All have a potential impact on environmental emissions as well as flue gas side fouling and corrosion of the fired equipment. Therefore, it is essential that the ABS is designed to serve only those units which are provided with suitable convection bank cleaning equipment to cater for the potential high fouling of surfaces and which have the capability of burning this fuel without impairing performance or causing damage to the equipment (e.g. by high/low temperature corrosion).

Storage of asphalt fuel is frequently not required and the system can be simplified significantly by taking the residue as hot run down from the process unit which produces it. The hot run down temperature is usually above the required ABS fuel distribution temperature and so there may be no need for a fuel heater. When there are no heating facilities, hot short or long residue shall be available on stand by for flushing purposes.

The design of an ABS relies on circulation for overcoming heat loss and the circulation loop should be taken as close as possible to the consumer, in order to minimise the length of dead legs. The circulation rate shall be sufficiently high to limit the loss of temperature at any point in the system to not more than 20 °C. To achieve this, the return flow should be as high as the fuel consumption rate and have a minimum velocity of 1 m/s. As a general guide, in order to avoid coking in the heater tubes, the maximum oil film temperature will be limited to 330 °C which will then limit the outlet bulk temperature to around 300 °C. Allowing a 20 °C temperature loss in the distribution loop, the temperature available at the burner will be 280 °C. Therefore, the viscosity at this temperature should be 20 mm^2/s or less. If this is not the case, a diluent must be added to the residue. The distribution system shall be based on a main distribution loop and parallel sub-loops as required. These sub-loops also maintain a circulation flow from the main supply discharging via a flow control valve back to the main return. The number of sub-loops is dependent on the number and geographical location of consumers as well as the unit maintenance shut-down requirements (such that a sub-loop can be taken out of service when required together with the consumers it supplies). The sub-loops shall therefore be provided with flushing and isolation facilities. Offtake lines from the sub-loops to the consumer's combustion system shall be taken from the top of the line and kept as short as possible.

Heat tracing and insulation shall be applied to a high standard throughout to minimise heat losses from the system. This includes all asphalt relief and drain conditions to minimise the risk of blockage. Insulation shall be according to DEP 30.46.00.31-Gen. Even though the main circulation loop is normally kept hot by circulation, this shall be heat traced to cover the situation of circulation failure. The preferred heating medium is MP steam (18 bar (ga)). Alternatively, electrical heating may be applied. All inside plot asphalt lines (i.e. not the main circulating distribution loop) shall be dual heat traced.

Start-up and shut-down of the ABS is performed with a lower viscosity fuel such as long residue. Not only is this a requirement for the system start-up, but it is also necessary for the consumer's fired equipment which must be operating and hot before asphalt is introduced. Thus, it shall be possible upon demand to switch in the lower viscosity fuel in the feed line to the system and vice versa.

Notwithstanding the above, flushing oil injection points shall be strategically located to ensure that all dead leg lines and sections which can be taken out of service may be flushed quickly and efficiently. The system shall be designed to avoid the risk of asphalt fuel leaking back into the flushing system. The asphalt shall be flushed to an appropriate reception point such as the fuel oil pool or returned to ABS surge vessel. The flushing medium shall not be so light that flashing may occur as it enters the high temperature system. The preferred flushing medium is straight run long residue which will also serve as a suitable back-up fuel in case of interruption of asphalt supply.

Thermal reliefs are required on sections which can be isolated. Relief valves and drain connections shall not be connected to flare headers or underground drainage systems. Liquid relief valves may discharge into open pits but it shall be ensured that water cannot accumulate in these pits.

Examples of ABS schemes with and without storage are shown in Figures 11 and 12.

4.1.5.2 Asphalt storage

It is not normally the intention to have long-term storage of asphalt but to take hot rundown from the producing units and to consume it as soon as possible. However, circumstances may dictate that provisions for storage are required. When storage provision is not required and the system has a secure back-up fuel supply, sufficient hold-up capacity for absorbing the normal swings in production and consumption shall be provided in the surge vessel. This shall also be sufficient to cater for short term upsets in the supply from the asphalt producer and to allow time to switch to an alternative fuel when the supply of asphalt fails. To meet these requirements, the hold-up of the surge vessel should not be less than 2 hours at design fuel consumption rate.

When additional storage capacity is required (e.g. another 2 hours), it may still be more economical to use an additional vessel rather than a storage tank. When a storage tank is provided, the capacity should not be less than 12 hours at design fuel consumption rate. Storage tanks shall be in accordance with DEP 34.51.01.31-Gen. and shall follow safety requirements as specified for bitumen storage. Hot asphalt rundown shall be cooled as necessary to avoid exceeding the maximum design temperature of the tank.

In order to maintain the asphalt at a pumpable temperature the asphalt storage tanks have to be maintained at the maximum safe storage temperature. Unblanketed tanks shall be limited to 200 °C maximum storage temperature whereas tanks blanketed with either steam, nitrogen or fuel gas may be operated up to a maximum temperature of 230 °C.

Although unblanketed tanks are permitted below 200 °C, there is a strong preference for higher temperature storage using blanketed tanks. This is particularly the case where the unblanketed tank would lead to the release of objectionable odours or where the viscosity of the fuel at the maximum storage temperature of 200 °C is too high for applying centrifugal pumps (in which case screw pumps have to be considered). If used, unblanketed tanks shall be designed such that air ingress into the vapour space below the roof is minimised to reduce the risk of fire hazard from low auto-ignition temperature deposits (albeit that deposits typically have an auto-ignition temperature around 240 °C).

Blanketing shall be by either steam, nitrogen or fuel gas. Vent gas shall be routed to a furnace via a water seal vessel for incineration unless there are other means available for treating the gas. Water from the seal vessel will become contaminated with hydrocarbon liquid and requires separation. Water shall be treated as sour water and hydrocarbon liquid pumped to slops.

The tank shall be heated, preferably using HTF as heating medium. If this is not available, electric heating may be applied provided that protection against element overheating (i.e. maximum surface temperature 300 °C) is provided and that the elements are withdrawable.

In line with avoidance of any water ingress into the asphalt, heating by steam is not permitted.

HTF/hot oil heating coils shall be of all-welded construction.

Consideration shall be given to the need of a mechanical mixer for maintaining a uniform temperature/viscosity of asphalt in the tank and for preventing localised overheating which may result in coke and vapour production. The need for such provision will increase with storage capacity and with the degree of heating normally required (via the heating coils).

The suction line from the tank shall be located at least 15 cm above the heating coils/elements to ensure that they are always below the liquid level.

4.1.5.3 Asphalt transfer pumps

The role of the transfer pumps is to supply asphalt to the circulation system as well as to maintain a constant circulation over the storage tank. The flow is controlled by a level controller in the surge drum acting on a flow controller in the asphalt supply line which regulates the feed to the furnace and return to the tank. (See Figure 11).

At least two transfer pumps in parallel shall be provided. For a two-pump arrangement, the pumps shall each be rated for 100% flow to the asphalt loop but will operate in parallel with recirculation to the tank. Alternatively, three pumps of equal but lower capacity may be provided in which the 100% flow to the asphalt loop is met by two pumps. In this arrangement all three pumps normally operate in parallel with recycle back to the tank. In both arrangements, therefore, the loss of one pump does not restrict asphalt flow to the loop.

Pumps shall be able to handle asphalt containing particles of coke up to 6 mm diameter. Centrifugal pumps are preferred as they have a better capability to meet this requirement. However, centrifugal pumps should be used only when the viscosity of the asphalt at the pump suction is acceptable. An acceptable viscosity is that at which a pump efficiency correction is less than 50% .

If centrifugal pumps cannot be applied, alternatives such as screw pumps may be considered. However, attention shall be given to pump sealing requirements and increased demand on the seal flushing system. The open seal flush system, however, has a higher seal flush oil consumption and may result in unacceptable downgrading of flushing oil to refinery fuel. The additional mechanical complexity of screw pumps and associated system requirements may be less attractive than providing for higher temperature storage and use of centrifugal pumps.

The selection of pump drives shall be based on reliability and the need to maintain some flow in the event of a failure of one pump drive power supply. The preferred arrangement is to have an independent supply to one of the pump drives, either steam or electric (if all electric drives, use power from different bus bars).

Centrifugal pumps shall be according to DEP 31.29.02.30-Gen. and electric motor drives according to DEP 33.66.05.31-Gen. Steam turbine drives shall be in accordance with DEP 31.29.60.10-Gen. and DEP 31.29.60.30-Gen. For screw pumps refer to DEP 31.29.02.11-Gen.

Reciprocating positive displacement pumps shall be according to DEP 31.29.12.30-Gen.

4.1.5.4 Asphalt heaters

If additional heating is required (see 4.1.5.1), direct heating of asphalt by fired heater is normally applied. However, if a high temperature HTF system is available, indirect heating via this medium may be applied.

Fired heaters shall be according to DEP 31.24.00.30-Gen. Heat exchangers shall be according to DEP 31.21.01.30-Gen.

If additional heating is required, consideration shall be given to the need for sparing the heater. The acceptability of single heater installation shall be judged in relation to the facilities available for flushing asphalt in the event of heater failure, and the economics of not having asphalt firing capability during periods where heater maintenance is required. If the ABS is based on hot run-down but requires a fired heater for back-up, then a single heater suffices. However, if there is a strong need to keep the ABS in operation then two heaters shall be provided, designed such that both will normally operate in parallel but each will have the capability to operate alone whilst maintaining the fuel system at the required capacity. Normally, this implies that each heater of a two-heater configuration will be designed for 100% capacity. However, a lower capacity may be acceptable where a lower asphalt consumption rate can be accommodated temporarily in the event that one heater is not available. This consideration shall include the alternative routing or storage of asphalt fuel component streams as well as the availability of alternate fuels for selected consumers connected to the asphalt system.

Additional heating capacity (e.g. 20%) should be built into the system if there is the likelihood of expansion to new consumers.

The heaters shall be designed such that the maximum film temperature of the asphalt does not exceed that at which cracking is to be expected. This temperature is dependent on the origin of the fuel components both in terms of the type of crude and the process by which the fuel is produced. However, as a guide, 330 °C is typical. Thus, where the asphalt temperature at the heater outlet is required to be 300 °C, particular attention to heater design is required to minimise the film temperature by minimising heat flux to the coils and by avoiding low asphalt velocity in the coils.

In order to minimise peak heat flux and maximise turndown on the firing side, fuel gas firing of the heaters is preferred.

A consequence of using thermally cracked residues is that there will be a continuous development of waste gas due to after-cracking. Therefore, provision has to be made for routing the gas to a point of incineration. When a fired heater is applied, this waste gas can be incinerated via the heater.

Provision shall be made for incinerating vapours vented from the surge drum via a waste gas burner arrangement which injects the waste gas in the main burner flame zone (and consumes air supplied to the main burner). Vent gas from the storage tank (blanket medium) may also be included in this stream. When fuel gas is used as blanketing medium it may be possible to include the vented gas in the waste gas stream to the heater, provided that this cannot result in an excessive heat input to the heater. The total heat input to the heater via the waste gas stream shall not exceed 15% of the furnace design duty and not exceed 25% heat input per burner.

In order to maintain asphalt flow through the heaters in the event of a supply failure (e.g. transfer pump), a recycle line shall be provided from the circulation pump discharge to the furnace inlet under pressure control. The heaters shall be designed to allow steam/air decoking of the coils.

4.1.5.5 Asphalt filters

As a minimum, hot filters shall be provided downstream the asphalt surge drum and, in addition, similar dual filters shall be provided upstream of the furnaces. However, due consideration shall be given to the thermal stability of the asphalt fuel together with the temperature and residence time in the circulating system in determining the need for additional filters, e.g. in sub-loops. Individual consumers shall also apply a final filtration step upstream of the combustion control set to protect the burners (these are not shown on the main fuel system scheme as this equipment forms part of the consumer's fuel control system package). The selection of filter type and design shall follow the same design principles as given in (4.1.4.5.). Thus capacity and pressure drop shall be based on the design flow in clean condition. However, as the fouling tendency of the fuel is higher than with lighter fuels, facilities for frequent cleaning are required. Therefore, there is a preference for auto-cleaning types such as "Auto-Klean" or for back-flushing types.

Flushing oil connections to enable displacement of asphalt after taking out of service shall be provided. Vent and drain connections shall be provided on the filter body.

4.1.5.6 Asphalt surge drum

The surge drum provides a constant pressure supply of hot asphalt to the circulation pumps. The hold-up capacity shall be sufficient to ensure that, in the event of a sudden interruption in supply of asphalt to the surge vessel from the heaters, the supply of asphalt to the consumers can be maintained at design rate for a period during which remedial action can be taken (either re-establishing hot asphalt supply or switching to alternative fuel). Unless clearly demonstrated to be otherwise, this period shall be taken to be 2 hours.

Make-up to the system is controlled via a slave flow controller in the line from the transfer pumps to the heaters under master control of asphalt level in the surge drum. High level alarm and high high level trip (of asphalt supply and heaters) shall be provided to avoid overfill. A low level alarm shall be provided. The low level alarm should be set such that, when the alarm occurs, there is still sufficient inventory for maintaining the system in operation for a period during which remedial action can be taken. A low low level trip of the circulation pumps is considered undesirable as a spurious trip would stop all pumps and circulation in the system would be lost. Circulation is essential for maintaining temperature and fluidity of the asphalt in the distribution lines.

Although the system is designed to minimise cracking of the asphalt fuel, experience shows that cracking continues to some extent, particularly as the V_{50} viscosity and thus temperature of the fuel increases. As a result of cracking, sludge and coke build-up will occur in the surge drum and shut-down of the system for drum clean-out will be required every 2 to 3 years. To minimise sludge accumulation, the drum shall be built at a slope of 1:100 with the inlet at the higher end and the outlet at the lower end.

Evolution of vapours from the asphalt will also occur in the surge drum and these should be vented via a line to the asphalt heater to be incinerated. If fired heaters are not employed, an alternative furnace or incinerator should be used for disposal of these vapours. It shall be possible to divert these vapours to atmosphere at a safe location or to flare when the furnace/incinerator cannot accept them, e.g. in the event of furnace trip. In the case of a design for diversion to flare, consideration shall be given to the consequences of potential fouling/corrosion deposits which may result in the flare system and, hence, the need for routing to flare via a scrubber.

The surge vessel should be designed for the shut-off head of the transfer pumps such that the risk of liquid relief is minimised. Safety relief valves (one in service, one spare) are required. The outlet lines from relief valves should be as short as possible and shall be heat-traced and routed to a sand pit at grade. This pit shall be cordoned off to protect against personal injury in the event of hot asphalt release occurring. The surge vessel shall be kept under positive pressure, typically 2 bar (ga), by injecting nitrogen or fuel gas into the vapour space when vapour production from the asphalt is insufficient to maintain the controlled pressure. The preferred arrangement is to inject the blanketing medium into the surge drum vent line from drum to furnace/incinerator. Drum pressure is controlled via separate high and low pressure controllers which act respectively on the blanketing medium inlet and vent outlet with a gap of about 0.2 bar between the two set points. The vent outlet has two possible routings, either to the furnace/incinerator or to atmosphere at a safe location (or flare), each line having a control valve. The control valves on blanketing medium inlet and vent outlets shall be tight shut-off. Normally, vent gas flows to the furnace/incinerator and the vent to atmosphere (or flare) will be closed. In the event of a furnace/incinerator trip, the vent to atmosphere (or flare) becomes operational and the vent to furnace/incinerator closes.

Both of the vent gas outlet control valves shall close on HH liquid level in the surge drum to prevent the possibility of hot asphalt overflow to the furnace or atmospheric release at elevated level. All vent and relief valve lines from the surge drum, and associated valves/instruments shall be heat-traced and insulated.

4.1.5.7 Asphalt circulation pumps

Circulation pumps shall be of the centrifugal type.

Three pumps shall be installed in parallel, each pump sized for at least 60% of the design asphalt circulation rate. Normal operation will be with two pumps running and one stand-by.

The selection of pump drives shall be based on reliability and the need to maintain some flow in the event of a failure of one pump drive power supply. The preferred arrangement is to have an independent supply to one of the pump drives, either steam or electric (if all electric drives, use power from different bus bars).

The stand-by and spare pumps shall be maintained in hot condition by means of a small reverse flow of hot asphalt passing via a bypass (typically 25 mm diameter) around the discharge check valve. The stand-by pump shall cut in automatically on falling fuel supply pressure such that asphalt fuel pressure is restored to normal without the system pressure falling to the low pressure trip setting of the consumers. The pump capacity and system normal circulation rate shall be selected to be compatible with this requirement, in order to achieve a smooth cut-in of the standby pump without incurring a low system pressure trip.

The circulation rate shall be sufficient to maintain the asphalt temperature in the circulation loop return within 20°C of the temperature of asphalt at the heater outlet. This will be dependent on the line size and length of the loop, the heat tracing and the insulation applied and the heat loss shall be estimated in each case. However, the return flow shall not be less than the design asphalt consumption rate and should maintain turbulent flow conditions throughout the circulation loop.

4.1.8 Instrumentation

Reliable instrumentation is essential for successful operation of the asphalt fuel system. The consequences of failure to maintain the correct heating and circulation are very serious. Overheating can result in excessive cracking and coke production which will block filters and burners and fouling of heater coils will lead to coil overheating failures. Loss of circulation and temperature will lead to line blockages and can render the fuel system and the consumer's combustion system inoperable. Therefore it is essential that adequate sparing/duplication is available in the critical measurement and control areas. The following list describes the main items to be addressed although this is not necessarily exclusive:

- main asphalt control valves to be provided with a 100% spare;
- main level controls (e.g. surge drum) to be provided with two independent transmitters: one supplying the control signal, the other supplying signals to the alarms. The transmitter signals may be interchanged by a panel mounted switch;
- main pressure controls to be provided with three independent transmitters with a selector to pass the mean value to the controller. All three transmitters to be connected to alarms and to be mounted above lines containing asphalt (to avoid fouling by

leakages);

- instrument tappings to be as short as possible, heat traced and insulated;
- all asphalt control valves to be heat traced and insulated;
- asphalt loop and sub-loop return control valves to be provided with a mechanical minimum stop set to an opening to provide sufficient flow for maintaining the asphalt at a pumpable temperature.

4.2 LBF SYSTEM

4.2.1 General

Low Boiling Fluids used in these systems are typically light tops, light naphtha and gasoline. LBF systems tend to be used intermittently for disposing of products which are off specification. In the past, fluids such as liquid butane or even liquid butane/liquid propane mixes have been used in high pressure systems (using pressure-atomised burner systems) but, nowadays, it is strongly preferred to burn such LPG mixtures as a gas (see (3.1.4) and (3.1.5)) rather than as a liquid due to the problems which can arise when burning liquid propane and/or butane. These problems relate to premature vaporisation causing burner instability and to the cooling effect of rapid vaporisation which can cause ice/hydrate formation in the burner. Therefore, LBF systems should be designed only for fluids which are liquid at ambient atmospheric temperature and pressure and only applied when a disposal facility by this route is considered to be necessary.

Burner systems used to fire LBF are based on pressure atomisation and all fuel linework shall be kept completely separate from fuel oil systems to avoid risk of contamination and also to ensure no heating of LBF occurs.

Leaking LBF is a fire hazard and so non-welded connections shall be kept to a minimum. This is of particular importance close to the consumer furnace.

4.2.2 LBF storage

The LBF storage system does not need to be designed as a primary fuel system in terms of storage capacity. Storage capacity is determined on the basis of intermediate storage required to hold a batch of off-spec. product. Tanks are designed to the same type and standard as the product storage tanks to which the product normally flows.

4.2.3 LBF pumps

Electrically driven centrifugal pumps shall be used to distribute the LBF to the consumers. Recirculation flow is only required for pump minimum flow protection and LBF supply pressure control and so the pump capacity relates to the design consumption rate only. The recycle line shall be taken from the header downstream of the pump discharge.

Two pumps of 100% capacity shall be used and operated in parallel so that in case one pump trips, the design flowrate can be maintained with the remaining pump.

4.2.4 Distribution header

A single bare pipe header is required.

4.3 GAS OIL SYSTEM

The practice of using gas oil as a start-up fuel for furnaces is now in decline and it is preferred to start up oil-fired furnaces with long residue type RFO using steam-atomised burner systems. Gas oil at ambient temperature should not be supplied to burners which use steam for fuel atomisation because this can result in condensation of steam in the burner which causes the burner to exhibit excessive fuel capacity. Also, fuel gas fired furnaces which used to be started up on gas oil for safety reasons are increasingly being equipped with safeguarding equipment which enables safe start-up on gas.

Therefore, the use of industrial grade gas oil in relation to fuel systems is now mainly as flushing medium for RFO systems or as a diluent for viscosity control of residual fuel oil systems. Gas oil should preferably not be used for flushing high temperature fuel systems, such as ABS, where the temperature is higher than the IBP (initial boiling point) and vaporisation may result.

Automotive grade gas oil (distillate fuel) is used in diesel engines and gas turbines. The systems are generally standard-packaged skid-mounted units which form part of the supply of the diesel engine or gas turbine Supplier.

4.4 OIL-IN-WATER EMULSIONS

A recognised method, recently developed, of reducing the viscosity of very heavy residues is to create an oil-in-water emulsion in which the water content is up to 30% weight. In an oil-in-water emulsion, the water forms the continuous medium and the fine droplets of residual oil are in suspension. The droplets are prevented from coalescing by use of a surfactant. This surfactant plays a crucial role in maintaining the stability of the suspension. Some surfactants are protected by patent and are expensive.

Refinery applications may be developed using cheaper surfactants which have the capability to maintain a stable emulsion over a short period only, i.e. a few days. In such a system, the storage capacity will be short-term, (about 24 hours) and the aim will be to burn the emulsion as soon as possible after it has been prepared.

Following the emulsion preparation system, the fuel system design will be similar to a RFO system for long residue. Even though the viscosity of the emulsion can be suitable for the burner atomisers without additional heating, the emulsion should not be delivered to steam-atomised burner systems at a temperature less than 120 °C, to avoid flame instability due to condensation of atomisation steam in the burner guns.

Due consideration shall be given to the impact of burning a fuel emulsion on the downstream equipment and on the atmospheric emissions. Fuel flows are significantly higher (as up to 30% is water), flue gases are higher in water content (possible stack plume problem), and the very heavy residues likely to be used in such systems probably contain a high proportion of undesirable contaminants such as sulphur, metals, ash, etc.

Water-in-oil emulsions do not behave in the same manner as oil-in-water emulsions and should not be used.

5. REFERENCES

In this DEP, reference is made to the following publications:

NOTE: Unless specifically designated by date, the latest edition of each publication shall be used, together with any amendments, supplements or revisions thereto.

SHELL STANDARDS

Index to DEP publications and standard specifications	DEP 00.00.05.05-Gen.
Design guide for high temperature heat-transfer fluid systems	DEP 20.05.50.10-Gen.
Thermal insulation for hot services	DEP 30.46.00.31-Gen.
Shell-and-tube heat exchangers (amendments/supplements to TEMA standards)	DEP 31.21.01.30-Gen.
Gas/liquid separators - Type selection and design rules	DEP 31.22.05.11-Gen.
Fired heaters, including waste heat boilers (amendments/supplements to API 560)	DEP 31.24.00.30-Gen.
Pumps - Selection, testing and installation	DEP 31.29.02.11-Gen.
Centrifugal pumps (amendments/supplements to API Std 610)	DEP 31.29.02.30-Gen.
Reciprocating positive displacement pumps and metering pumps (amendments/supplements to API Std 674 and API Std 675)	DEP 31.29.12.30-Gen.
Centrifugal compressors (amendments/supplements to API Std 617)	DEP 31.29.40.30-Gen.
Reciprocating compressors (amendments/supplements to API Std 618)	DEP 31.29.40.31-Gen.
Steam turbines - Selection, testing and installation	DEP 31.29.60.10-Gen.
General-purpose steam turbines (amendments/supplements to API Std 611)	DEP 31.29.60.30-Gen.
Combustion gas turbines - Selection, testing and installation	DEP 31.29.70.11-Gen.
Piping classes - Basis of design	DEP 31.38.01.10-Gen.
Piping - General requirements	DEP 31.38.01.11-Gen.
MF Piping classes	DEP 31.38.01.12-Gen.
Electric motors - Cage-induction and synchronous type	DEP 33.66.05.31-Gen.
Electrical trace heating	DEP 33.68.30.32-Gen.
Standard vertical tanks - Selection, design and fabrication	DEP 34.51.01.31-Gen
Pressure relief and flare system	DEP 80.45.10.10-Gen.

STANDARD DRAWINGS

Refinery Fuel Gas System	S 01.001

BRITISH STANDARDS

Specification for atomizing burners (other than monobloc type) together with associated equipment for single burner and multi burner installations	BS 799: Part 4
Specification for fuel oil for agricultural and industrial engines and burners	BS 2869: Part 2

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6. FIGURES

FIGURE 1 REFINERY FUEL GAS SYSTEM

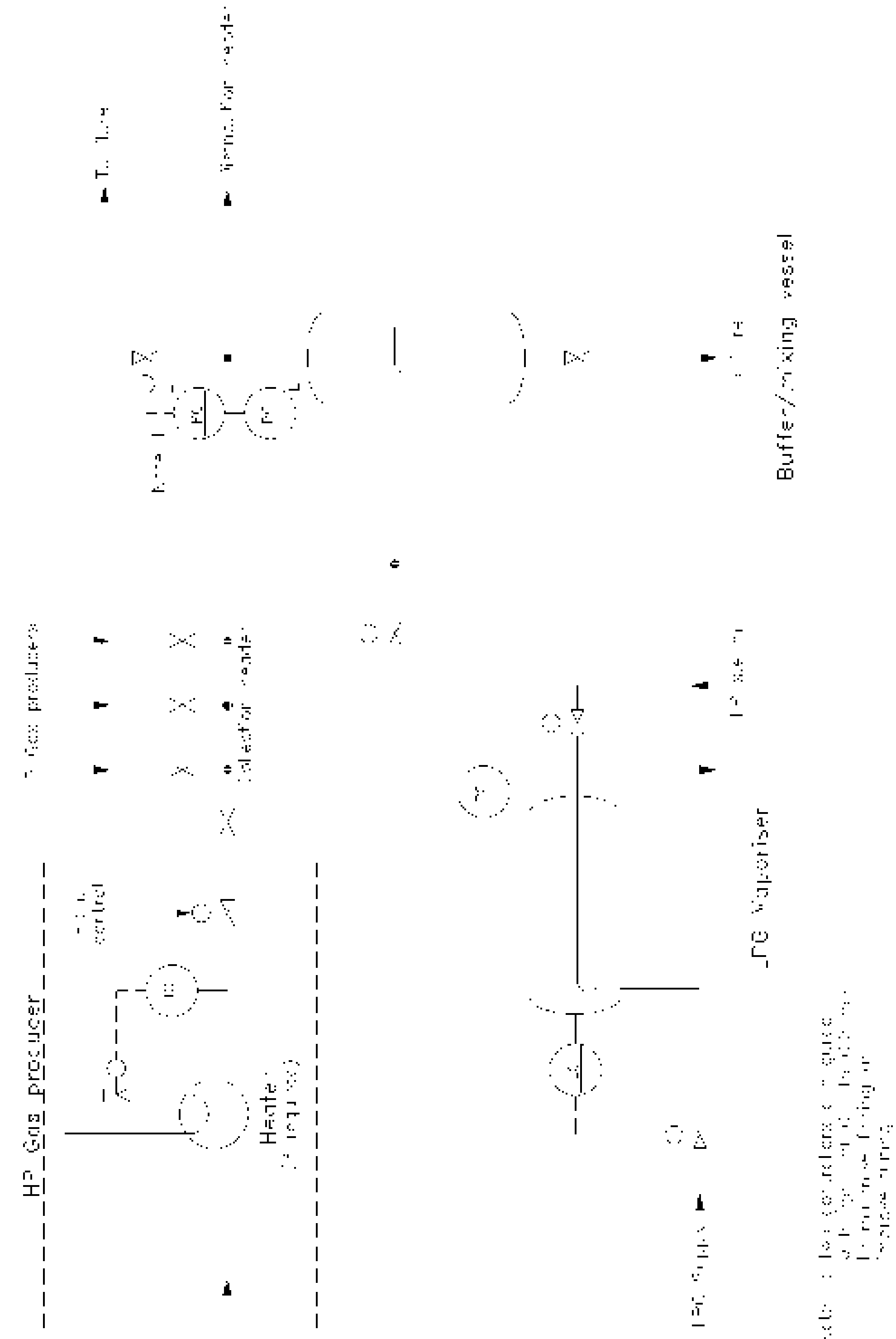


FIGURE 2 HP GAS CONNECTION VIA HP BUFFER

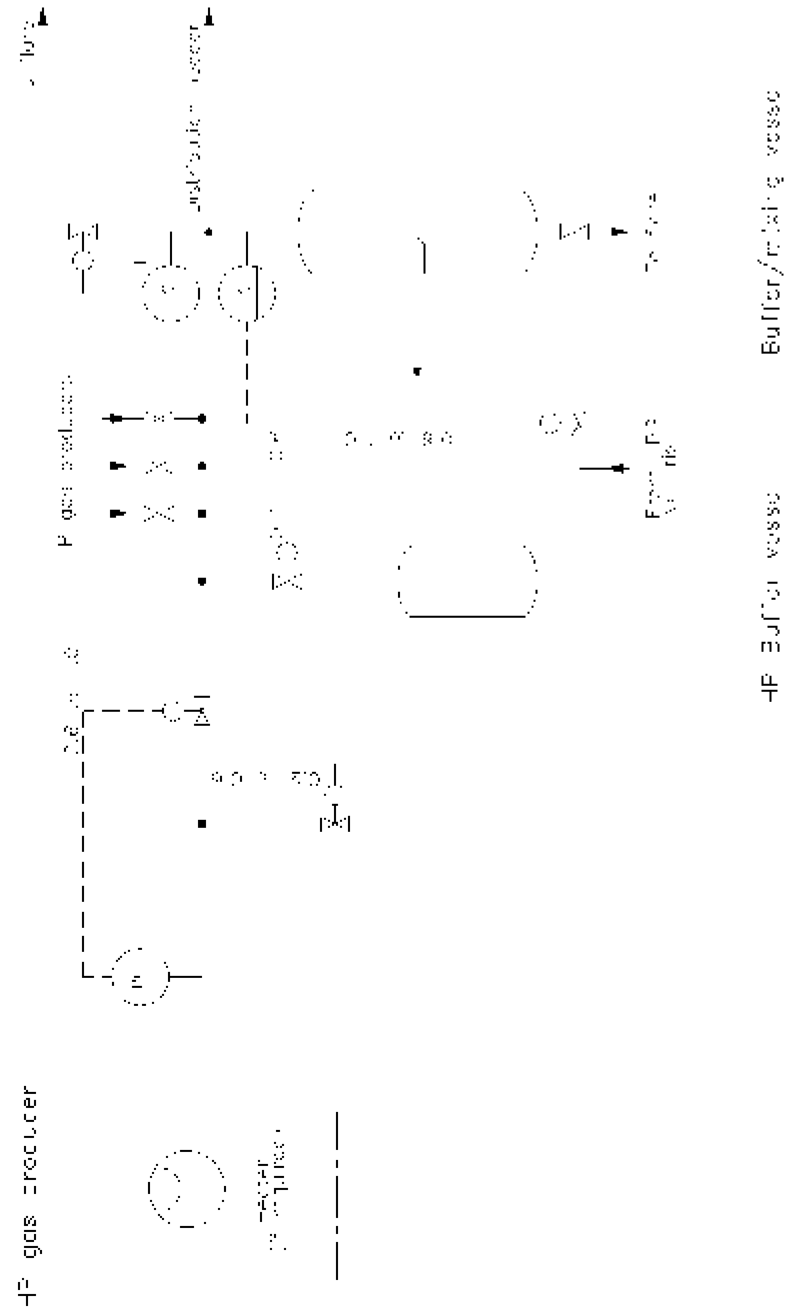
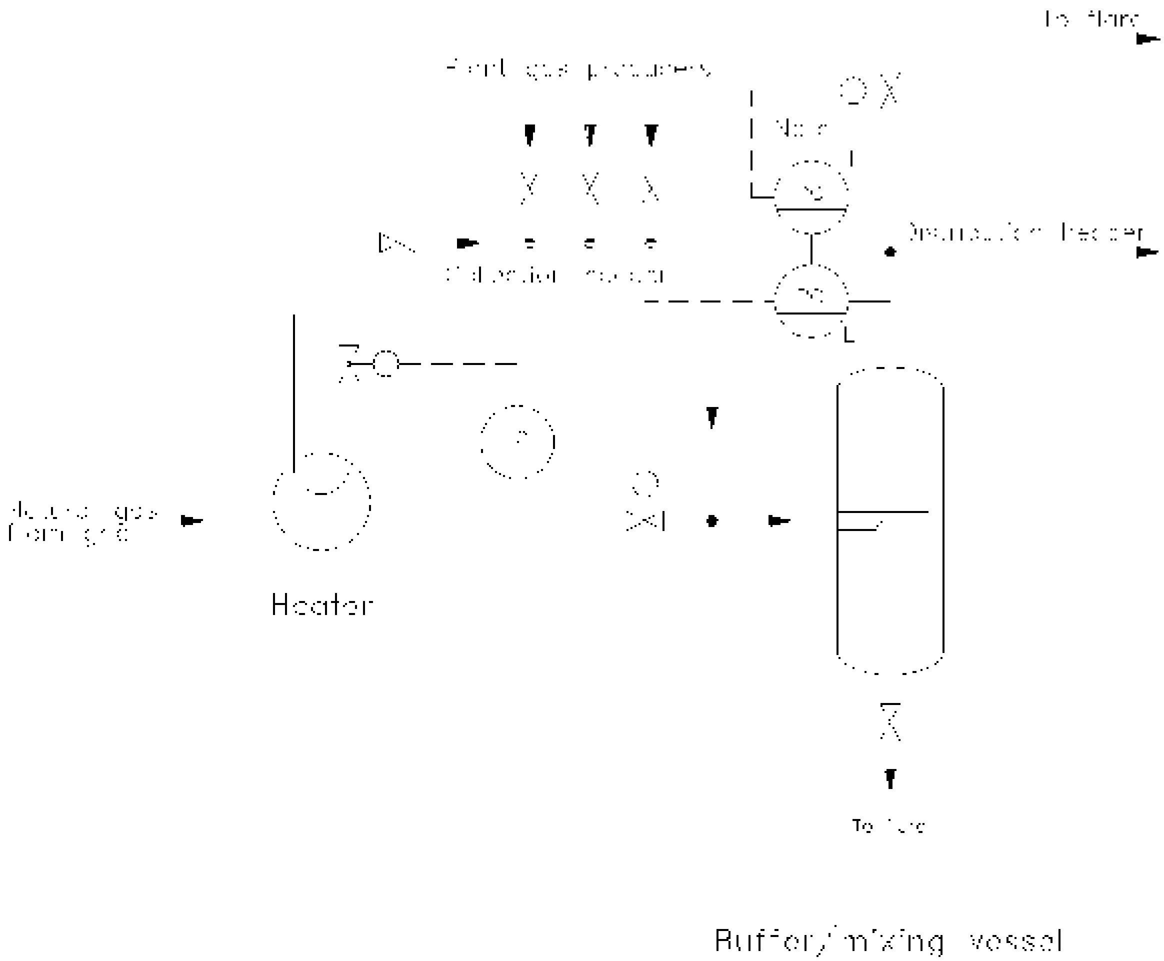


FIGURE 3 NATURAL GAS BACK-UP (ALTERNATIVE TO LPG VAPORISER)



Note: [illegible] to minimise flaring and improve tuning.

FIGURE 4 FLARE GAS RECOVERY

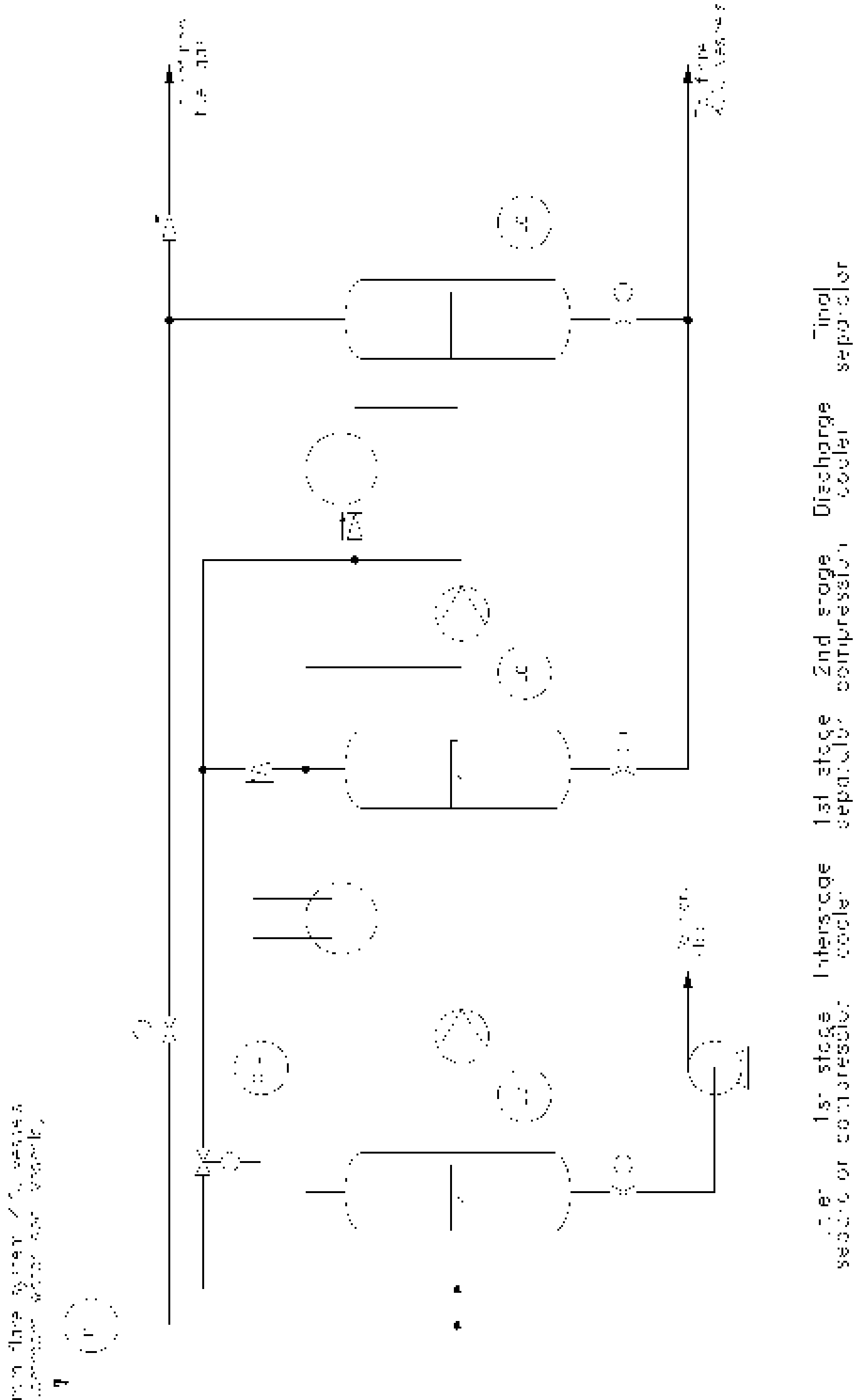


FIGURE 5 GAS TURBINE NATURAL GAS SUPPLY WITH DIESEL BACK-UP

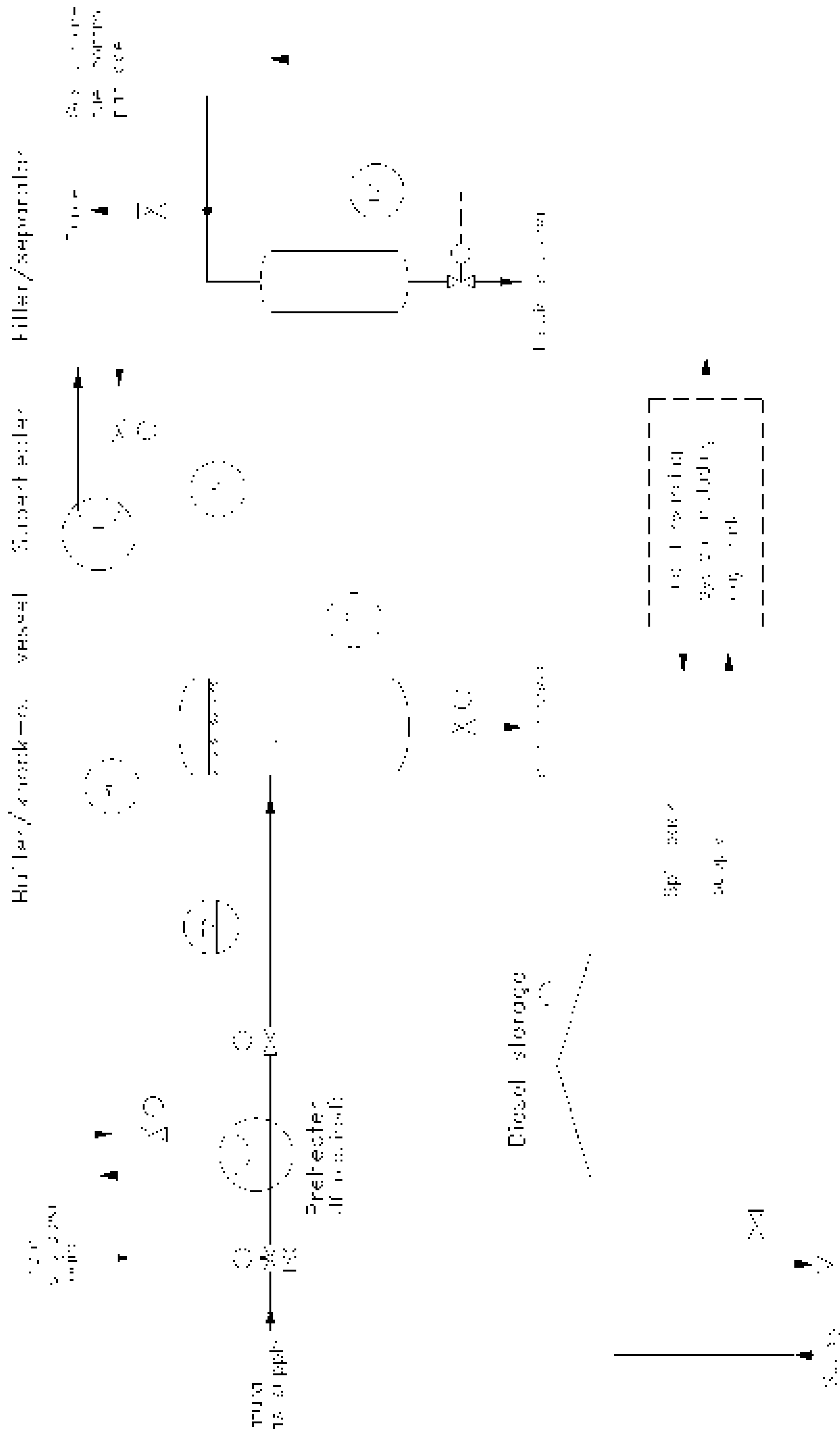


FIGURE 6 GAS TURBINE COMPRESSED FUEL GAS SUPPLY SYSTEM WITH VAPORISED LPG BACK-UP

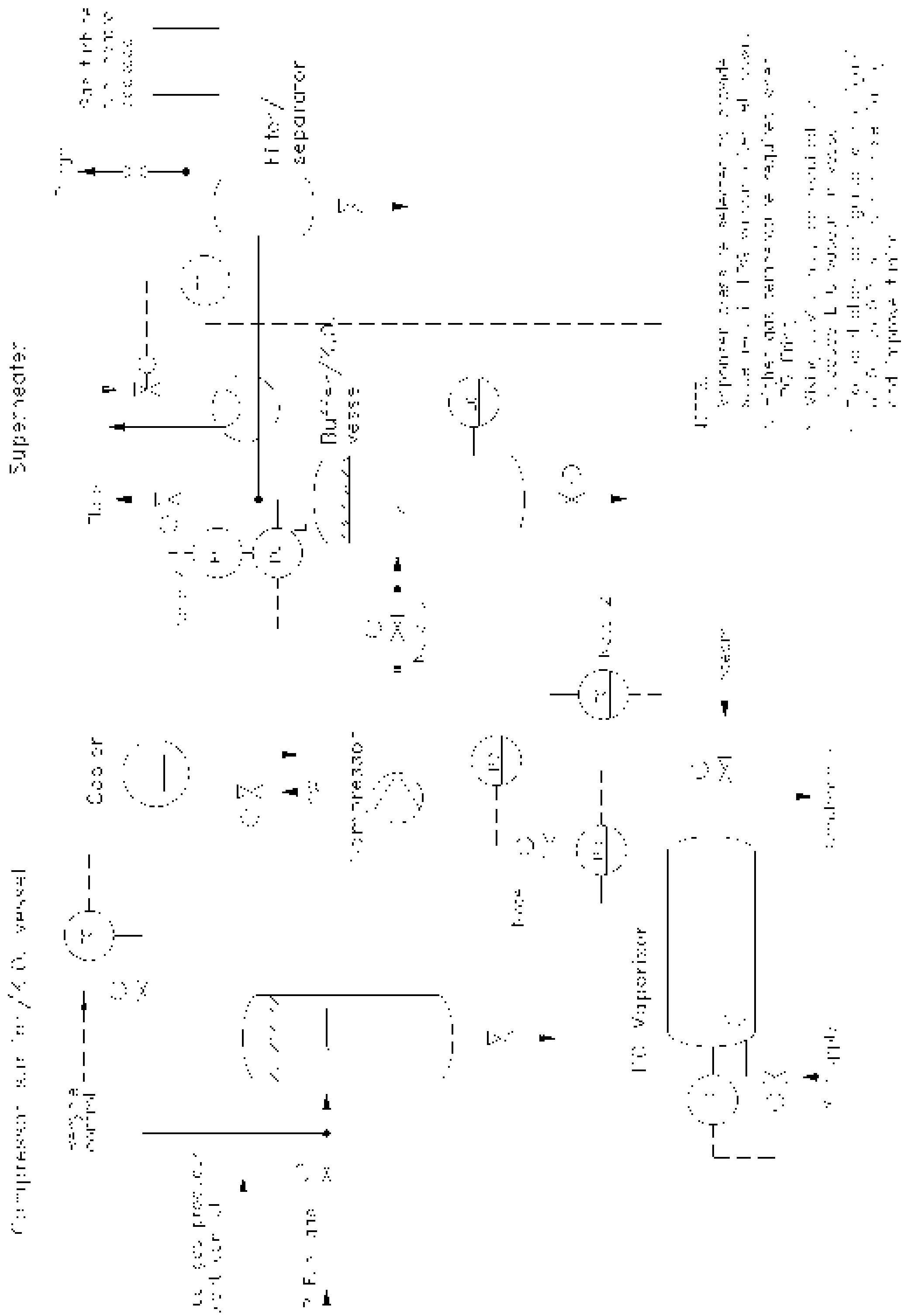


FIGURE 7 FUEL SYSTEM FOR SUPPLYING SYNGAS BLENDED WITH LPG TO A DUAL GAS FIRED GAS TURBINE

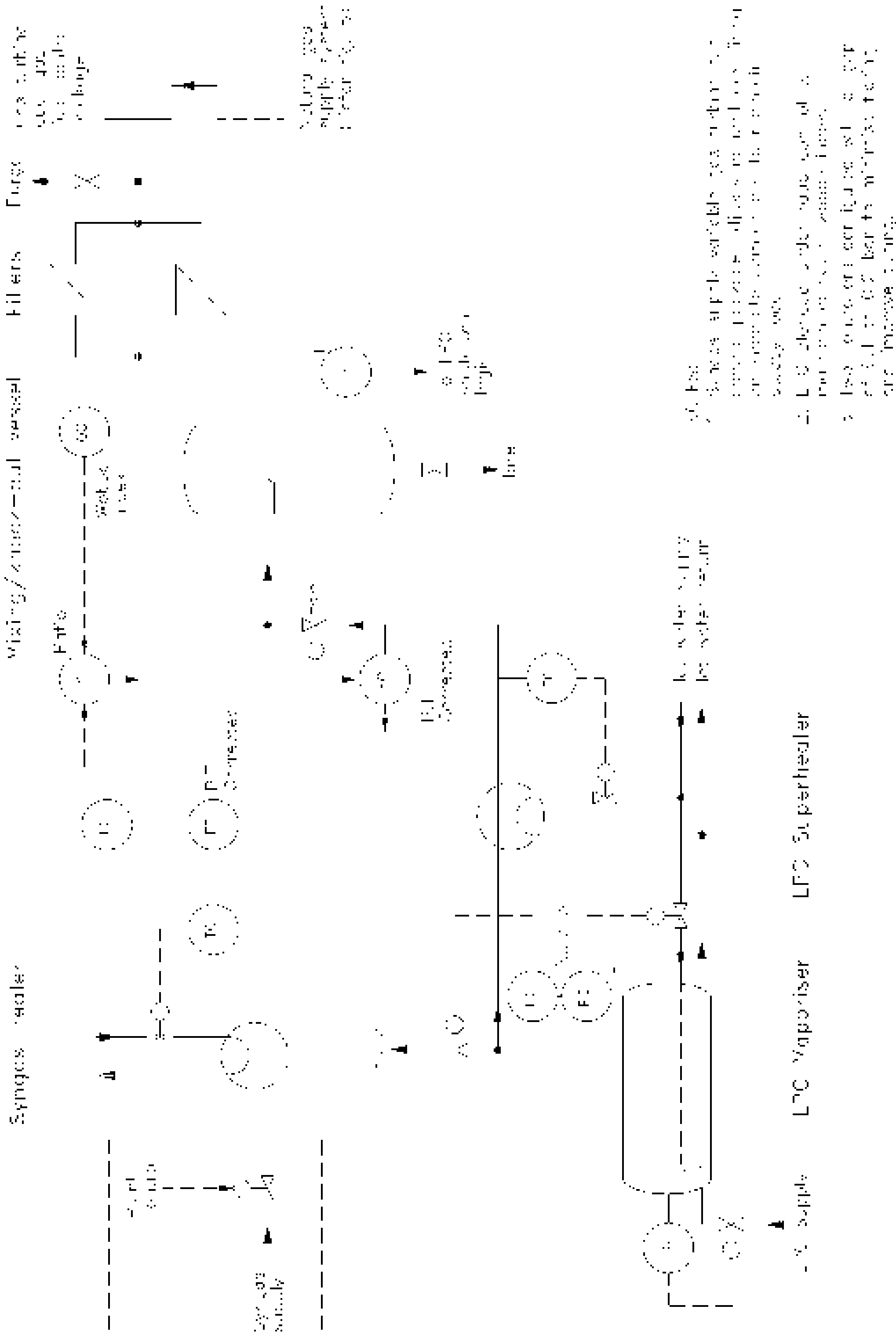
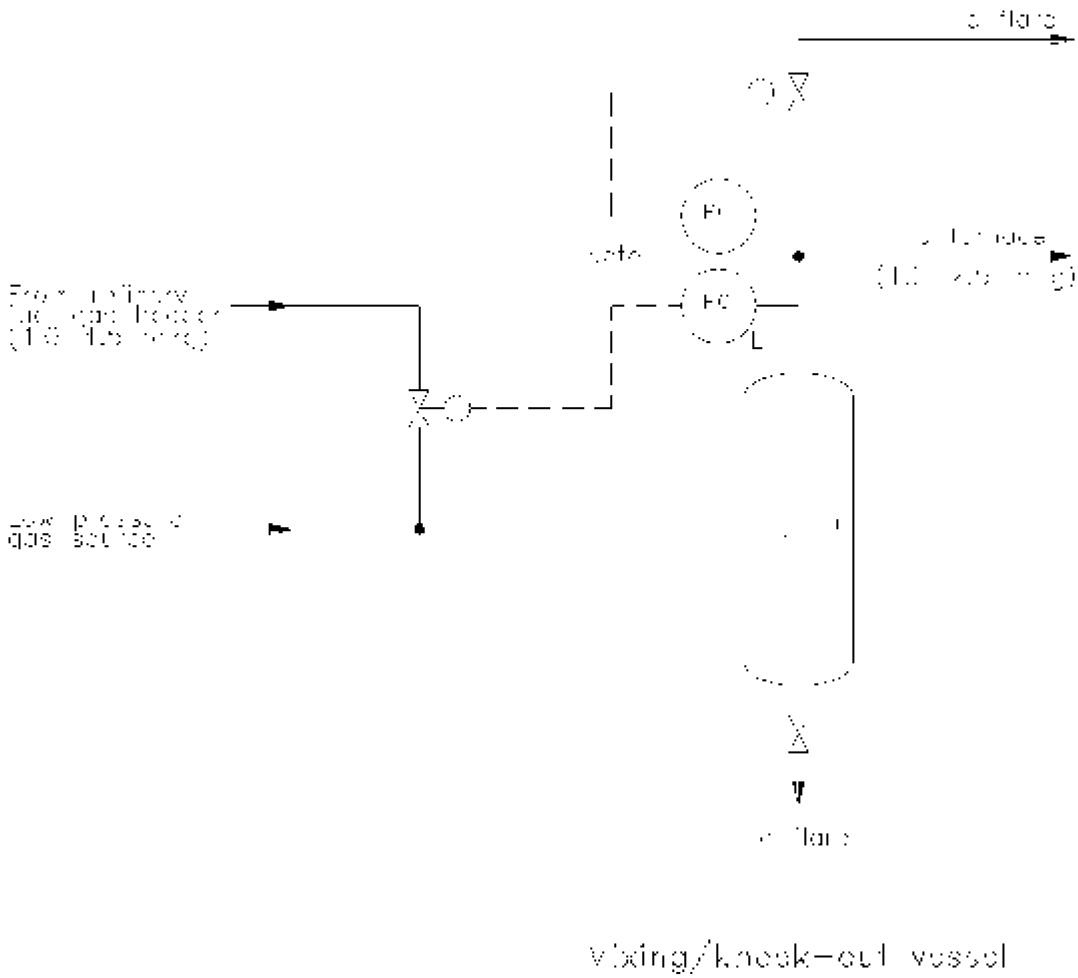


FIGURE 8 LOW PRESSURE GAS SYSTEM WITH REFINERY FUEL GAS LET-DOWN



Note: [illegible]

FIGURE 9 REFINERY FUEL OIL SYSTEM (LONG RESIDUE)

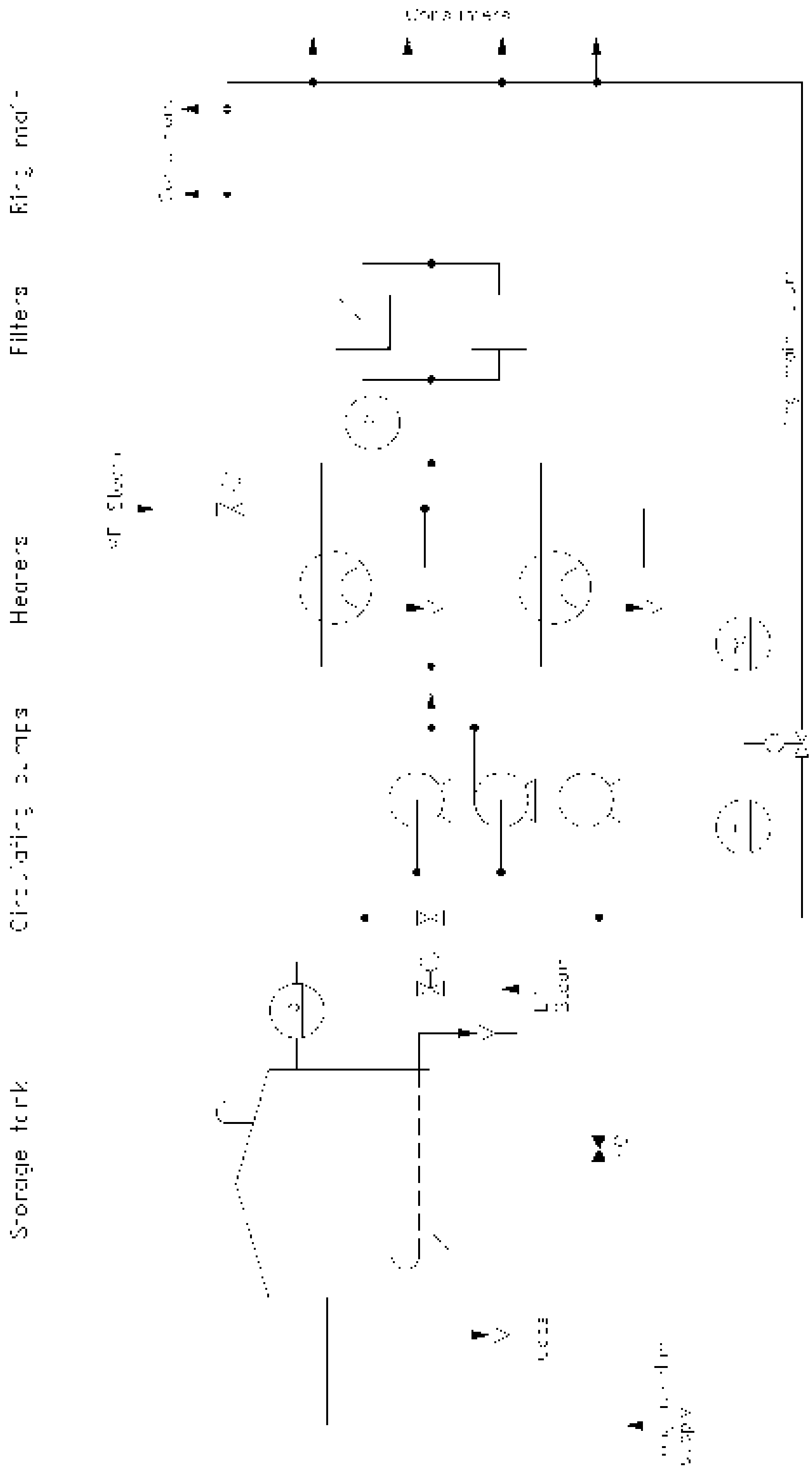


FIGURE 10 REFINERY FUEL OIL SYSTEM (SHORT RESIDUE)

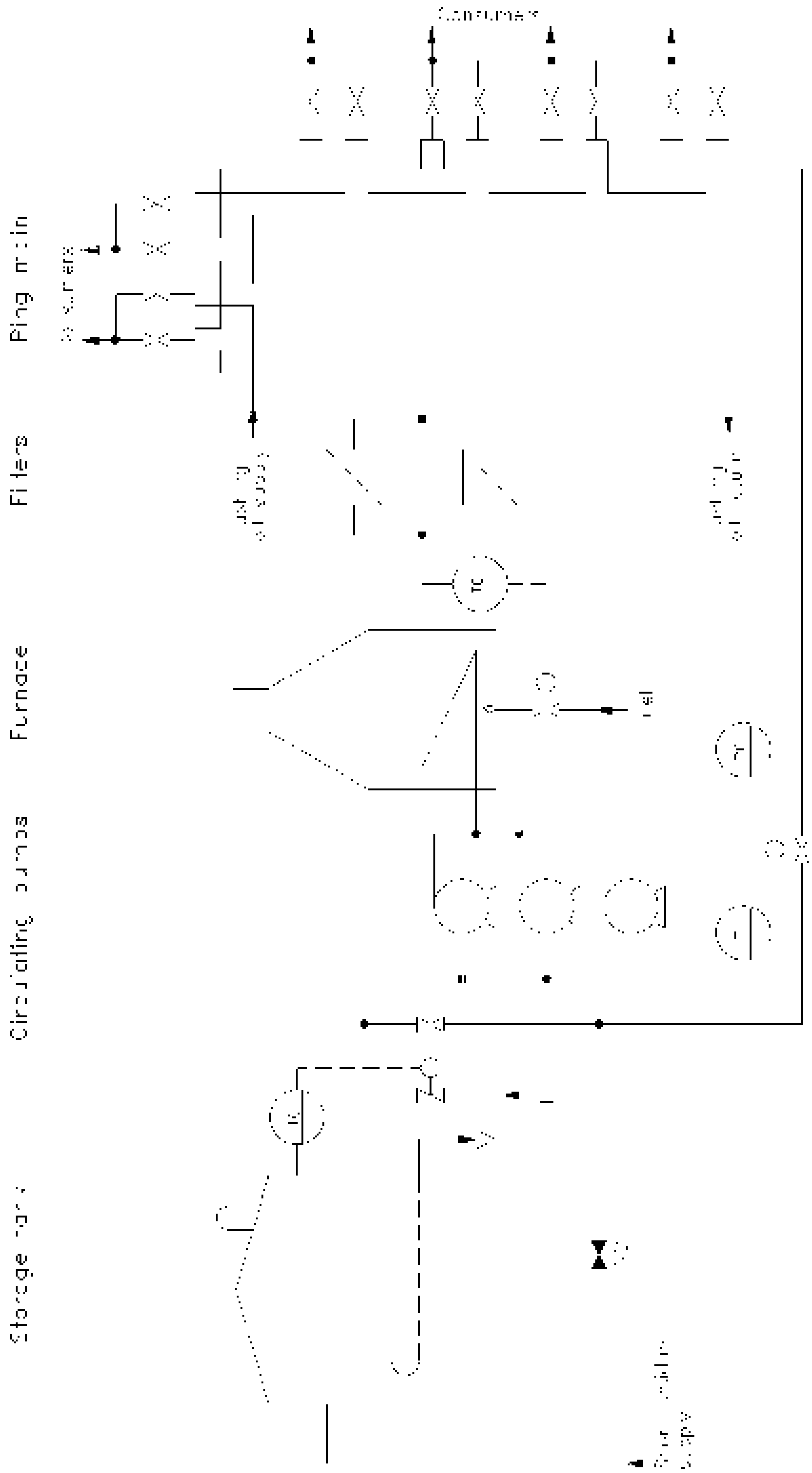


FIGURE 11 ASPHALT BURNING SYSTEM

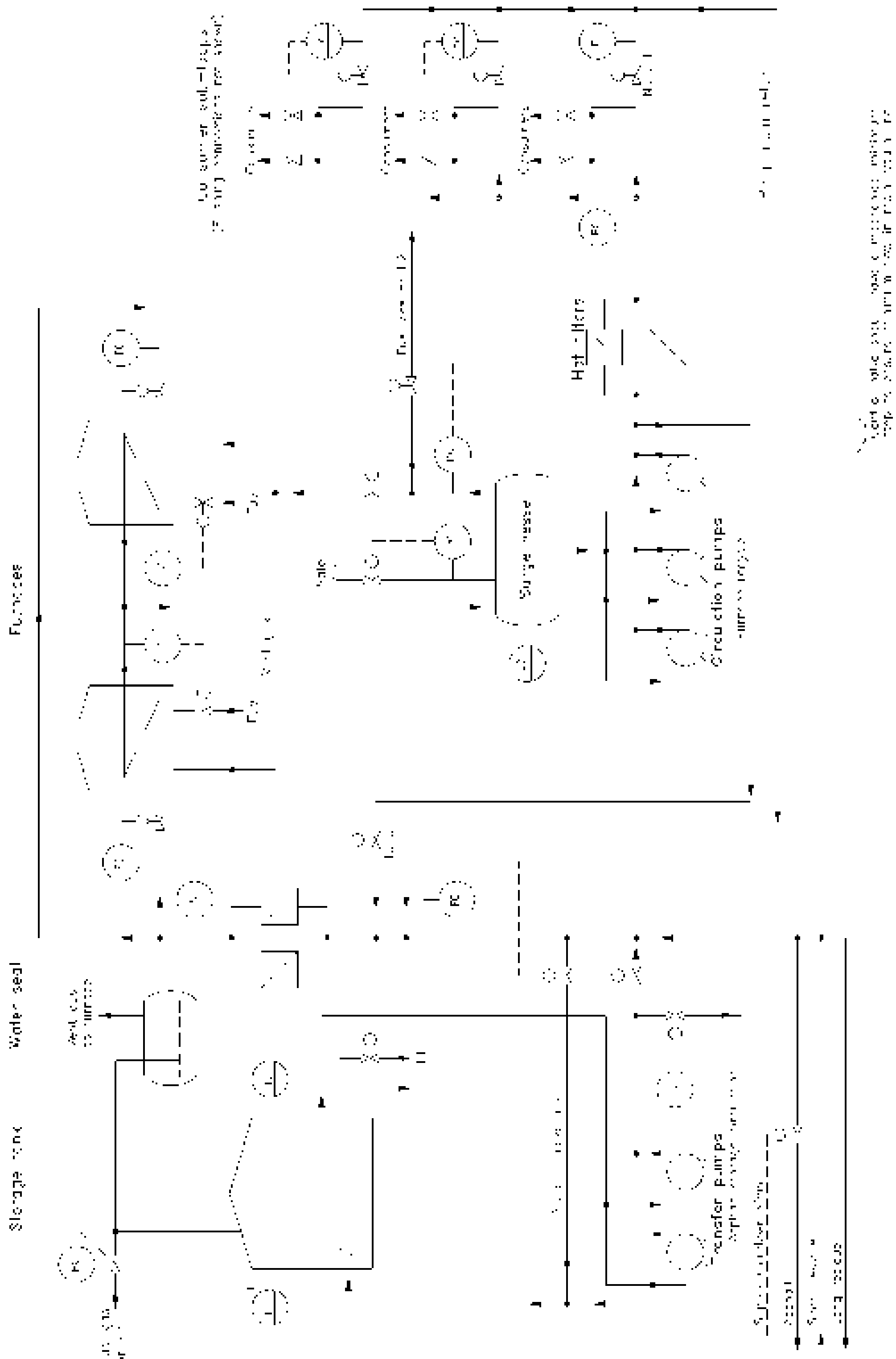


FIGURE 12 ALTERNATIVE ASPHALT