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Design Considerations for Naphtha Fuel Systems in Combustion Turbines

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BREAK

ABSTRACT

Naphtha fuel for combustion turbines possesses some unique physical properties that must be considered in the design of the fuel delivery system for trouble free operation. The fuel system must be designed to start the turbine on natural gas; distillate or naphtha, transfer to the secondary fuel and back to the original fuel; over a defined load range. The timing and permissives required for these events to occur smoothly, without tripping the unit, demand full control over the flow, temperature and pressure of all fuels involved. The same delivery system is often used to deliver other fuels that differ in density, volatility, vapor pressure and flow, compounding the design process. This paper examines some of the design attributes employed in Westinghouse combustion turbines that are fueled by naphtha and natural gas. The design considerations and modifications to the conventional fuel delivery system are the subjects of this paper.

INTRODUCTION

The ability to utilize a wide range of fuels has been a key advantage of combustion turbines over competing technologies. Until recently, the traditional fuels for combustion turbines have been natural gas and distillate fuels. Today, regional economics have made a wider variety of fuels to burn economically, particularly in the growing electricity power markets outside the United States. Fuel system designs have evolved to accept these fuels.

Westinghouse combustion turbines were originally designed to handle fuels meeting ASTM specification D2880 Grade 2 GT, commonly referred to as no. 2 distillate fuel. Certain modifications to the fuel handling, preparation and combustors allow the combustion turbine to burn almost any liquid fuel ranging from light distillates such as naphtha, marine gas oil, or JP-4, to residual fuels such as ASTM no. 6 or Bunker C and coal derived liquids. Although flexible in fuel input variability, all fuels must adhere to limitations on fuel contaminants, particularly vanadium, sodium, potassium and lead, in order to achieve acceptable turbine parts life.

Westinghouse is in the process of installing three 251B11 combustion turbines, rated for a nominal 50 MW each. The power plant is sited in Kakinada, within the Andhra Pradesh State of India. The nominal 200 MW power plant is configured in a combined cycle mode, using three combustion turbines with three heat recovery steam generators supplying steam to a single steam turbine. The steam cycle is water cooled with mechanically induced draft cooling towers.

The plant will use naphtha as the primary fuel, with natural gas as backup. Each combustion turbine is capable of firing on either fuel alone, or mixed fuel operation, within certain operating limits. Naphtha is a generic, loosely defined term that covers a wide variety of light petroleum distillates. The naphtha classification includes common fuels such as gasoline, kerosene, mineral spirits and many petroleum solvents. Light crude naphtha generally refers to the first overhead product coming off the distillation column with a boiling range of 38° to 191°C. Heavy crude naphtha refers to the second overhead product, with a boiling range of 177° to 232°C. The fuel properties of the naphtha fuel used in this project are shown in Table 1.

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Conventional fuel delivery systems can handle the distillate and natural gas systems without design modifications. However, naphtha is a low viscosity, highly volatile fuel compared to distillate. The design considerations and modifications to the conventional fuel delivery system are the subjects of this paper.

Table 1. Naphtha Fuel Properties

Final boiling point	176 °C
Aromatics	8.1% volume
Specific gravity @15 °C	0.7
Reid vapor pressure	0.39 kg/cm^2
Gross calorific value	11,400 kcal/kg
Viscosity	0.5 centistokes
Sulfur	0.2 ppm
Vanadium	0.1 ppm

FUEL SYSTEM DESIGN CRITERIA

The primary design objective of any liquid fuel delivery system is to safely deliver the fuel at the required flow, pressure and viscosity from the storage site, usually a storage tank, to the point(s) of use, in this case, the fuel nozzles. Many codes and standards have been adopted by various governing bodies to support fuel delivery design. Selection of the proper standard is highly dependent upon the fuel selected and its intended use. Table 2 is a partial list of standards that can apply to the design of fuel delivery systems. The applicability of each code must be checked with local codes, insurance and fire emergency officials. These standards influenced this design in some form or another.

A liquid fuel delivery system will possess some common elements that remain consistent between systems, regardless of the fuel properties. Figure 1 represents a typical distillate fuel system.

Table 2. Standards Applied to Fuel Systems Design

NFPA 30	Flammable and Combustible Liquids Code
ASTM D2880-94	Standard Specification for Gas Turbine Fuel Oils
NFPA 77	Recommended Practice on Static Electricity
ASTM D4865-91	Generation and Dissipation of Static Electricity in Petroleum Fuel Systems
BS-5351	Anti-Static Valves

Naphtha System Components and Design

Certain naphtha properties, including low viscosity, high vapor pressure and an affinity for water, precludes the use of conventional distillate fuel systems design. Pump and flow divider components are affected by the low lubricity characteristics of the fuel. The high vapor pressure of naphtha (compared to distillate fuel oil) allows it to vaporize into the air more readily than distillate fuel, creating an ignition concern. Vapor lock, a condition that effects the ability of the turbine to perform a hot restart, is also more prevalent because of the higher vapor pressure (Hoffman, et. al., 1994). The presence of water creates a material corrosion problem, in addition to fuel flow disruptions.

The lower specific gravity of naphtha requires a higher volumetric flow of fuel for firing, compared to distillate fuel. This is somewhat offset by the slightly higher heating value of the fuel. The combustor nozzles require a somewhat larger orifice size for the larger flow in order to maintain a reasonable pressure drop at base load flows.

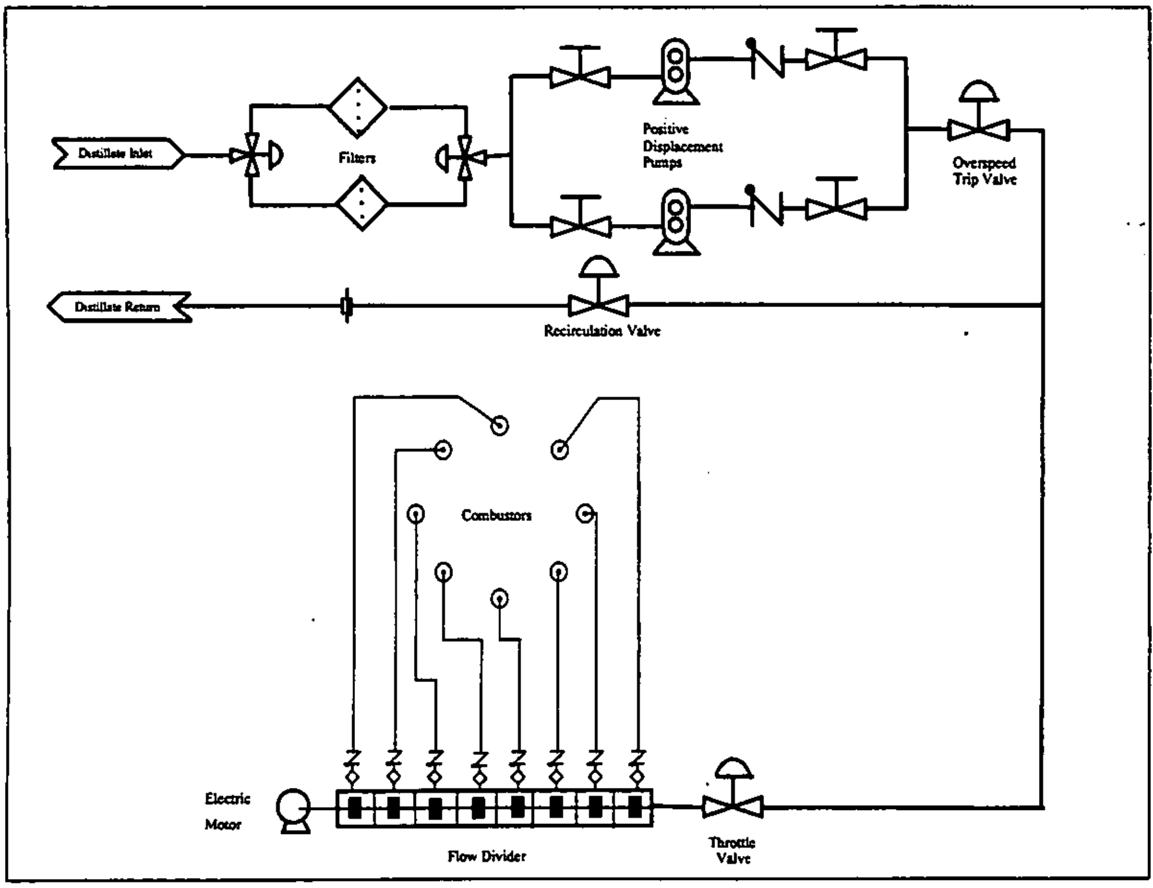

Figure 1 Distillate Fuel System Schematic

The flow divider is used in all Westinghouse combustion turbines firing liquid fuels. It meters precise equal amounts of liquid fuel to each fuel nozzle during starting, when the pressure drops across the fuel nozzles are too low to assure balanced flow. Pressurized air is used to atomize the fuel to enhance ignition. Starting the combustion turbine on liquid fuels requires the use of a flow divider to evenly distribute the fuel to each of eight combustor nozzles, which are located at different elevations. As fuel demand and flow increase, the pressure drop between the flow control valve(throttle valve) and each fuel nozzle outlet increases. The difference in elevation between nozzles, at higher fuel flows, has negligible influence on the pressure drop of each fuel line. Since the piping to each of the fuel nozzles is nearly the same length and diameter, at high flows, the pressure drop and therefore the flow to each nozzle is nearly the same, reducing the need for a flow divider to evenly distribute fuel flow.

Current design in flow dividers requires a viscosity higher than that provided by naphtha. Operational life is reduced to 10% of normal design life because the additional friction created by the poor lubricity characteristics of naphtha. Therefore, a bypass around the flow divider is provided to compensate for the low lubricity of naphtha during post ignition operation, as shown in figure 2. The flow divider is still required for ignition. Once starting and acceleration have been confirmed, valves automatically bypass the naphtha around the flow divider, minimizing wear on high friction components.

A liquid fuel filter is supplied to serve three functions. First, the filter is the primary means of protecting the pump from foreign objects entering the suction nozzle and damaging rotating components. Second, valves and instrumentation are protected from contaminants. Third, the filter can absorb water that may be present in small quantities. A duplex configuration is specified to allow quick changeover to the spare filter. A three way transfer valve on the inlet and outlet provided ease of transfer when the pressure differential exceeds allowable limits. The filter cartridge, a coalescing type, contains a special pleated water absorbing medium that can absorb short duration water slugs.

The quantity of water in the fuel is difficult to estimate and can vary with time. Although customer specifications often do not cite water as a component in the fuel, experience with naphtha has dictated that water is often present. The water absorbing capacity of coalescing filters is small, typically less than 2 liters per cartridge. If large quantities of water are present, the coalescing filter will rapidly increase pressure drop across the filter and the spare will need to be brought on line before the unit trips. The filter transfer can occur while online, without a unit trip, providing the spare is equalized before the transfer. The coalescing filter design approach is valid for small amounts of water contamination. Large amounts of water contamination require a different design approach. Contingencies for a gravity separator or centrifuge must be made in the design to increase water removal capacity.

Pump Selection

The pump of choice for distillate fuel systems is a positive displacement three screw type pump that features a relatively flat pressure/flow, or system characteristic curve. Positive displacement pumps produce whatever pressure is imposed on the discharge system curve. Neglecting slippage, the maximum pressure is limited by the power of the drive and the strength of the pump parts. As fuel volumetric flow increases to meet higher turbine/generator power output, the pressure requirements increase in proportion to the square of flow. The positive displacement pump delivers the required pressure with negligible decrease in volumetric flow over a wide range of flow, since the characteristic curve is relatively flat. Selection of the positive displacement pump simplifies pump selection because the required pressure is delivered to the fuel system, while all excess volumetric flow is diverted back to tank. Since the pressure-flow curve is relatively flat over a wide range of pressure, the designer need only consider the range of flows required for the operational range of the plant. The required pressure is dictated by the system restrictions, within the physical limits of the pump and motor.

The three screw positive displacement pump imposes a limitation on the fuel properties to satisfy proper pump clearances during operation. The viscosity of the fuel must be maintained above a minimum value for the pump to operate satisfactorily. Naphtha possesses a viscosity too low for proper operation of this type of pump. To alleviate this problem, viscosity enhancers maybe injected upstream of the pump to increase the effective viscosity of the fluid. The cost of the viscosity injection skid and viscosity enhancer, over the life of the plant, can amount to several hundreds of thousands of dollars. This additional cost can be avoided by the use of a centrifugal pump. Fortunately, the cost difference between the positive displacement and centrifugal pump in this size range is small. However, the centrifugal pump requires a different set of system design and control criteria to properly function over the desired range of operating conditions.

Nitrogen Purge

While firing or starting the combustion turbine on natural gas, the naphtha piping and header could be filled with a combustible mixture of fuel and air. Removal of combustibles in this area by means of purging with nitrogen is required. Purging of the idle piping and manifolds is also necessary to prevent the backflow of hot combustion products into these areas. The hot gases can accelerate internal corrosion at elevated temperatures, particularly the fuel nozzles. Although check valves are installed to prevent backflow, they do not provide zero leakage at all times.

Nitrogen is the preferred media for purging because of its inherent inertness and the ability to directly contact fuels without creating a combustible mixture. Prior to ignition, each naphtha fuel line leading to a combustor is purged with nitrogen to remove any combustible mixture that might exist. The lines of the starting fuel, whether it be natural gas or naphtha, do not receive the purge. The starting fuel will discharge any air-fuel mixture that might exist, during the ignition sequence.

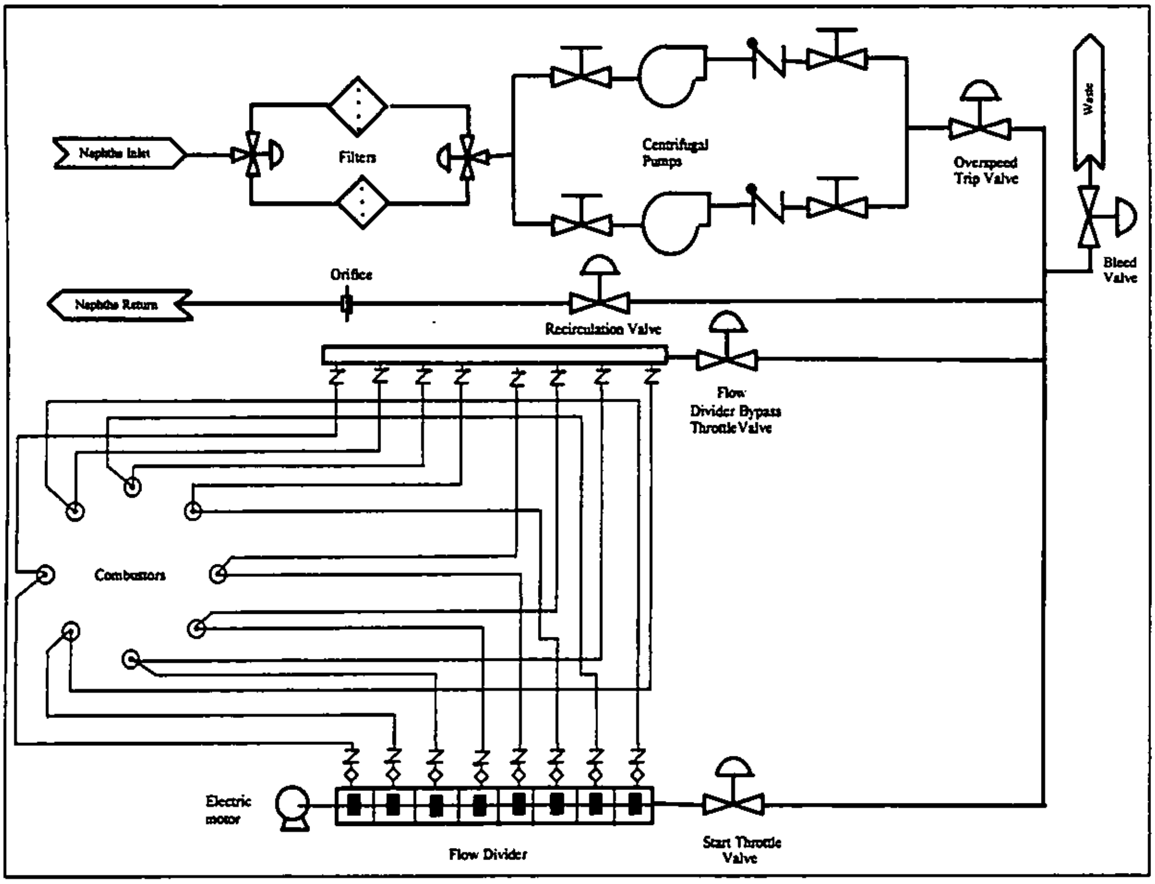

Figure 2. Naphtha System Schematic

CONTROL AND FUEL TRANSFER

The plant is designed to fire with naphtha or natural gas entirely or with a combination of the two fuels within certain operating limits. The combustion turbine may ignite with natural gas or naphtha. Natural gas ignition and control is conventional. However, naphtha operation departs from the conventional distillate fuel operational sequence in the areas of ignition and control.

Initial fuel system operation starts with energizing the primary fuel pump and recirculating the naphtha back to tank. A minimum pump discharge pressure must be maintained on the centrifugal pump at all times. The starting motor accelerates the turbine to ignition speed and the overspeed trip valve and start throttle valve are opened. Fuel flows through the starting circuit, flow divider and then to each combustor. Ignition occurs and the turbine is accelerated by slowly opening the start throttle valve and increasing fuel flow. Prior to reaching synchronous speed, the naphtha flow divider bypass throttle valve opens and the start throttle valve begins to close. The coordination of these two valves is monitored by the two differential pressure transmitters. The distributed control system maintains a constant heat input to the turbine during the flow divider bypass transfer to assure a smooth transition. The flow divider bypass transfer is completed when the start throttle valve is closed and all fuel flows through the flow divider bypass throttle valve.

Transfers between natural gas and naphtha must occur while the naphtha start throttle valve is closed and the naphtha system is in the flow divider bypass mode. A minimum load is necessary before mixed fuel operation can be initiated. The natural gas and naphtha throttle valves are coordinated by maintaining a constant heat input to the combustion turbine. A minimum naphtha flow, typically 30% of the thermal input, is required for proper steady state mixed fuel operation. Likewise, a minimum natural gas flow must be maintained in a steady state mixed fuel operational mode.

When it is necessary to restart a combustion turbine while it is still hot from previous operation, ignition with naphtha requires special attention. The high vapor pressure of naphtha can create a vapor lock condition whereby fuel flow is highly irregular and difficult to control. The hot fuel system components can cause the naphtha to vaporize and disrupt normal flow. In these situations, it is necessary to lower the temperature of the hot components. This is accomplished by spin cooling the turbine.

CONCLUSION

The design of naphtha fuel delivery systems require consideration of the properties of the fuel. The distillate fuel system design normally employed for most combustion turbines will not provide satisfactory service for naphtha based fuels. The flow divider bypass and purge systems are added to the conventional fuel system design for naphtha operation. The simplest system with the fewest components is selected to achieve maximum service reliability and availability.

A wider variety of fuels with even greater variability in fluid properties is expected in the future. The diverse locations where combustion turbines are finding application is ever expanding. Future fuel systems will need to cope with challenging design requirements imposed by the nontraditional fuels.

REFERENCES

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