GE Power Generation

Liquid Fuel Treatment Systems

Howard J. Kaplan
Technical Leader, Fluid Systems Engineering

Kenneth E. Majchrzak
Principal Engineer, Power Plant Engineering

GE Power Systems
GE Company
Schenectady, NY

GE Power Generation

Liquid Fuel Treatment Systems

Howard J. Kaplan
Technical Leader, Fluid Systems Engineering

Kenneth E. Majchrzak
Principal Engineer, Power Plant Engineering

GE Power Systems
GE Company
Schenectady, NY

Howard J. Kaplan

Howard Kaplan is Technical Leader of Gas Turbine Power Plant Fluid Systems. He has over 25 years' experience in design and development of gas turbine auxiliary systems, serving three years as principal engineer for fuels-related systems. Current responsibilities include fuel oil, fuel gas, fuel purge, Dry Low NO_X, atomizing air, water injection and lube oil.

Kenneth E. Majchrzak

Kenneth E. Majchrzak is a Principal Mechanical Engineer in the Power Plant Engineering Department. He is Technical Leader for the department on fuel systems, power plant pumps, and provides primary support for HRSGs. Ken joined GE in 1982 as Manager – Compressor Application Engineering in Fitchburg, Massachusetts. He has nearly 25 years' experience with rotating equipment in the areas of application and systems design for aircraft gas turbines, process centrifugal compressors, radial inflow steam turbines and pumps.

A lists of figures and tables appears at the end of this paper

LIQUID FUEL TREATMENT SYSTEMS

H. J. Kaplan and K. E. Majchrzak
GE Power Systems
Schenectady, NY

INTRODUCTION

GE heavy-duty gas turbines are capable of burning a variety of liquid fuels, from petroleum naphthas to residuals. These fuels vary substantially in hydrocarbon composition, physical properties, and levels of contaminants. Operation with ash-forming fuels such as crude and residual oils requires special measures to prevent high-temperature corrosion and contend with ash fouling in the turbine section. More than three decades ago, GE initiated a major program to develop a totally integrated system for economically utilizing ash-forming fuels. This paper will highlight the results of that effort by describing liquid fuel characteristics, methods of treatment, system design considerations, and GE experience.

LIQUID FUEL PROPERTIES

Liquid petroleum fuels fall into two basic classifications; true distillates and ash-forming oils. True distillate oils are most frequently the lighter oils such as naphtha, kerosene, and No. 2 distillate oil. This class of fuel is clean burning and behaves in a manner similar to natural gas in the internal portions of the gas turbine.

Ash-forming oils are normally the heavier oils, such as blends, crude, and residual oils. Since they usually contain trace metal contaminants, fuel treatment is required to remove or modify the effects of harmful constituents prior to combustion in the gas turbine.

The degree of the fuel treatment equipment sophistication, plant equipment investment, and operating costs required for this equipment are tied directly to key physical and chemical properties of the fuel. Physically, the parameters of interest include specific gravity, viscosity, flash point, pour point, and wax content. Chemically, the prime interests are the amounts of corrosive trace metals present, the overall fuel washability, and the compatibility of one fuel with another. The latter is particularly significant for users who obtain fuel from multiple sources.

Trace Metals

Trace metal contaminants of concern include sodium, potassium, calcium, lead, vanadium, and magnesium. At elevated temperatures, vanadium, sodium, potassium, and lead are corrosive to the turbine buckets, particularly when present in amounts above specification limits. All of these materials, plus calcium, can also form hard deposits which are difficult to remove with a normal turbine wash system. These deposits can cause plugging and reduced output.

Table 1 lists the trace metals of interest, their effect on the turbine, and the means of treatment to reduce harmful effects, along with GE's typical permissible limits. Dealing with these metal contaminants will be discussed in the Fuel Treatment section of this paper.

Table 1
TRACE METAL EFFECTS

Trace Metal	Limits in Raw Fuel	Effect on Turbine	Type of Treatment	Limits in Fuel to Turbine
Sodium plus Potassium	150 ppm	High temperature corrosion	Fuel Washing	1 ppm
Calcium	10 ppm	Fouling deposits	Fuel Washing to a limited extent	10 ppm
Lead	1 ppm	High temperature corrosion	None (controlled by fuel spec)	1 ppm
Vanadium	**	High temperature corrosion	Inhibited by magnesium	0.5 ppm
Magnesium	None	Inhibits vanadium / forms deposits	Used to inhibit vanadium	none

** Maximum vanadium levels may be dictated by local codes regarding stack particulate emissions and the user's acceptable costs to inhibit.

Specific Gravity

The specific gravity of a fuel oil is the ratio of the weight of a given volume of the material at 16 C (60 F) to the weight of an equal volume of distilled water at the same temperature. The closer the specific gravity of the fuel is to that of water, the more difficult it is to treat it.

Viscosity

The viscosity of a fluid is a measure of its resistance to flow and is expressed in various units. The most common viscosity units are Saybolt Universal Seconds (SSU), Saybolt Furol Seconds (SSF), and Kinematic Viscosity Centistokes (cSt).

GE experience has shown that viscosities of 380 cSt at 50 C (4200 SSU at 100 F or 160 SSU at 210 F) can easily be processed. Greater viscosities can be handled, but they are evaluated on an individual basis.

Flash Point

The flash point is the lowest temperature at which application of a flame causes the vapor above the sample to ignite. This value indicates the potential fire hazard associated with handling the fuel. Consideration should be given to explosion proofing if the flash point of any fuel which may be used in the system is below 60 C (140 F). Crude oils typically have flash point temperatures lower than distillate oils, resulting in the use of explosion-proof separators.

Pour Point

The pour point is the lowest temperature at which the oil will flow under standard test conditions. High pour points are characteristic of paraffin-base oils and dictate the need for increased storage temperatures, higher-capacity suction heaters, heat tracing of lines, as well as certain equipment and recirculation circuits to establish/maintain operating temperatures.

Wax Content

Wax can be present in fuel oil, particularly crude oil and heavy distillates. The percentage of wax and its melting point must be determined, and suitable heating and heat tracing must be provided to ensure that the wax in the fuel is dissolved at all times. These steps will help prevent system clogging.

FUEL TREATMENT

In the case of a true light distillate oil, treatment is required primarily to capture dirt and shipment contaminants that have not been removed by the storage tank settling system arrangement. Undetected and untreated, a single shipment of contaminated fuel can cause substantial damage to the gas turbine. Filters are the most commonly used device, although centrifuges may also be required to remove sodium if present as a result of seawater contamination.

Treatment and conditioning systems for ash-forming fuels are more complex because of the processing steps required to remove or control their characteristic trace metal contaminants. Particular attention must be paid to sodium and vanadium. Complete fuel treatment includes three basic steps:

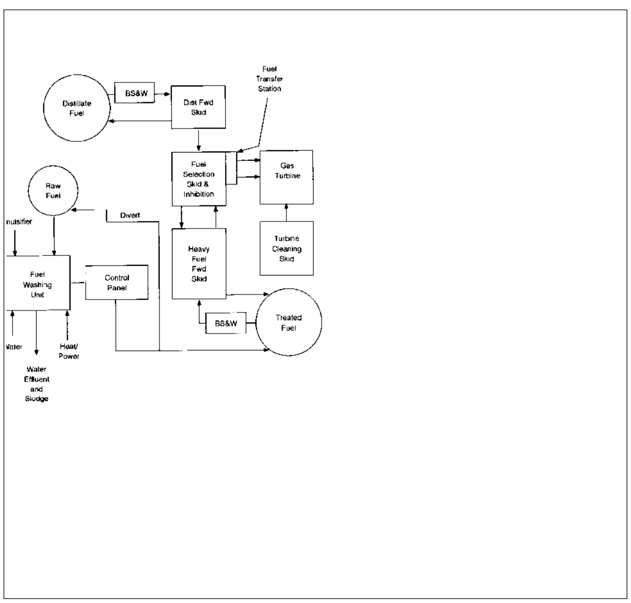
1. Fuel/Water Separation
   - Washing:
     Washing involves addition of water to the fuel and subsequent removal of the contaminant laden water. Washing is done to remove the water soluable trace metals - such as sodium, potassium and certain calcium components - and much of the organic and inorganic particulate material that is normally forwarded to the filtering systems.
   - Purification:
     Under special circumstances, it is possible to obtain adequate contaminant removal without the addition of any water to the fuel. This process is called purification, and it is frequently applied to lighter crudes and distillates.
2. Filtering the fuel to remove solid oxides, silicates, and related compounds that are not adequately removed prior to forwarding to the gas turbine. These particles can clog fuel pumps, flow dividers, and fuel nozzles.
3. Inhibiting the vanadium in the fuel with magnesium compounds in a ratio of three parts of magnesium, by weight, to each part of vanadium. This form of treatment inhibits the corrosive characteristics of vanadium by forming high melting-temperature ash composed of magnesium sulfate, magnesium oxide, and magnesium vanadates.

It should be noted that lead is also corrosive to turbine components and should be avoided. Since there is no known economical technique for removing lead or providing inhibition, it is necessary to restrict purchases to fuel with extremely low amounts of lead (less than 1 ppm).

Fuel Treatment System Equipment

Figure 1 presents a schematic arrangement of a heavy-duty gas turbine fuel system which was developed after years of experience with ash-forming fuels. The system is configured to provide simplified plant operation. It has the flexibility to incorporate future improvements, and can provide a means for performing planned and unplanned maintenance without interruption to the gas turbine operation.

Typical fuel-wash equipment includes heat exchangers, heat economizers, mixers, and oil-water separation devices. The fuel is pumped from the storage tank through a strainer where foreign materials are removed. After straining, the fuel goes through a pressure-reducing valve, where the demulsification agent is injected. The fuel then flows through an economizing heat exchanger where heat is removed from the hot fuel leaving later stages of the wash system. The raw fuel flows to another heat exchanger where the fuel is brought to its process temperature through either steam or electric heating. At this stage, the demulsification agent is thoroughly mixed into the fuel. A short distance upstream from the mixer, water is injected at a rate of up to 10 percent of the fuel flow rate. The water, which is normally condensate, comes from a water skid which contains a heat exchanger in order to raise the water temperature to within 10 or 20 degrees of the fuel temperature. The washing operation is performed one or two times. After washing is complete, the fuel flows through the economizing heat exchanger, the water-in-oil monitor, and then into the washed fuel storage tanks.



GT24348A

Figure 1. Heavy fuel gas turbine system

Fuel Washing

Since ash-forming fuel oils are almost universally contaminated with salts and salt water, they normally require water washing to remove the water-soluble salts of sodium and potassium. Fuel washing involves mixing heated fuel with 5 to 10 percent of potable water along with a small amount (0.02 percent) of an emulsion-breaking fluid to aid in separation. The washing process is a one- or two-stage extraction procedure with the extraction water flowing counter-current to the fuel. Each stage has a mixer to initiate contact of the wash water with the fuel, followed by a mechanism to separate the salt-laden water from the extracted fuel. Either centrifuges or electrostatic desalters are used for this separation process. GE has found that centrifuges remove fuel contaminants more reliably and completely than the electrostatic desalters. Currently GE is only using centrifuges in its fuel treatment systems.

The number of extraction stages required depends on the salt level in the fuel to be processed and on certain properties of the fuel, such as specific gravity and viscosity. Since the successful operation of the fuel-washing system depends on a working difference between the specific gravities of the fuel and that of the water, fuels with specific gravities above 0.98 may not be washable unless they are first blended with a compatible liquid which has a lower specific gravity, such as distillate fuel.

Chemicals referred to as demulsifiers are added to the fuel to assist in breaking up difficult oil-water emulsions. Water is added to the oil and subjected to controlled mixing in order to distribute the sodium-seeking water throughout the raw oil. The mixture then goes to a separator. Here, the oil and water are separated, and the clean oil flows into one pipe, and the wash water with a high concentration of salts flows out another.

To comply with local codes, the effluent water may require a treatment system to remove entrained oil. For example, a customer specification of “no visible sheen” is equivalent to a surface thickness of 3 x 10-6 in. (7.62 x 10-6cm), or approximately 15 ppm of free oil content in the water. Reduction of oil content below these values may require complicated systems that include bacteria digestion.

Separation by Electrostatic Systems

Figure 2 gives a schematic arrangement of a typical two-stage electrostatic system, while Figure 3 shows an actual installation.

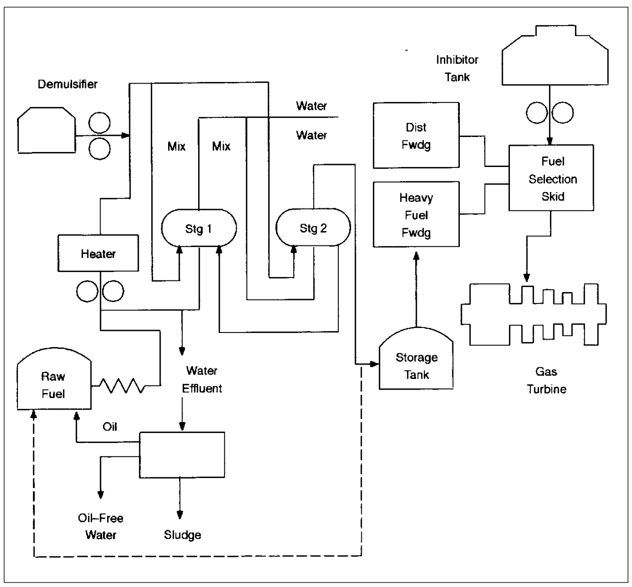
The principle behind any electrostatic system is that the oil/water separation process is induced through the application of an electric field. The electric field causes finely dispersed water droplets to coalesce, thereby increasing the droplet diameter. This phenomena increases settling rates according to Stokes Law, which states that “the velocity of a water droplet falling through oil is proportional to the square of the diameter of the droplet.”

There are two types of electrical separators presently used: direct-current and alternating-current. Direct-current electrostatic systems are very efficient devices when employed with light refined fuels of low conductivity. Alternating-current electrostatic separators are applicable for heavier fuels having greater conductivity. Electrostatic separators are appealing because there are no high-speed rotating parts within the vessel. Maintenance intervals can be long, but on-line operation can be complicated with changes in fuel properties or fuels having high sediment content.

Sludge removal is accomplished by the transport of solids in the effluent water from the vessel. This can be accelerated by a hydraulic system within the vessel that recirculates the water.

Electrostatic units generally perform reasonably well, and generous sizing can be incorporated with minimal increase in cost. The key parameter in sizing such a system is the selection of the number of stages. Generally, one can expect 85 to 90 percent sodium removal per stage. Three-stage systems are usually considered for initial sodium plus potassium inputs up to 150 ppm and two-stage systems are considered for initial sodium plus potassium inputs of up to 100 ppm. Although system start-up times using electrostatic precipitators are somewhat long, usually taking three or four hours per stage, the operator is capable of detecting small changes in operating effectiveness of the system and can take corrective action with the system on line.

Electrostatic systems are pressure vessels; thus the oil temperatures can be raised as high as 149°C (300°F), without concern for boiling the water. This in turn can permit significant reductions of fuel viscosity, but the high temperatures may lead to fuel degradation.



GT24346

Figure 2. Heavy fuel treatment system – electrostatic

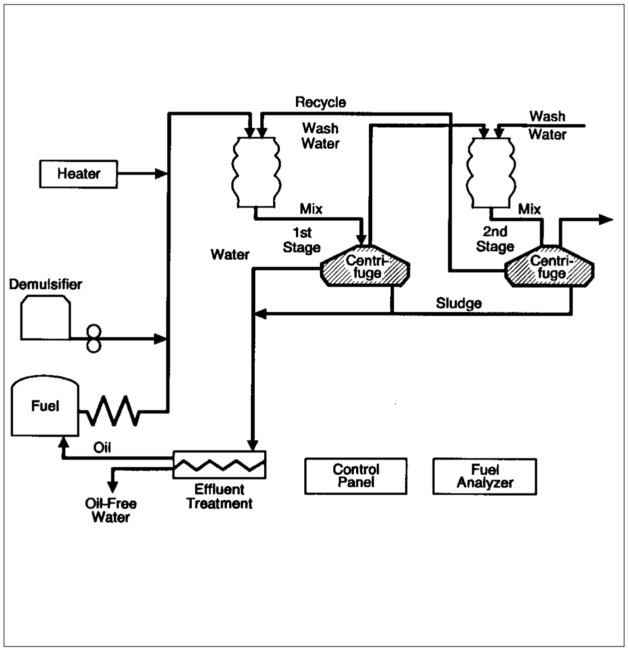
GT2041

Figure 3. Heavy fuel treatment system – electrostatic

Separation by Centrifugal Force

The mechanical process of washing fuel is shown schematically in Figure 4. This arrangement represents a typical two-stage centrifugal separation system. Figure 5 is an actual installation. The principle behind this centrifugal process is that the oil and water are separated as a result of the high centrifugal forces developed in the centrifuge. In contrast to electrostatic precipitators, which rely on increased particle diameters in a high voltage gradient field and a 1G gravity field, the centrifuge employs only a high gravity field of many thousands of Gs to accomplish the oil and water separation. A variety of centrifuge models are currently available, having capacity ranges from 5 to 660 U.S. gpm (1.1 to 150 cubic meters/hour).

Centrifugal fuel washing systems have been successfully applied on GE gas turbine systems since



GT24347

Figure 4. Heavy fuel treatment system – centrifugal

GT2040

Figure 5. Heavy fuel treatment system – centrifugal

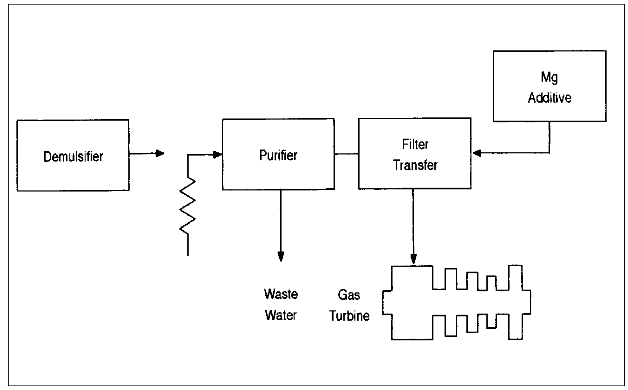
the early 1970's using fuels with specific gravities up to 0.995 before blending.

With correct systems parameters, a typical two-stage system can reduce sodium from 150 ppm to less than 1 ppm for ash-forming oils. Centrifuges are also effective in removing inorganic particles and dirt which are forced out with the effluent wash water. This added benefit minimizes the load on the downstream fuel filtration system.

Fuel Purification – Simplified Washing

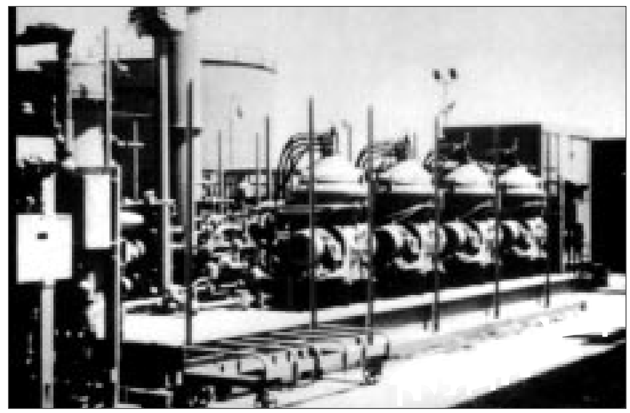
The purification process is shown schematically in Figure 6, and an actual installation is shown in Figure 7.

Fuel purification is a one-stage extraction procedure to treat light distillates and crude oils with-



GT03729B

Figure 6. Fuel purification



GT10248

Figure 7. Qaisumah purification system

out adding water to the fuel. This process relies on the fact that the salts are already dissolved in the entrained water; thus by removing the water the salts are removed.

Purification is practical with distillate and crude oils having a minimum 0.5 percent water in the fuel, and a salt concentration not exceeding 20 ppm of sodium plus potassium. Since the purification process eliminates the need for added water and demulsifiers, it also simplifies the overall waste disposal process.

Direct-Feed Approach

Another purification technique employing centrifuges is the direct feed approach. This is different from the other systems discussed because it forwards the fuel directly to the gas turbine without going through an intermediate fuel storage tank or a fuel forwarding skid. The centrifuge generates the proper pressure required by the turbine main fuel pump. However, some of the functions from the fuel forwarding skid need to be retained in the delivery system upstream of the gas turbine to ensure that the fuel being delivered

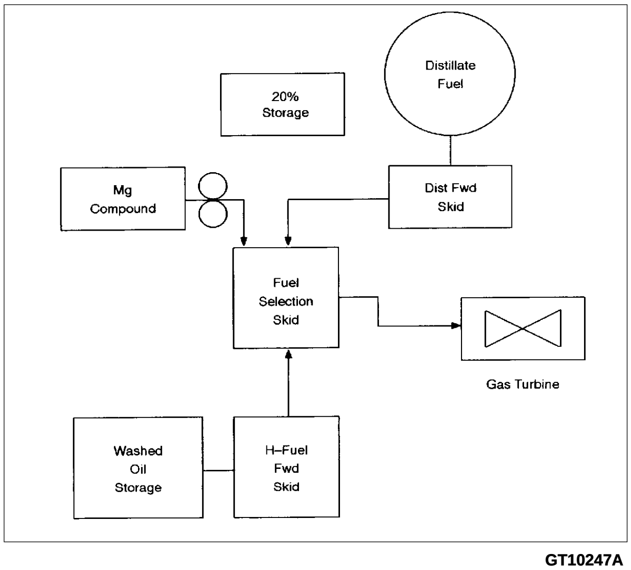


Figure 8. On-line inhibition Schematic

to the gas turbine has been handled and treated properly. These functions include the flow meter and solenoid operated stop valve.

The basic flow diagram of this type of purification system, illustrated in Figure 8, applies either to turbines starting and stopping on crude, or to units that start on distillate and then transfer to crude. The flow path of fuel is as follows:

- The raw fuel (crude or distillate) is pumped from a raw-fuel storage tank into the centrifuge(s), where it is purified. The purified fuel is then pumped directly to the turbine by the centrifuge. Any excess fuel the turbine cannot use (or all of the fuel if the turbine is not operating) is sent to a clean reserve tank, where it is stored. If the reserve tank is full, the clean fuel overflows into the raw-fuel storage tank. The vanadium inhibitor is injected downstream of any recirculation loop or return lines. Thus, all of the inhibited fuel is burned.
- If the processed fuel does not meet the value for water content set on the water-in-oil monitor (WOM), the fuel is automatically diverted back to the raw storage tank for processing.
- If the centrifuges are not operating or the fuel is being diverted back to the raw-fuel tank because it does not meet the specification, the reserve fuel pump will pump fuel from the reserve tank to the turbines through a set of duplex filters.
- If the raw fuel does not require purification due to low particulate and/or low sodium levels, the fuel can be bypassed around the centrifuges through the duplex filters, using the raw-fuel pump.

While this system uses the direct-feed as the primary approach, it also functions in an indirect fuel mode, i.e., pumping from the reserve fuel tank. If the user desires it, the system can be designed for normal operation in either direct or indirect mode, permitting the user to elect the operational mode for normal use. The size of the centrifuge system, reserve fuel tank, and in-line heaters are a direct function of the planned operating modes of the gas turbines, expected direct vs. indirect operation of the system, and the type, quality, and availability of the raw fuel.

GE concludes that the purification process described can be used on most distillates and on light crude oils with sodium plus potassium levels of up to 20 ppm. Greater levels can be permitted depending upon the fuel. In some cases involving higher sodium, it may be necessary to allow the fuel to settle to 20 ppm and to drain the water from the fuel prior to processing.

Filtration

Solids, oxides, silicates, and related compounds that are not adequately removed by the fuel treatment systems must be removed by the fuel system filters prior to entering the fuel pump and flow divider. The particles that are not removed may clog the flow divider and fuel nozzles.

Incorporating a motor-driven, self-cleaning filter minimizes the load on the downstream high-efficiency filters. The use of a duplex filtration system for the high efficiency filters permits filter maintenance without turbine shutdown.

Inhibition

Crude oils and heavy residual fuels usually contain organic vanadium which is extremely corrosive to the hot gas path parts of the turbine. This vanadium is not present in liquid fuels in a water soluble form, hence it cannot be removed through the washing process. Instead, its effects are inhibited by the addition of magnesium to the fuel in the ratio of three parts of magnesium by weight to each part of vanadium. At this level of inhibition, the corrosive vanadium pentoxide that is formed during combustion reacts to form magnesium orthovanadate. This has a melting point sufficiently high to allow its passage downstream through the turbine with deposition that is easily removed, and without resultant corrosion.

A variety of magnesium-containing inhibition agents are available, and their choice is determined largely by the economics of the system and the overall amount of vanadium present in the fuel. Three additives frequently employed are magnesium sulfonate, which is oil soluble and delivered ready for use, magnesium oxide, which is an oil-based slurry, and magnesium sulfate, commonly known as Epsom salts, which must be mixed with water on the site. On-line inhibition systems are the preferred method of applying the magnesium agent. The inhibitor is injected into the fuel immediately ahead of its introduction to the gas turbine (Figure 9). The system consists of a small in-line metering pump and a flow switch which provides an alarm signal in the event flow of inhibitor stops. Either constant flow systems or systems that provide a flow varying with the actual fuel use rate are available.

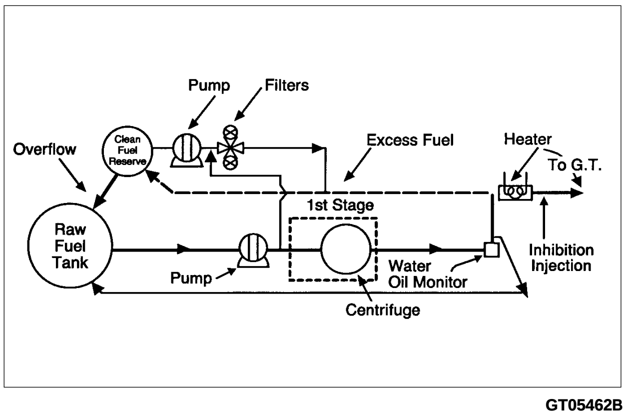


Figure 9. Purifying and burning fuel

SYSTEM CONSIDERATIONS

There is no one fuel-treatment system suitable for all applications. A design must be tailored to the specific needs and requirements of each customer. The optimum approach results from an evaluation of operational requirements for the gas turbine, the expected fuel characteristics, the desired maintenance philosophy, the choice of equipment, the choice of additive, and the desired system flexibility. Generally, there is a tendency to request "worst case" design without giving due thought to the many constraints that may exist. This may result in an overdesigned and expensive installation.

Fuel Selection

Residual fuels display a wide range of properties including vanadium content, specific gravity, and viscosity. Depending largely on economic trade-offs, the user may or may not decide to burn all of the fuels available at his location. The maximum allowable vanadium content may be controlled by local regulations governing total stack particulate emissions. Lower vanadium level fuels, where available, can substantially reduce fuel treatment additive costs.

Users requiring a capability for washing fuels with a specific gravity and/or viscosity higher than specified for the fuel-washing system can accommodate these fuels by blending them with a compatible distillate fuel before washing.

Fuel Handling and Storage

Ash-forming fuels do not generally have consistent chemical and physical properties; purchased supplies can vary in composition by wide margins. Observation of the following precautions for storage and handling of fuel prior to use can enhance fuel washing and assure greater consistency in the fuel delivered to the gas turbine.

1. The use of three tanks sized to provide a 24-hour settling time needed for electrostatic systems will permit one tank to be in use while the second tank is being filled and the third is settling after being filled.
2. Tanks should be covered and provide for easy drainage of water and sediment from the bottom, which should be done daily.
3. Fuel should not be pumped directly from the bottom of the tank.
4. All fuel delivered should be filtered to remove any large particles, and piping should be arranged to minimize agitation of sediment at the bottom of the tank.
5. Storage tanks for high viscosity fuels such as residuals should be heated to keep the viscosity low enough so that the fuel can be pumped.
6. Oil storage temperature should be as low as possible, consistent with the operation. Washed oil must be delivered to the day tank below the flash point.
7. Cadmium, zinc, and copper catalyze the decomposition of hydrocarbons. These elements and their alloys, therefore, should not be used in the construction of storage tanks and related items.

Fuel-Wash Capacity

The fuel-use profile is significant in establishing the size of the fuel-washing equipment and treated fuel storage tank.

Fuel demand is a function of the site ambient temperature and number of hours each turbine is on line. Demand determines the required fuel treatment capacity to support the site operation. Final sizing depends on the margin desired by the customer and the maintenance philosophy adopted to keep the washing equipment on line.

Table 2
COMPARISION OF CENTRIFUGE AND ELECTROSTATIC FEATURES

Parameter	Electrostatic	Centrifuge
1. Type of mechanism	Static	Dynamic
2. Control system	Manual	Automatic-complete
3. Time to reach start-up stability	4 hours (per stage) 12 hours total	20 minutes total
4. Reliability	Good	Good
5. Maintenance	Low	Low
6. Solid removal	Fair — additional filtration needed	Excellent
7. Desludging	By water effluent but can accumulate in vessels. Approximately once a year vessels should be cleaned.	By water effluent and by automatic bowl opening.
8. Amount of heating required for fuel treatment	260–280 F	210 F
9. Performance in Na + K removal	Meets specification if fuel is within system design specification. (Specific gravity less than 0.98)	Exceeds specification even if raw fuel exceeds design specification. (Specific gravity less than 0.99)
10. Oil content in water effluent	500–2000 ppm — typical 50,000 ppm maximum	50 ppm typical 500 ppm maximum
11. Response time to correct fuel not meeting washed fuel specification.	Long (hours)	Short (minutes)
12. Fuel required to change system (cannot be used)	Approximately 500,000 gallons	50–100 gallons
13. Flexibility — servicing while operating	System cannot be partially shut down.	Centrifuges can be removed from service without total system shutdown.
14. Space required	Large area	Limited area
15. Cost		
— small systems	Higher	Lower
— large systems	Lower	Higher

Selection of Fuel-Washing Equipment Type

The selection of either centrifuges or electrostatic precipitators to reduce the soluble trace metals to acceptable limits is usually dictated by the application. For example, where space is at a premium or for higher salt levels, the natural choice is centrifuges. Where space is not a major constraint, where the customer has large storage tanks, and the raw fuel has low salt levels, electrostatic desalters may be a choice to consider. Table 2 gives a functional comparison of both types of systems.

Fuel-Washing Equipment Design

Fuel washing support equipment, which includes mixers, demulsifier injection pumps, heat exchangers, economizers, etc., must be compatible with overall system objectives. The performance of the support equipment can determine the performance of the entire fuel treatment system. On-line redundancy of critical components, such as heat exchangers, economizers, pumps and motors, is necessary for continuously running systems. This redundancy also permits the fuel washing equipment size to be minimized, which helps to reduce initial cost. Peaking systems require little redundancy, as maintenance may be performed during scheduled outages.

Turbine Cleaning

Both compressor fouling and ash build-up on the hot gas path parts contribute to turbine performance deterioration. Fouling occurs when contaminants injested into the inlet deposit on the compressor blades.

The ash deposits result primarily from crude and heavy residual oils containing vanadium and magnesium for inhibition. Effective fuel washing and treatment can reduce the frequency of cleaning required.

Fuel Analysis and System Controls

A modern, ash-forming fuel gas turbine installation requires controls for the fuel treatment equipment as part of the total system control. Actual control philosophy is dictated by customer preference. Generally, each functional component is equipped with its own control system and has manual set points. Once the set points are preselected, the system can be initiated on-site or at a remote location, after which the entire process is self-regulating. Monitoring of critical functions can be incorporated if desired.

Fail-safe and permissive features are provided as part of the control system. When a malfunction occurs in the fuel wash equipment, the fuel is automatically diverted back to the raw fuel storage tank until the malfunction is cleared.

Additionally, the fuel quality must be monitored at various steps of the process: sodium and vanadium level after washing, and total sodium, vanadium, and magnesium after inhibition.

For light fuels not requiring inhibition (vanadium less than 0.5 ppm), only the sodium level is monitored. This is most readily accomplished with a flame photometer, which is available as a manual instrument for spot checks.

Fuels requiring both washing and vanadium inhibition by a magnesium additive should be monitored with a direct-reading, rotating disk electrode (RDE) (Figure 10). While this is a complex instrument, its operation is very simple and suitable to use by on-site labor. The operator collects samples, inserts them sequentially in the excitation chamber, presses a button, and one minute later reads the analysis printed from a printer. About once every two weeks the instrument calibration is checked.

EXPERIENCE

GE has accumulated extensive experience in fuel purification and washing (Table 3). The following section describes some important examples which have contributed significantly to the state of the art of fuel treatment.

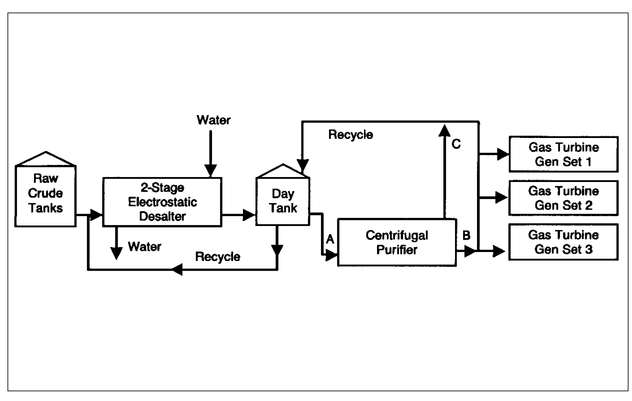
Figure 10. Fuel analysis spectrometer

Purification

The effect of purification had been studied on Guatemalan and Middle Eastern Crude. See Table 4 for typical analyses of these crude oils.

Guatemala

At times, the raw crude fuel contained high levels of contamination that the two stage electrostatic fuel treatment system could not handle without recycling of the fuel back through the system. A centrifuge was added to the original treatment system between the day tank and the turbine manifold (Figure 11), to improve the removal of water and solids from the fuel. It was found that the centrifuge greatly reduced asphaltic and inorganic particulates, reduced moisture to very low levels, and provided the needed support to the electro-



GT07653B

Figure 11. Final modification, February 1981

Table 3

GE'S EXPERIENCE WITH HEAVY FUEL TREATMENT SYSTEMS FEBRUARY 1994

C = Crude *CDS-P = Centrifuge Purification*
R = Residual *CDS-W = Centrifuge Washing*
B = Blend *EDS-W = Electrostatic Washing*

Fuel	Treatment System Type	Customer	Frame Size	Number	Gas Turbine Fired Hours
C	EDS-W	APS, Arizona	7	4	3,600
C	CDS-W	ARAMCO, Saudi Arabia	3	9	
C	CDS-W	Caltex, Sumatra	5	9	200,000
C	CDS-W	Caltex, Indonesia	5	1	16,000
C	CDS-W	China National, China	5	1	
C	CDS-W	Electrico, Saudia Arabia	5	6	39,000
C	CDS / EDS-W	Empressa, Guatemala	5	2	22,000
C	EDS-W	FPC, Bartow, Florida	7	4	12,000
C	CDS-W	MEW (Dona, Al Wajbah) Quatar	9	4	150,000
C	CDS-W	Phillips, North Sea	3	6	45,000
C	CDS-P	SCECO-C Al Juba Saudi Arabia	6	7	104,000
C	CDS-P	SCECO-C Leyla Saudia Arabia	5	6	81,000
C	EDS-W	SCECO-C Riyadh Saudi Arbia	5	2	48,000
C	EDS-W	SCECO-C Riyadh Saudi Arabia	7	14	919,000
C	CDS-P	SCECO-E Al Quisumah Saudi Arabia	5	4	60,000
C	CDS-P	SCECO-E Al Quisumah Saudi Arabia	6	2	90,000
C	CDS-P	SCECO-S Al Duba Saudi Arabia	5	2	20,000
C	CDS-P	SCECO-S Gizan Saudi Arabia	6	2	10,000
C	CDS-P	SCECO-S Gizan Saudi Arabia	7	1	
C	CDS-P	SCECO-S Asir Saudi Arabia	7	4	
C	CDS-P	SCECO-S Tihama Saudi Arabia	7	5	53,000
C	EDS / CDS-P	SCECO-W Jeddah Saudi Arabia	7	7	693,000
C	CDS-W	SEDC Shantou China	6	6	8,100
C	CDS-W	SMPPC Shenzmeh China	6	2	40,000
C	CDS-W	SOE Mosul Iraq	5	10	
C	CDS-P	Sonatrach Djamha Algeria	3	2	250,000
C	CDS-P	Sonatrach Elnamra & Dishra Algeria	3	2	12,000
C	CDS-P	Sonatrach Elnamra II Argeria	3	1	180,000
C	CDS-P	SOPEG Algeria	3	2	120,000
C	CDS-W	WED Al Ain VAE	5	2	10,000
C	CDS-W	ZDC Zhuhhai China	6	2	6,400

NOTE: The "Gas Turbine Fired Hours" reported in this table are not current in all cases.

Table 3 (Continued)
GE'S EXPERIENCE WITH HEAVY FUEL TREATMENT SYSTEMS
FEBRUARY 1994

C = Crude	*CDS-P = Centrifuge Purification*
R = Residual	*CDS-W = Centrifuge Washing*
B = Blend	*EDS-W = Electrostatic Washing*

Fuel	Treatment System Type	Customer	Frame Size	Number of Units	Gas Turbine Fired Hours
R	CDS-W	Alcoa, Suriname	7	1	26,000
R	CDS-W	Alto Ferrara Italy	5	2	54,000
R	CDS-W	Central Vermont Power, Vermont	5	1	700
R	CDS-W	EDF, France	9	5	13,000
R	CDS-W	EECI, Ivory Coast	5	4	70,000
R	CDS-W	EMSA, Argentina	5	2	60,000
R	CDS-W	ENDESA, Chile	5	2	50,000
R	CDS-W	ENDESA, Chile	6	1	9,000
R	CDS-W	EPC, Burma	5	1	
B	EDS-W	FPC, Debary, Florida	7	6	45,000
R	CDS / EDS-W	GE Lynn	5	2	50,000
B	CDS-W	General Petro, Syria	5	6	101,000
B	EDS-W	Golden Valley, Alaska	7	2	47,500
R	CDS-W	Green Mountain Power, Vermont	5	1	600
R	CDS-W	Hess, St. Croix	5	1	
R	CDS-W	IPCL, India	5	3	200
R	CDS-W	IPCL, India	6	2	120,000
R	EDS-W	O.N.E. Morocco	5	6	192,000
R	CDS-W	O.N.E. Mohammedia Morocco	6	3	19,000
R	CDS-W	O.N.E. (Tan-Tan), Morocco	6	3	15,400
R	CDS-W	Pee, Syria	5	3	15,000
B	CDS-W	PLN, Indonesia	5	2	40,000
B	CDS-W	PLN, Indonesia	7	4	30,000
R	CDS-W	Progil, France	5	8	1,080,000
R	EDS-W	Puerto Rico	7	8	
R	CDS-W	Reksten, Norway	5	1	9,100
R	CDS-W	SEDC Nanshan, China	5	3	400
R	CDS-W	SENELEC Dakar Senegal	5	1	24,000
B	CDS-W	Shell, Curacao	5	1	17,000
R	CDS-W	Slough Estates, England	5	1	2,000
R	CDS-W	Taunton, Mass	5	1	10,000
R	CDS-W	TPC Tunghsaio, China	7	6	117,000
R	EDS / CDS-W	WAPDA Kot Addu, Pakistan	9	4	63,000

NOTE: The "Gas Turbine Fired Hours" reported in this table are not current in all cases.

Table 4
TYPICAL CRUDE ANALYSIS

		Light Saudi		Guatemala	
	Unit	Max	Min	Max	Min
Gravity at 100 F (38 C)	API	34	39	31	33.5
Viscosity at 100 F (38 C)	cSt	11	5.5	10	6
at 122 f (50 C)	cSt	8.5	4.0	6.6	4.5
Water Content	vol%	1.0	0.01	1.0	0.1
Bottom Sediments & Water	vol%	0.7	0.01	1.5	0.2
Flash Point	F (C)	<20, (<-7)	<20, (<-7)	<20, (<-7)	<20, (<-7)
Pour Point	F (C)	–	-22 (<-30)	22 (<-7)	0 (-18)
Sulfur	wt%	1.2	1.0	3.5	3.3
H_2S	ppm	150	33	144	35
Wax	wt%	5	2	30	14
Ash	wt%	0.1	0.01	0.428	0.001
Sodium	ppm	20	1.5	50	5
Potassium	ppm	1	0.1	3	0.4
Vanadium	ppm	15	6	8	4

Table 5
DATA FROM CENTRIFUGAL PLANT OPERATIONS
ON GUATEMALAN CRUDE WITHOUT WATER WASHING

Ref. No.	Temp. (C)	Sample Point	Mg	Ca	V	Pb	Na	K	Fe	Cr	Sn	Ni	Water (vol%)	Sp. Gr. (at 20 C)	Viscosity (SSU at 50 C)
15/2	60	Raw Fuel	0.6	2.1	4.2	0.7	4.5	1.7	12.5	0	0	6	1.4	0.885	57
		Purified Fuel	0.1	0.5	4.7	0.8	0.6	0.1	4.6	0.4	0	7	>0.05		
15/1	70	Raw Fuel	12	0.8	3	0.2	4.0	1.4	3.8	0.6	0	5	1.3	0.865	61
		Purified Fuel	1	0.2	3	0	0.2	0	1.4	1.0	0	5	>0.05		
11/1*	22	Raw Fuel	21	32	6	0.8	104	34	62	0.7	6	10	6.0	0.865	58
		Purified Fuel	3	3	4	0	7	0.4	14	0.8	2	11	>0.05		
12/1*	77	Raw Fuel	11	31	7	1	143	36	54	0.2	1	7	14	0.873	60
		Purified Fuel	0	2	7	0.2	9	0.8	14	0.4	2	9	>0.05		

*These samples were from tank bottom and had a high sodium concentration
Two-stage Purification did not reduce sodium
However, when adding 1% water, sodium was reduced to less than 1 ppm

Source: EEG Test Program analysis by Baird FAS 2 GT static system to eliminate any need for fuel recycling to meet the required fuel specification. In addition, considerable data was taken on the operation of the centrifuge at this site. It showed that this crude could be desalted from initial levels of about 20 ppm of sodium to less than 1 ppm by single stage centrifugal purification without water addition (see Table 5).

Another problem experienced was gumming of gas turbine and system parts by the vanadium inhibitor being used (oil-soluable magnesium napthenate). While it was injected into the crude in very small quantities - on the order of 0.015 percent by volume - the napthenate had the properties of detergents, and a gummy mass would be formed in the presence of trace moisture. The gumming had a deterimental effect on the life of "on-base" equipment such as filters, flow dividers, high pressure pumps, and combustion nozzles. Even though this chemical has good oil soluability, it did not go into solution well. The chemical was being injected ahead of the storage tanks and it was found that sedimentation and loss of magnesium content resulted. Moving the injection point further downstream cured the sedimention problem. A change to an additive less sensitive to moisture further helped the problem. The addition of the centrifuge to the treatment process elimated the problem because it reduced the moisture to a level where the additive created no further gumming.

Qaisumah

The Qaisumah power station is located in north central Saudi Arabia. Crude, with the typical analysis shown in Table 4, was delivered by pipeline. Sodium levels in “as-received” fuel run from 4 to 10 ppm, only rarely exceeding 10 ppm. The fuel purification system consists of electric heaters followed by four centrifuges operating in parallel (see Figure 7). The capacity of the system is 200 U.S. gpm (45.4 cubic meters/hour). Operation was without water addition or demulsifier injection.

The only operational difficulty observed was as fuel temperatures dropped below 55°C (131°F), which appeared to be the approximate “wax point”, waxes began to precipitate from solution. Furthermore, it is interesting that there were no failures of flow dividers, high-pressure pumps, fuel nozzle coking, etc. Due to a duty cycle of frequent startups and shutdowns, the magnesium based deposits were spalled-off the turbine buckets. This allowed the turbine water wash cycle to be extended to 2500 hours.

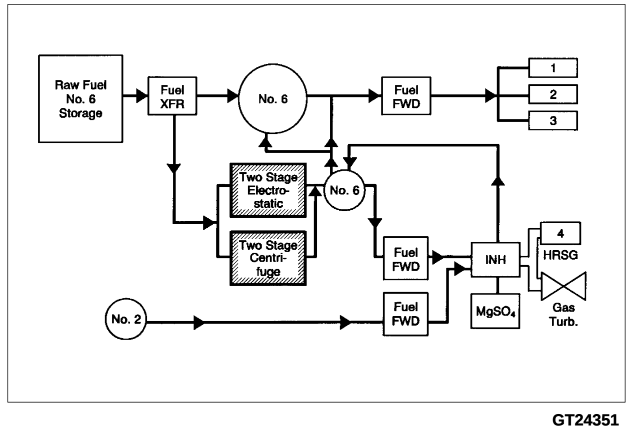


Figure 12. GE Lynn arrangement

Washing Residual Fuel

The effect of fuel washing on residual fuel has been studied at both GE’s Lynn, Massachusetts site and Paranam, Surinam.

GE Lynn

GE Lynn had been operating boilers using No. 6 oil for more than 30 years. This installation provided the opportunity to evaluate the performance of a modern gas turbine burning very heavy oils and, at the same time, provided the means to conduct exhaustive tests on various new elements of ash-forming fuels treating and handling. Figure 12 illustrates the overall plant arrangement. It should be noted that the arrangement incorporated two fuel-wash systems: a two-stage electrostatic unit and a two-stage centrifuge unit.

GE’s purchases of fuel from many sources provided a large sampling of different fuels with various characteristics, yielding a representative picture of the regionally available No. 6 oils. Figure 13 illustrates the wide array of fuel properties received over a 6-year period. Note that the sodium contents varied from a low of 10 ppm to a high of 100 ppm, the API gravity ranged from as low as 12 to 21 degrees API, (SpGr 0.986 to 0.928), and the vanadium from 15 ppm to 220 ppm.

Evaluations of the two-stage centrifuge system were conducted to examine the effects of temperature, water/oil mixing, viscosity, demulsifiers and throughput. Figure 14 delineates the progress made on the system from installation to the final performance, and key events are noted. Sodium removal to less than 1 ppm was readily achieved.

A similar program to evaluate and improve the performance of the two-stage electrostatic desalter was also carried out. Figure 15 presents the

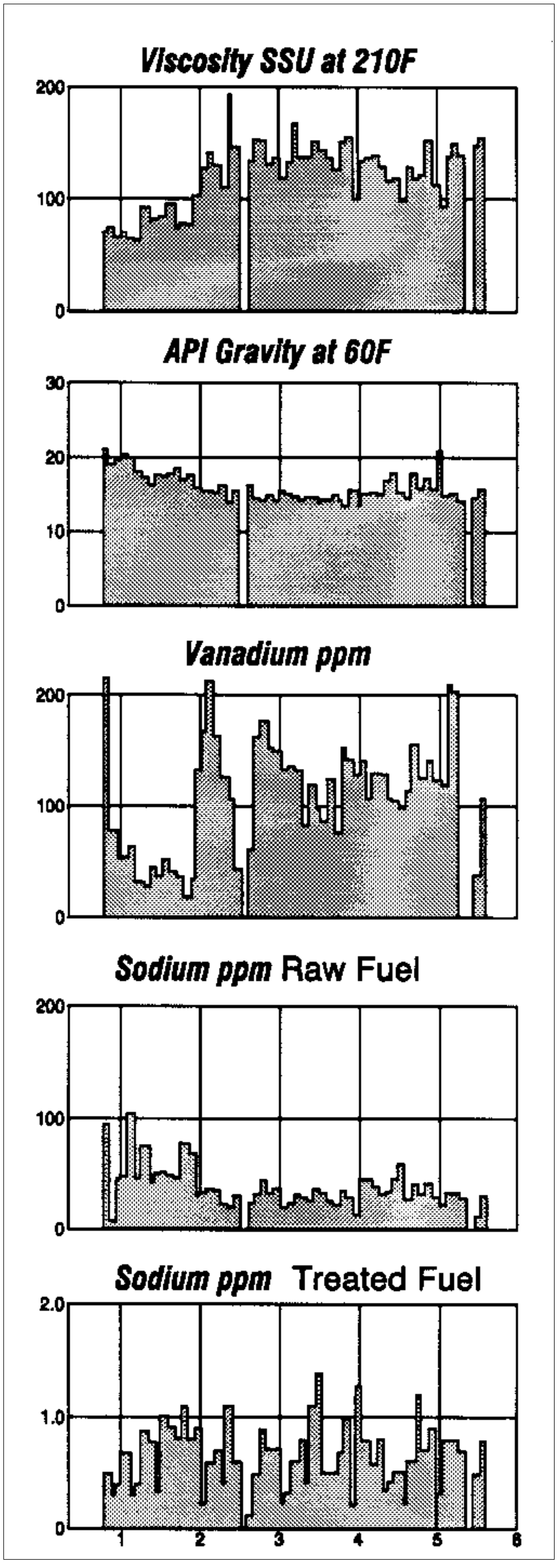


Figure 13. Fuel characteristics

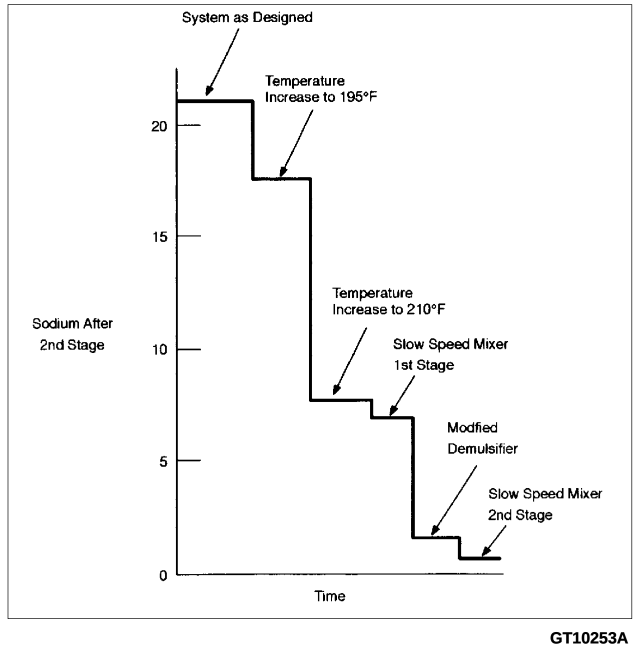


Figure 14. Two-stage centrifuge performance

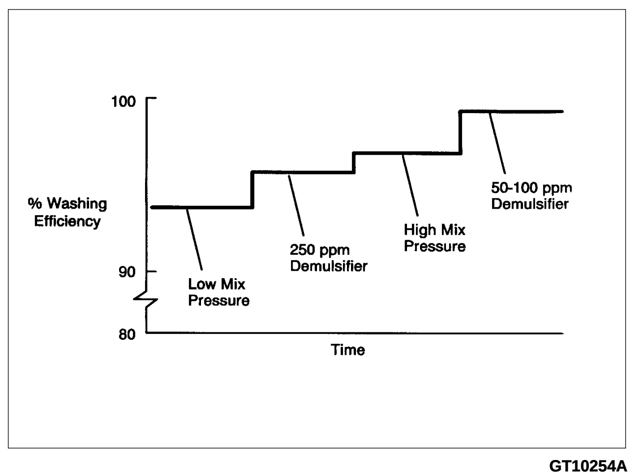


Figure 15. Two-stage electrostatic performance

improvement and best performance. The data is given in percentage washing efficiency. A 90 percent efficient 1 stage system removed 90 ppm of sodium from an initial 100 ppm input. Addition of a second stage raised the removal efficiency accordingly.

Surinam

The No. 6 residual oil typically had a specific gravity of 0.955 at 15.5°C (60°F)and a viscosity of 330 cSt at 38 C (100.4 F), and contained as much as 100 ppm vanadium and 250 ppm sodium and potassium. The fuel treatment was a two-stage fuel-wash system with three automatic desludging centrifuges in each stage, and was rated for a maximum of 100 gpm (22.7 cubic meters/hour) fuel flow. The system successfully desalted 17,000 bbls of fuel during a 120 hour test run.

The system also processed residual oils with a specific gravity of 0.966 and reduced sodium and potassium levels to less than 1.0 ppm from an initial level of sodium plus potassium of 122 ppm (see Table 6).

The above operational experiences enabled GE to improve the flexibility of site operation, accumulate more experience using ash-forming fuel, and maximize reliability and availability for burning these fuels.

SUMMARY

The work described in this paper represents a major undertaking by GE to arrive at optimal, well-balanced, reliable fuel systems capable of economically burning ash-forming fuels. The prime objective has been to extend our past experience to new applications with even more demanding requirements.

Objective evaluation of electrostatic and centrifugal types of separation equipment has resulted in greater awareness of techniques for fuel washing. Development of the fuel purification concept for distillates and light crudes has resulted in simple, low-cost systems with considerable flexibility and reliability. Centrifuge systems have also been refined and developed for application in newer, simplified fuel systems. Lessons learned in raw-fuel handling and storage have enabled us to improve system operational capability and minimize the serious consequences of field problems.

In all, GE has evolved new types of fuel treatment systems with simplified design, automated operation, and demonstrated success in real installations in many parts of the world.

REFERENCES

1. “Liquid Fuel Treatment Systems,” Shlomo S. Dreymann and Ernest H. Gault - GER 3481

Table 6
RAW RESIDUAL FUEL CHARATERISTICS FOR SURINAM ALUMINUM COMPANY

• API Gravity	14.8	• Nitrogen, %	0.49
• Specific Gravity	0.966	• Trace Metals, ppm	
• Viscosity - 100°F/38°C, cSt	802	- Vanadium	85
• Viscosity - 201°F/99°C, cSt	29	- Sodium	120
• High Heating Value Btu/lb (kcsi/kg)	18,350 (10.193)	- Potassium	2
• Carbon Residue, %	7.50	- Magnesium	5
• Hydrogen, %	11.40	- Calcium	11
• Sulfur, %	2.00	- Nickel	34

LIST OF FIGURES

LIST OF TABLES

For further information, contact your GE Field Sales Representative or write to GE Power Systems Marketing

GE Power Systems

General Electric Company
Building 2, Room 115B
One River Road
Schenectady, NY 12345

8/96