**MEMORIA DE CÁLCULOS – DISCIPLINAS MECÁNICA Y PROCESOS**

**AGM-02-0204-CAL-M-0001**

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1. purpose

The purpose of this document is to present results, criteria, calculations, assumptioms, functional requirements and technical methodology used in arriving at the design for Dual Fuel Modification Package.

1. scope

The scope of this document is to present all results obtained from mechanical and process calculation through proper development for design solutions related to systems, equipment package, equipment, instruments and devices required for the Dual Fuel Modification Package. To cover every aspect of the design, it will be used the same approach as described on the document AGM-02-0204-ESP-P-0004 by breakdown in three sections the engineering details to design, fabricate and install systems to support dual fuel operations. The Dual Modification Package can be broken out into three sections:

• Existing System on turbine that require modification.

• New systems that will be added to the turbine.

• Additional balance of plant equipment that will need to be support for dual fuel operations.

1. location

La Planta de Generación Juan Bautista Arismendi estará ubicada en la zona de El Guamache, municipio Tubores (ver Figura 1 y Figura 2), al lado oeste de la planta de Distribución de combustible El Guamache de PDVSA.

**Figura 1.** Ubicación de la Nueva Planta de Generación Juan Bautista Arismendi



**Fig. 2**. Parcela de Ubicación de Nueva Planta de Generación Juan Bautista Arismendi



* 1. Área y ubicación

La parcela ocupará un área aproximada de 50 hectáreas, la cual forma un polígono de cuatro (04) lados, definidos por los siguientes puntos de coordenadas UTM - REGVEN:

|  |  |  |
| --- | --- | --- |
|  | **Vértices de Linderos** | |
| **Punto** | **Norte** | **Este** |
| 220A | 1.203.129,416 | 386.707,723 |
| 220B | 1.203.060,674 | 387.201,966 |
| 221A | 1.202.267,719 | 387.261,708 |
| 221B | 1.202.232,067 | 386.775,330 |

Elevación Sobre El Nivel Del Mar (m.s.n.m.): 5 m.

1. REFEREnces

|  |  |
| --- | --- |
| AGM-02-0204-ESP-P-0004 | Design basis |
| AGM-02-0204-PLA-P-0009 | Flow and Process Diagram |
| AGM-02-0204-PLA-P-0048 | Liquid Fuel System PID’s |
| AGM-0204-PLA-G-0057 | Plot Plan |
| GER-4211 | Emissions Control |
| AGM-0204-PLA-P-0047 | Water Injection Skid PID |

1. Existing System on turbine that require modification

Cooling Water, Drains, Turbine Control, MCC, Trip Oil, Turbine Lube Oil,

1. New systems that will be added to the turbine

Purge Air, Atomizing Air, Liquid Fuel, Water Injection

1. Additional balance of plant equipment that will need to be support for dual fuel operations.
   1. Mechanical Calculations – Liquid Fuel Forwarding (P-1004 A/S, P-1005 A/S)
      1. Assumptions

* Pressure required at unit – 70psi (from AGM-02-0204-PLA-P-0048)
* Liquid Fuel Requirement at unit– 108gpm (from GER-4211)
* Total Liquid fuel pump capacity – 150gpm (from AGM-02-0204-PLA-P-0048)
* Lightoff fuel rate – 6.5gpm
* Piping, skid locations, elevations per AGM- 02-0204-PLA-G-0057 and supplied orthographic drawings
* Pump suction assumed to be flooded for sizing, as accurate NPSHA cannot be calculated from information supplied.
* Discharge losses calculated from skid losses, pipe run, and pipe fitting count only. Customer supplied valves not included.
* Design factor = 1.125
  + 1. Calculation for turbine demand at full load

From GER 4211:

Typical base load distillate fuel – m = 13lb/s

ρ = 53.94 lb/ft3

SG= 53.94 lb/ft3 / 62.4 lb/ft3

SG = .8644

13 lb/s \* 60 sec/min / (8.33 lb/gal \* .8644) = **108.32 gpm 🡪** Liquid fuel **normal** operation rate

Calculation of velocity in 4” suction assuming maximum flow rate: 150 gpm

Q = Av

Q = Flow rate (ft3/sec)

A= Average cross sectional area (ft2)

v = Average velocity (ft/s)

231 in3 = 1gal

(150 gpm \* 231 in3/gpm) = π x 42/4 x v

v = 2757 in / min or **3.83 ft / sec**

Per AGM 02-0204-PLA-P-0009:

μ = .004Pa-s

.0209 (lb-s/ft2)/Pa-s

.004Pa-s \* .0209 (lb-s/ft2) = **8.36 x 10-5 lb-sec/ft2**

ρ = 53.94 lb/ft3

SG= 53.94 lb/ft3 / 62.4 lb/ft3

SG = .8644

1lb = 0.03108 slugs

53.94 lb/ft3 \* .03108 lb/slug = **1.6765 slugs/ft3**

**Solving for on-skid suction losses:**

Losses in Fittings

hfl = K \* v2/2g

hfl = Friction Loss through obstruction

K = Friction coefficient (dimensionless)

g= acceleration due to gravity (ft/sec2)

v = velocity (ft/sec)

|  |  |  |  |
| --- | --- | --- | --- |
| **LF Suction Losses** | | | |
| **Description** | | **qty** | **K** |
| 4" reg 90 ell | | 1 | 0.225 |
| 4” tee branch flow | | 1 | 0.7 |
| 4” butterfly valve | | 1 | 1.5 |
| 4”x3” reducer | | 1 | 0.25 |
| basket strainer | | 1 | 1.1 |
|  |  |  |  |
|  |  | K = | 3.775 |

hfl1 = 3.775 \* (3.832 ft/s)2 / (2\*32.2 ft/s2)

hLl1 = 0.295ft Diesel \* 0.8644 = **.86 ft Diesel**

hLl2 skid = 1.15 ft Diesel \* 0.8644 = **0.743 ft H20**

.743 ft \* .433 psi/ft = **0.322 psi**

Assuming 1 psi suction head (flooded suction):

1psi + 0.322 psi = **1.322 psi suction required at inlet flange**

* + 1. Calculation of velocity discharge piping assuming maximum flow rate: 150 gpm

Q = Av

Q = Flow rate (ft3/sec)

A= Average cross sectional area (ft2)

v = Average velocity (ft/s)

231 in3 = 1gal

For Skid Piping:

(150 gpm \* 231 in3/gpm) = π x 32/4 x v

v = 4902 in / min or **6.8 ft / sec**

(150 gpm \* 231 in3/gpm) = π x 42/4 x v

v = 2757 in / min or **3.83 ft / sec**

Reynolds Number Calculation:

NR = [3.83ft/sec x 4 in/12in/ft x 1.6765 slugs/ft3] /8.36 x 10-5 lb-sec/ft3

NR = 25599

RR = (3/12)/1.5x10-4 = 2222

Moody’s Diagram 🡪 **f=.025**

Head Loss Calculation:

hL = f x L/D x v2 /2g

Where:

hL = Head loss in straight pipe (ft)

L = Length (ft)

D = Diameter (ft)

f= Friction Factor (dimensionless)

v = Average Velocity (ft/s)

hLf = 0.025 x [100 ft/(4/12)] x [(3.83 ft/sec)2 / (2 x 32.2 ft / sec2)]

hLf = 1.71 ft diesel / 100 ft

hLf = 1.71 ft diesel / 100 ft \* 0.8644 = **1.48 ft H20/100ft**

|  |  |  |  |
| --- | --- | --- | --- |
| **Length of Pipe Run** | | | |
|  |  | **Suction** | **Discharge** |
| **Unit 1** | | (ft) | (ft) |
| Liquid Fuel | | 228 | **1546** |
|  |  |  |  |
| **Unit 2** | |  |  |
| Liquid Fuel | | **367** | 1493 |

Pipe Run = 1546’

hLf = 1546 ft/ 100ft x 1.48 ft H20 / 100 ft = **22.82 ft H20**

Losses in Fittings:

hfl = K \* v2/2g

hfl = Friction Loss through obstruction

K = Friction coefficient (dimensionless)

g= acceleration due to gravity (ft/sec2)

v = velocity (ft/sec)

|  |  |  |  |
| --- | --- | --- | --- |
| **LF Discharge Losses - 4"** | | | |
| **Description** | | **qty** | **K** |
| 4" Ball Valve | | 3 | 0.06 |
| 4" gate valve | | 2 | 0.15 |
| 4" reg 90 ell | | 21 | 0.225 |
|  |  |  |  |
|  |  | K = | 5.205 |

hLl =5.205 \* (3.83 ft/s )2/ (2\*32.2 ft/s2)

hLl = 1.09 ft Diesel \*0.8644 = **1.02ft H20**

|  |  |  |
| --- | --- | --- |
| **LF Discharge Losses - 3"** | | |
| **Description** | **qty** | **K** |
| 2x3 reducer | 1 | 0.05 |
| 3" branch flow | 1 | 0.7 |
|  |  |  |
|  | K = | 0.75 |

hLl =.75 \* (6.81 ft/s )2/ (2\*32.2 ft/s2)

hLl = 0.54 ft Diesel \*0.8644 = **0.47ft H20**

|  |  |  |
| --- | --- | --- |
| **LF Discharge Losses - 2"** | | |
| **Description** | **qty** | **K** |
| 2 x 1.5 reducer | 1 | 0.05 |
| 2" ball valve | 1 | 0.07 |
| 2" 90 ell | 1 | 0.37 |
| 2" check | 1 | 2 |
|  |  |  |
|  | K = | 2.49 |

hLl =2.49 \* (15.32 ft/s )2/ (2\*32.2 ft/s2)

hLl = 9.07 ft Diesel \*0.8644 = **7.84ft H20**

Flow Metering Spool:

|  |  |  |
| --- | --- | --- |
| **Flow Metering Spool - 3"** | | |
| **Description** | **qty** | **K** |
| Butterfly Valves | 2 | 1.5 |
| Y strainer | 1 | 0.7 |
|  |  |  |
|  | K = | 6.6 |

hLl =6.6 \* (6.80 ft/s )2/ (2\*32.2 ft/s2)

hLl = 4.75 ft Diesel \*0.8644 = **4.11ft H20**

From Brodie spec sheet: Differential = >1 psid at 25% flow

From 1098EGR spec sheet 🡪 assume 5psid across valve ideal

6psi / .433psi/ft = **13.86ft H2O**

hL = hLf + hLl…

hL = 22.82 ft H20 + 1.02 ft H20 + 0.47 ft H20+ 7.84 ft H20 + 4.11 ft H2O + 13.86 ft H2O

hL = **50.12 ft H20**

Calculation for total losses:

Turbine Elevation: 7.44M + .25m

Liquid Fuel Elevation: 5.3M

Difference in Elevation: 2.39M = 7.83 ft diesel \*0.8644 = **6.77 ft H20**

Pressure required at Unit: 70 psi

+ 161.66 ft H20 – Pressure at unit

+ 6.77 ft H20 - Elevation

+50.12 ft H20 – Friction losses

-0 – NPSHA

Required differential – 218.5 ft H20 = 94.6 psi

Design Pressure = Req. Differential \* 1.125 = **106.5 psi**

**Liquid Fuel Forwarding Skid Discharge**

Pressure required at unit – 35-70psi

Total losses – 56.89ft

Design Factor – 1.125

56.89psi + (35psi / .433psi/ft) \* 1.125 = **67psi** 🡪 minimum discharge pressure

56.89psi + (70psi / .433psi/ft) \* 1.125 = **106.5psi** 🡪 maximum discharge pressure

**Fuel Management Spool –**

Total Losses = 17.96ft H2O = 7.8 psi

Pressure required at unit – **35-70psi** 🡪 Outlet pressure range

35psi + 7.8psi = **43 psi** 🡪 minimum inlet pressure

70psi + 7.8psi = **78 psi** 🡪 maximum inlet pressure

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Liquid Fuel Forwarding Pump Requirements vs. Turbine Demand** | | | | |
|  |  | **Pressure Required at Unit** |  | **Estimated Bypass Flow to Tank** |
|  | **Fuel Req at Unit** | **Pump Pressure** |
|  | gpm / [m3/h] | psi / [kPa] | (psi / [kPa]) | (gpm / m3/h) |
| **Startup/Trip** | 0 / [0] | 70 / [413] | 106.5 / [734] | 150 / [34.1] |
| **Light off** | 6.5 / [1.48] | 70 / [413] | 106.5 / [734] | 143.5 / [32.62] |
| **Increasing load** | 6.5-108 / [1.48-24.5] | 70 / [413] | 106.5 / [734] | 143.5 - 42 / [32.62 - 9.6] |
| **Full Speed Full load** | 108 / [24.5] | 70 / [413] | 106.5 / [734] | 42 / [9.6] |

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **Liquid Fuel Forwarding Conditions** | | | | | | |
| **ρ =** | 53.94 | lb/ft3 | | |  |  |
| **μ =** | 8.36E-05 | lb-sec/ft2 | | |  |  |
|  |  |  | | |  |  |
| **Lightoff rate (minimum)** | | | | | 6.5 | gpm |
| **Max Turbine Demand (normal)** | | | | | 108 | gpm |
| **Forwarding Rate (nominal)** | | | |  | 150 | gpm |
| **Pressure required at Unit** | | | | | 70 | psi |
|  |  | | |  |  |  |
| **Total Losses** | | | |  | 50.1 | ft |
|  |  | | |  |  |  |
| **Required Differential** | | | | | 94.6 | psi |
| **Design Differential** | | |  | | 106.5 | psi |

* 1. mechanical Calculations – Demineralized Water Forwarding (P-0403A/S, P-0404 A/S)
     1. Assumptions
* Pressure required at unit – 40psi (from AGM-02-0204-PLA-P-0047)
* Demineralized water max rate – Sufficient to abate NOx emissions within operational range of 42-150 ppm.
* Lightoff demineralized water rate – 0gpm
* Piping, skid locations, elevations per AGM- 02-0204-PLA-G-0057 and supplied orthographic drawings.
* Pump suction assumed to be flooded for sizing, as accurate NPSHA cannot be calculated from information supplied.
* Discharge losses calculated from skid losses, pipe run, and pipe fitting count only. Customer supplied valves not included.
* Design factor = 1.125
  1. Calculations for Pump / Motor Specifications

From Liquid Fuel Calculations:

Typical base load distillate fuel – 13lb/s 🡪 **108.32gpm**

From GER4211:

Maximum baseload water to fuel mass ratio – 1:1

Qfuel \* mfuel  = Qwater \* mwater

108.32gpm \*8.33 lb/gal \*.8644 = Qwater \* 8.33 lb/gal

Qwater = 93.63 gal/min 🡪 **Water Injection normal operating rate**

* 1. Calculation of velocity in 4” suction assuming maximum flow rate: 230 gpm

Q = Av

Q = Flow rate (ft3/sec)

A= Average cross sectional area (ft2)

v = Average velocity (ft/s)

231 in3 = 1gal

(230 gpm \* 231 in3/gpm) = π x 42/4 x v

v = 4228 in / min or **5.87 ft / sec 🡪 A single 4” pipe has insufficient flow area for reliable operation and does not conform to velocity requirements per Corpolec standard of 4 ft/sec maximum for suction piping. Derrwick recommends that suction piping with a flow area of at least 18.5 in2** **be used to prevent operational reliability of system.**

AGM-02-0204-PLA-P-0009:

µ =.000851 Pa\*s

.0209 (lb-s/ft2)/Pa-s

.000851Pa-s \* .0209 (lb-s/ft2) = **1.7786 x 10-5 lb-sec/ft2**

1lb = 0.03108 slugs

62.8 lb/ft3 \* .03108 lb/slug = **1.95 slugs/ft3**

Demineralized Water Forwarding – Skid Suction Losses

Q = Av

Q = Flow rate (ft3/sec)

A= Average cross sectional area (ft2)

v = Average velocity (ft/s)

231 in3 = 1gpm

(115 gpm \* 231 in3/gpm) = π x 32/4 x v

v = 3758 in / min or **5.21 ft / sec**

|  |  |  |  |
| --- | --- | --- | --- |
| **Description** | | **qty** | **K** |
| 3" tee - branch | | 1 | 0.7 |
| 3" ball valve | | 1 | 0.07 |
| 3" 90 ell | | 1 | 0.325 |
| 3" butterfly | | 1 | 1.5 |
| 3"x1.5" reducer | | 1 | 0.5 |
|  |  |  |  |
|  |  | Total K | 3.095 |

K= 3.095

hLl skid = 3.095 \* (5.21 feet/sec )2/ (2\*32.2 ft/s2)

hLl skid = **1.30 ft H20**

1.3 ft H20 \* .433 psi/ft = 0.5629 psi

Assuming 1 psi suction head (flooded suction):

1psi + 0.563 psi = **1.563 psi suction required at inlet flange**

* 1. Calculation of velocity in 3” discharge assuming maximum flow rate: 115 gpm

From above:

v = 5.21 ft/s

μ = 1.7786 x 10-5 lb-sec/ft2

Reynolds Number Calculation:

NR = (vDρ)/μ

Where:

NR = Reynolds Number

v = Average Velocity (ft/s)

ρ = Density (lb / ft3)

μ = Dynamic Viscosity (lb-sec/ft2)

NR = [5.21 ft/sec x 3in / 12in/ft x 1.95 Slugs/ft3] /1.7786 x 10-5 lb-sec/ft2

NR = 142,801

RR = (3in / 12in/ft)/1.5x10-4 = 1666 🡪Moody’s Diagram

**f=0.0215**

Head Loss Calculation:

hL = f x L/D x v2 /2g

Where:

hL = Head loss in straight pipe (ft)

L = Length (ft)

D = Diameter (ft)

f= Friction Factor (dimensionless)

v = Average Velocity (ft/s)

hLf = 0.0215 x [100 ft/(3/12)] x [(5.21 ft/sec)2 / (2 x 32.2 ft / sec2)]

hLf = **3.64 ft H20 / 100 ft**

|  |  |  |  |
| --- | --- | --- | --- |
|  |  |  |  |
| **Pipe Runs** | | | |
|  |  | **Suction** | **Discharge** |
| **Unit 1** | | (ft) | (ft) |
| Water Injection | | 228 | **1546** |
|  |  |  |  |
| **Unit 2** | |  |  |
| Water Injection | | **22** | 1116 |

Pipe run = 1116 feet

hLf = 1116 ft/ 100ft x 3.64 ft H20 / 100 ft = **40.60 ft H20**

Losses in Fittings

hfl = K \* v2/2g

hfl = Friction Loss through obstruction

K = Friction coefficient (dimensionless)

g= acceleration due to gravity (ft/sec2)

v = velocity (ft/sec)

|  |  |  |  |
| --- | --- | --- | --- |
| **Demin Water Forwarding - 3"** | | | |
| **Description** | | **qty** | **K** |
| 3" tee - branch | | 1 | 0.7 |
| 3" ball valve | | 3 | 0.07 |
| 3" gate valve | | 1 | 0.2 |
| 3" 90 ell | | 18 | 0.325 |
|  |  |  |  |
|  |  | Total K | 6.76 |

hfl =6.76 \* (5.21 ft/s)2 / (2\*32.2 ft/s2)

hLl = **2.86 ft H20**

|  |  |  |
| --- | --- | --- |
| **Demin Water Forwarding - 2"** | | |
| **Description** | **qty** | **K** |
| 2x3 reducer | 1 | 0.05 |
| 1.5x2 reducer | 1 | 0.05 |
|  |  |  |
|  | K = | 0.1 |

(115 gpm \* 231 in3/gpm) = π x 22/4 x v

v = 8453 in / min or **11.74 ft / sec**

hfl = 0.1 \* (11.74 ft/s)2 / (2\*32.2 ft/s2)

hLl = **0.214 ft H20**

hL = hLf + hLl…

hL = 38.61 ft H20 + 2.86 ft H20 + 0.214 ft H20

hL = **43.68 ft H20**

Calculation for total losses:

Turbine Elevation: 7.44m + .25m

Demineralized Water Elevation: 6m

Difference in Elevation: 1.69m = 5.54 ft H20

Pressure required at Unit: 40 psi

+ 92.38 ft H20 – Pressure at unit

+ 5.54 ft H20 - Elevation

+43.68 ft H20 – Friction losses

-0 – NPSHA

Required differential – 141.6 ft H20 = 61.31 psi

Design Pressure = Req. Differential \* 1.125 = **68.98 psi**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Demineralized Water Forwarding Pump Requirements vs. Turbine Demand** | | | | |
|  |  | **Pressure Req. at WI Skid** |  | **Estimated Bypass Flow** |
|  | **Demin Req at Unit** | **Pump Pressure** |
|  | (gpm / m3/h) | (psi/kPa) | (psi/kPa) | (gpm / m3/h) |
| **Startup/Trip** | 0 / [0] | **40 / [275.8]** | 69 / [475] | 115 / [26.1] |
| **Light off** | 0 / [0] | **40 / [275.8]** | 69 / [475] | 100 / [22.7] |
| **Full speed, increasing load** | 18-94/ [4.09-21.4] | **40 / [275.8]** | 69 / [475] | 97 - 21 / [22 – 4.7] |
| **Full Speed Full load** | 94 / [21.4] | **40 / [275.8]** | 69 / [475] | 21 / [4.7] |

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **Demineralized Water Forwarding Conditions** | | | | | | |
| **ρ =** | 62.8 | lb/ft3 | | |  |  |
| **μ =** | 1.78E-05 | lb-sec/ft2 | | |  |  |
|  |  |  | | |  |  |
| **Minimum Rate - Begin injection** | | | | | 18 | gpm |
| **Max Turbine Demand** | | | |  | 94 | gpm |
| **Forwarding Rate** | | | |  | 115 | gpm |
| **Pressure required at Unit** | | | | | 40 | psi |
|  |  | |  | |  |  |
| **Total Losses** | | |  | | 49.22 | ft |
|  |  | |  | |  |  |
| **Required Differential** | | |  | | 47.33 | psi |
| **Design Differential** | | |  | | 53.12 | psi |

1. GENERAL 1

Texto GENERAL 1

1. Caso 1
2. Caso 2
3. Caso 3

* Viñeta GENERAL 1
* Viñeta Indentada 1
* Viñeta Indentada 2
  1. TITULO GENERAL 2

Texto GENERAL 1

1. Caso 1
2. Caso 2
3. Caso 3

* Viñeta GENERAL 1
* Viñeta Indentada 1
* Viñeta Indentada 2
  + 1. TITULO GENERAL 3

Texto GENERAL 1

1. Caso 1
2. Caso 2
3. Caso 3

* Viñeta GENERAL 1
* Viñeta Indentada 1
* Viñeta Indentada 2
  + - 1. Titulo General 4

Texto GENERAL 1

1. Caso 1
2. Caso 2
3. Caso 3

* Viñeta GENERAL 1
* Viñeta Indentada 1
* Viñeta Indentada 2

TITULO ANEXO 1