EJECTORS

- PRINCIPLES
- APPLICATION
- DESIGN FOR STEAM JET AIR EJECTOR (SJAE)
- PHOTOS
- ATTACHMENT - VACUUM FOR POWER PLANT
Ejectors consist of six basic parts:
1. Motive Fluid Chest
2. Converging/Diverging Nozzle
3. Mixing Chamber
4. Converging Inlet Diffuser
5. Diverging Outlet Diffuser
6. Diffuser Throat

The operating principle of the ejector is that the pressure energy in the motive fluid (1) is converted to velocity energy by an adiabatic expansion in the Converging/Diverging Nozzle (2). The Nozzle exit velocity is normally in the supersonic range of 3000 to 4000 feet/second when using steam as the motive fluid. (Velocities may vary depending on molecular weight, temperature, and pressure of the motive fluid.)

This high-velocity (cone shaped) jet enters the Mixing Chamber (3) and entrains the suction fluid being pumped. The mixture attains a velocity of approximately 2000 to 3000 feet per second.

The mixed motive fluid and suction fluid then enter the Converging Inlet Diffuser (4) where a portion of the velocity energy is converted to pressure energy. The mixture is then compressed in the Diverging Outlet (5) section of the Diffuser to attain the final discharge pressure, normally 5 to 15 times the suction pressure. There is a corresponding rise in mixture temperature as this compression occurs.

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Figure 9-1. Basic ejector components and diagram of energy conversion in nozzle and diffuser. By permission, Ingersoll-Rand Co.
Steam Jets Serve the Entire Pressure Range

Assume same steam consumption, 100-psig steam and 85°F water

Fig. 2
APPLICATION

**REFINING**
- Crude oil vacuum distillation:
  - Three-stage Ejectors
  - Precondenser with two-stage Ejectors
  - Precondenser with Liquid Ring Vacuum Pump
- Lube oil dryers:
  - Single-stage Ejectors
  - Two-stage Ejectors
  - Liquid Ring Vacuum Pumps

**PROCESS**
- Units used for urea, synthetic fibers, pharmaceuticals, tobacco drying, crystallizers, evaporators, and desalinization.

**POWER**
- Steam surface condensers:
  - Twin-element two-stage Ejectors
  - Liquid Ring Vacuum Pumps
- Combination Steam Ejector/Liquid Ring Vacuum Pump

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Three-stage Ejector system in refinery service.

Ejectors in vacuum distillation service.

Triple element booster Ejectors in refinery service.

Combination system for polyester plant.

Ejector and Condensers in a urea plant.

Large Condenser exhauster system.

Booster Ejectors and Condensers for enhanced venting of surface condenser.

Combination system with graphite intercondenser for a pharmaceutical plant.

A 166,000 sq. ft. steam surface Condenser.
GEOTHERMAL STEAM CONDENSERS
AND GAS REMOVAL SYSTEMS

Graham has many years of experience designing systems with high non-condensable gas loadings. Since geothermal steam is highly corrosive and contains large amounts of noncondensible gases (1-10%), the design and fabrication of Geothermal Steam Condensers is radically different than conventional power plant condensers. Special consideration must be given to:
- Reduced overall heat transfer rates (U value) and weighted LMTD due to noncondensible gases.
- Flow path for venting large volumes of noncondensible gases.
- Pressure drop of noncondensible gases.
- Subcooling of noncondensible gases.
- Preventing subcooling of the condensate.
- Special materials to prevent corrosion.

The associated vacuum system can be multi-stage Steam Ejectors or a combination of a Steam Ejector and Liquid Ring Vacuum Pump. Since these systems are very large, Graham engineers will carefully evaluate the design and selection of components for each application, to provide the most efficient system.

METAL RENING
For vacuum melting and vacuum degassing.

A 54,000 sq. ft. steam surface condenser for 32 MW geothermal power plant in California.

FOOD
For flash cooling, evaporators, degassing, and deodorizing.

PULP AND PAPER
Liquid Ring Vacuum Pumps: Steam Vacuum Refrigeration to chill water for chlorine dioxide bleach plants.

MARINE
Ejectors for main and auxiliary Condensers and distilling equipment.

Direct contact geothermal condenser for 9 MW plant.

Combination ejector and liquid ring pump for a juice evaporator.

3,400 ton steam vacuum refrigeration unit.
# MPS FOR NUEVA PROJECT

## CAPACITY SUMMARY SHHET for Steam Jet Air Ejector

### Design Conditions:

<table>
<thead>
<tr>
<th>Equipment</th>
<th>Quantity</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total No of system</td>
<td>1 set</td>
<td></td>
</tr>
<tr>
<td>Steam jet air ejector</td>
<td>2 sets</td>
<td>1st 100% x 1, 2nd 100% x 1</td>
</tr>
<tr>
<td>Ejector condenser</td>
<td>1 set</td>
<td>Integral 1st 100% x 1 plus 2nd 100% x 1</td>
</tr>
<tr>
<td>Hogging ejector</td>
<td>1 set</td>
<td>1 x 100%</td>
</tr>
<tr>
<td>Silencer for Hogging Ejector</td>
<td>1 set</td>
<td>1 x 100%</td>
</tr>
<tr>
<td>All required valves, piping, instruments, counter flange, bolts, nuts, washers, gaskets</td>
<td>1 lot</td>
<td></td>
</tr>
<tr>
<td>Skid (all equipments mounted)</td>
<td>1 set</td>
<td></td>
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### Design Capacity:

<table>
<thead>
<tr>
<th>Component</th>
<th>Capacity, total</th>
<th>Unit</th>
<th>Remarks</th>
</tr>
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<tbody>
<tr>
<td>Holding</td>
<td>99</td>
<td>kg/h</td>
<td>@ 25.4 mmHgA Design</td>
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<tr>
<td>Dry air</td>
<td>31</td>
<td>kg/h</td>
<td>@ 25.4 mmHgA Design</td>
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<tr>
<td>Water vapor</td>
<td>68</td>
<td>kg/h</td>
<td>@ 25.4 mmHgA Design</td>
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<tr>
<td>Condenser press</td>
<td>4</td>
<td>kPaA</td>
<td></td>
</tr>
<tr>
<td>Condenser temp</td>
<td>28.98</td>
<td>°C</td>
<td></td>
</tr>
<tr>
<td>Hogging</td>
<td>10,000</td>
<td>m³</td>
<td>@ 254 mmHgA Design</td>
</tr>
<tr>
<td>Air</td>
<td>10,000</td>
<td>m³</td>
<td>@ 254 mmHgA Design</td>
</tr>
<tr>
<td>Time</td>
<td>Bellow 30</td>
<td>min.</td>
<td></td>
</tr>
</tbody>
</table>

### Motive Steam for Ejector Condition

<table>
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<th>Flow</th>
<th>Unit</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inlet press</td>
<td>15</td>
<td>barA</td>
<td></td>
</tr>
<tr>
<td>Inlet temp</td>
<td>Sat. Temp.+50</td>
<td>°C</td>
<td></td>
</tr>
</tbody>
</table>

### Cooling Water for Ejector Condenser

<table>
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<th>Unit</th>
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</thead>
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<td>inlet press</td>
<td>15</td>
<td>barA</td>
</tr>
<tr>
<td>inlet temp</td>
<td>29.09</td>
<td>°C</td>
</tr>
</tbody>
</table>
**CALCULATION FOR HOGGING**

- **Volume of load**

  Steam from turbine exhaust

  According to HEI code

<table>
<thead>
<tr>
<th>Standards for Steam Surface Condensers para 6.0 Venin Equipment Capacities</th>
<th>Dry Air</th>
<th>Water Vapor</th>
<th>Total Mixture</th>
</tr>
</thead>
<tbody>
<tr>
<td>Table 3 (1,000,000 ~ 2,000,000 lbs/hr)</td>
<td>315 lbs/hr</td>
<td>693 lbs/hr</td>
<td>1,008 lbs/hr</td>
</tr>
</tbody>
</table>

- **Weight of load**

  \[ W : \text{Weight of Gas (Air)} \]

  \[ 1.429 \text{ kg/hr} \]

- **Suction Condition**

  \[ L_s : \text{Load (kg/hr)} \]

  \[ P_s : \text{Pressure (mm Hg A)} \]

  \[ \begin{align*}
  L_s & = 1429 \text{ Weight of Load} \\
  P_s & = 254
  \end{align*} \]

- **Motive Condition**

  \[ L_m : \text{Load (kg/hr)} \]

  \[ P_m : \text{Pressure (kg/\text{atm} A)} \]

  \[ \begin{align*}
  L_m & = 3040 \text{ Motive Suction Consumption} \\
  P_m & = 15
  \end{align*} \]

- **Discharge Condition**

  \[ L_d : \text{Load (kg/hr)} \]

  \[ P_d : \text{Pressure (mm Hg A)} \]

  \[ \begin{align*}
  L_d & = 4469 \text{ \( L_s + L_m \)} \\
  P_d & = 800 \text{ \( * \)}
  \end{align*} \]

* The discharge pressure has to design more than atmospheric pressure (760mm Hg A), or less than the suction pressure for next stage.
**DESIGN**

*CALCULATION FOR HOGGING*

- **Expansion Ratio (E)**
  \[ E = \frac{\text{Motive Pressure (mm Hg A)}}{\text{Suction Pressure (mm Hg A)}} = \frac{11,400}{254} = 45 \]

- **Consumption Ratio (K)**
  \[ K = \frac{\text{Discharge Pressure (mm Hg A)}}{\text{Suction Pressure (mm Hg A)}} = \frac{800}{254} = 3.15 \]

- **Suction Ratio Graph: \( \alpha = 0.47 \)**

- **Motive Suction Consumption**
  \[ = \frac{\text{Suction Condition Load (kg/hr)}}{\text{Suction Ratio Graph (\( \alpha \))}} = \frac{1,429}{0.47} = 3,049 \text{ kg/hr} \]
### CALCULATION FOR HOGGING

#### RAPID EVACUATION EQUIPMENT CAPACITIES

<table>
<thead>
<tr>
<th>Total Steam Condensed</th>
<th>*SCFM - Dry Air at 10 in HgA Design Suction Pressure</th>
</tr>
</thead>
<tbody>
<tr>
<td>lbs/hr</td>
<td></td>
</tr>
<tr>
<td>Up to 100,000</td>
<td>50</td>
</tr>
<tr>
<td>100,001 to 250,000</td>
<td>100</td>
</tr>
<tr>
<td>250,001 to 500,000</td>
<td>200</td>
</tr>
<tr>
<td>500,001 to 1,000,000</td>
<td>350</td>
</tr>
<tr>
<td><strong>1,000,001 to 2,000,000</strong></td>
<td><strong>700</strong></td>
</tr>
<tr>
<td>2,000,001 to 3,000,000</td>
<td>1050</td>
</tr>
<tr>
<td>3,000,001 to 4,000,000</td>
<td>1400</td>
</tr>
<tr>
<td>4,000,001 to 5,000,000</td>
<td>1750</td>
</tr>
<tr>
<td>5,000,001 to 6,000,000</td>
<td>2100</td>
</tr>
<tr>
<td>6,000,001 to 7,000,000</td>
<td>2450</td>
</tr>
<tr>
<td>7,000,001 to 8,000,000</td>
<td>2800</td>
</tr>
<tr>
<td>8,000,001 to 9,000,000</td>
<td>3150</td>
</tr>
<tr>
<td>9,000,001 to 10,000,000</td>
<td>3500</td>
</tr>
</tbody>
</table>

Note: In the range of 500,000 lbs/hr steam condensed and above, the above table provides evacuation of the air in the condenser and L.P. turbine from atmospheric pressure to 10 in. HgA in about 30 minutes if the volume of condenser and L.P. turbine is assumed to be 26 cu ft / 1000 lb/hr of steam condensed.

*SCFM - 14.7 psia at 70°F - to convert to lbs/hr, multiply above values by 4.5.

<table>
<thead>
<tr>
<th>Effective Steam Flow Each Main Exhaust Opening lbs/hr</th>
<th>Total Number of Exhaust Openings</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
</tr>
</thead>
<tbody>
<tr>
<td>Up to 25,000</td>
<td>*SCFM</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dry Air lbs/hr</td>
<td>13.5</td>
<td>18.0</td>
<td>22.5</td>
<td>22.5</td>
<td>33.8</td>
<td>33.8</td>
<td>33.8</td>
<td>45.0</td>
<td>45.0</td>
<td></td>
</tr>
<tr>
<td>Water Vapor lbs/hr</td>
<td>29.7</td>
<td>39.6</td>
<td>49.5</td>
<td>49.5</td>
<td>74.4</td>
<td>74.4</td>
<td>74.4</td>
<td>99.0</td>
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<td></td>
</tr>
<tr>
<td>Total Mixture lbs/hr</td>
<td>45.2</td>
<td>57.6</td>
<td>72.0</td>
<td>72.0</td>
<td>108.2</td>
<td>108.2</td>
<td>108.2</td>
<td>144.0</td>
<td>144.0</td>
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<td>25,001 to 50,000</td>
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<td></td>
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<tr>
<td>Dry Air lbs/hr</td>
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<td>Water Vapor lbs/hr</td>
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<td>74.4</td>
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<td>99.0</td>
<td>123.6</td>
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<tr>
<td>Total Mixture lbs/hr</td>
<td>57.6</td>
<td>72.0</td>
<td>108.2</td>
<td>108.2</td>
<td>144.0</td>
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<td>50,001 to 100,000</td>
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<tr>
<td>Dry Air lbs/hr</td>
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<td>Water Vapor lbs/hr</td>
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<td>123.6</td>
<td>123.6</td>
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<td>179.8</td>
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<td>251.8</td>
<td>288.0</td>
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<td>432.0</td>
<td>540.0</td>
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<td>Dry Air lbs/hr</td>
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<td>179.8</td>
<td>216.0</td>
<td>251.8</td>
<td>288.0</td>
<td>360.0</td>
<td>432.0</td>
<td>540.0</td>
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<td>500,001 to 1,000,000</td>
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<td>35.0</td>
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<td>648.0</td>
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<td>799.2</td>
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<td>2,000,001 to 3,000,000</td>
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<td>90.0</td>
<td>135.0</td>
<td>157.5</td>
<td>180.0</td>
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<td>225.0</td>
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<td>270.0</td>
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<td>Water Vapor lbs/hr</td>
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<td>297.0</td>
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<td>396.0</td>
<td>445.5</td>
<td>495.0</td>
<td>544.5</td>
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<td>Total Mixture lbs/hr</td>
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<td>504.0</td>
<td>576.0</td>
<td>648.0</td>
<td>720.0</td>
<td>799.2</td>
<td>864.0</td>
<td>936.0</td>
<td></td>
</tr>
</tbody>
</table>

*14.7 psia at 70°F
Note: These tables are based on air leakage only and the air vapor mixture at 1 inch HgA and 71.5°F.

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Table 8

Table 9A
* CALCULATION FOR 1ST HOLDING

- Weight of load
  HEI Standard (5.0 Venting equipment capacity) it follows,

  Dry Air : 67.5 lbs/hr = 31.0 kg/hr
  Water Vapor : 140.5 lbs/hr = 68.0 kg/hr
  Total Mixture : 216.0 lbs/hr = 99.0 kg/hr
  Mole Weight : 20.31

- Suction Condition
  \[ L_s : \text{Load (kg/hr)} = 99.0 \quad \text{Weight of Load} \]
  \[ P_s : \text{Pressure (mm Hg A)} = 25.4 \]

- Motive Condition
  \[ L_m : \text{Load (kg/hr)} = 295 \quad \text{Motive Suction Consumption} \]
  \[ P_m : \text{Pressure (kg/air A)} = 15 \]

- Discharge Condition
  \[ L_d : \text{Load (kg/hr)} = 394.2 = L_s + L_m \]
  \[ P_d : \text{Pressure (mm Hg A)} = 148 \]

* The discharge pressure has to design more than atmospheric pressure (760 mmHg A), or the suction pressure for next stage.

- Dry Air Equivalent
  \[ AE = \frac{L_s}{0.86} = \frac{99.0}{0.86} = 115 \quad \text{kg/hr} \]
* CALCULATION FOR 1ST HOLDING

- **Expansion Ratio (E)**
  \[
  E = \frac{\text{Motive Pressure (mmHg A)}}{\text{Suction Pressure (mmHg A)}} = \frac{11,400}{25.4} = 448.8
  \]

- **Consumption Ratio (k)**
  \[
  k = \frac{\text{Discharge Pressure (mmHg A)}}{\text{Suction Pressure (mmHg A)}} = \frac{148}{25.4} = 5.83
  \]

- **Suction Ratio Graph**: \( \alpha = 0.39 \)

- **Motive Suction Consumption**
  \[
  = \frac{\text{Dry Air Equivalent (kg/hr)}}{\text{Suction Ratio Graph (\( \alpha \))}} = \frac{115}{0.39} = 296 \text{ kg/hr}
  \]
* CALCULATION FOR 2ND HOLDING

- Weight of load

\[
\begin{align*}
\text{DryAir} & : \quad 31.0 \text{ kg/hr} & \text{1st Holding Ejector Load} \\
\text{Water Vapor} & : \quad 12.0 \text{ kg/hr} & \text{Non-Condensate of the After Condenser} \\
\text{Total Mixture} & : \quad 43.0 \text{ kg/hr} \\
\text{Mole Weight} & : \quad 24.77
\end{align*}
\]

- Suction Condition

\[
\begin{align*}
L_s & : \text{Load (kg/hr)} = 43.0 \quad \text{Weight of Load} \\
P_s & : \text{Pressure (mmHg A)} = 143 \quad \text{1st Holding Ejector Disch.}
\end{align*}
\]

- Motive Condition

\[
\begin{align*}
L_m & : \text{Load (kg/hr)} = 195 \quad \text{Motive Suction Consumption} \\
P_m & : \text{Pressure (kg/cm A)} = 15
\end{align*}
\]

- Discharge Condition

\[
\begin{align*}
L_d & : \text{Load (kg/hr)} = 238 \quad = L_s + L_m \\
P_d & : \text{Pressure (mmHg A)} = 800 \quad *
\end{align*}
\]

* The discharge pressure has to design more than atmospheric pressure (760 mmHg A), or less than the suction pressure for next stage.

- Dry Air Equivalent

\[
AE = \frac{L_s}{0.88} = \frac{43.0}{0.88} = 49 \quad \text{kg/hr}
\]
*CALCULATION FOR 2ND HOLDING*

- Expansion Ratio ($E$)
  
  $E = \frac{\text{Motive Pressure (mm Hg A)}}{\text{Suction Pressure (mm Hg A)}} = \frac{11,400}{143} = 79.7$

- Consumption Ratio ($K$)
  
  $K = \frac{\text{Discharge Pressure (mm Hg A)}}{\text{Suction Pressure (mm Hg A)}} = \frac{800}{143} = 5.69$

- Suction Ratio Graph: $\alpha = 0.25$

- Motive Suction Consumption
  
  $= \frac{\text{Suction condition Load (kg/hr)}}{\text{Suction ratio graph (\alpha)}} = \frac{49}{0.25} = 196 \text{ kg/hr}$
* PERFORMANCE TEST
PHOTO

* NUEVA STEAM JET AIR EJECTORS
* RAS-LAFFAN STEAM JET AIR EJECTORS