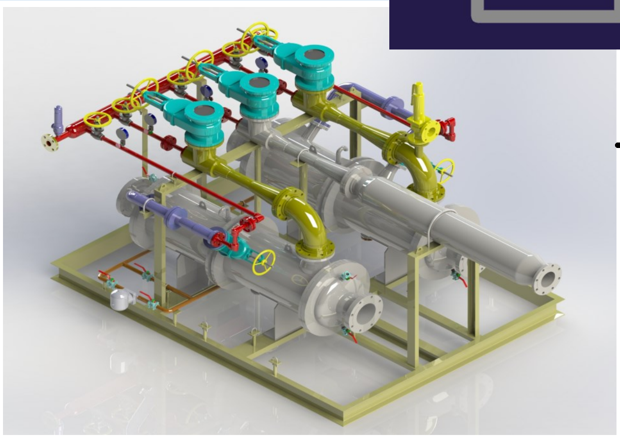
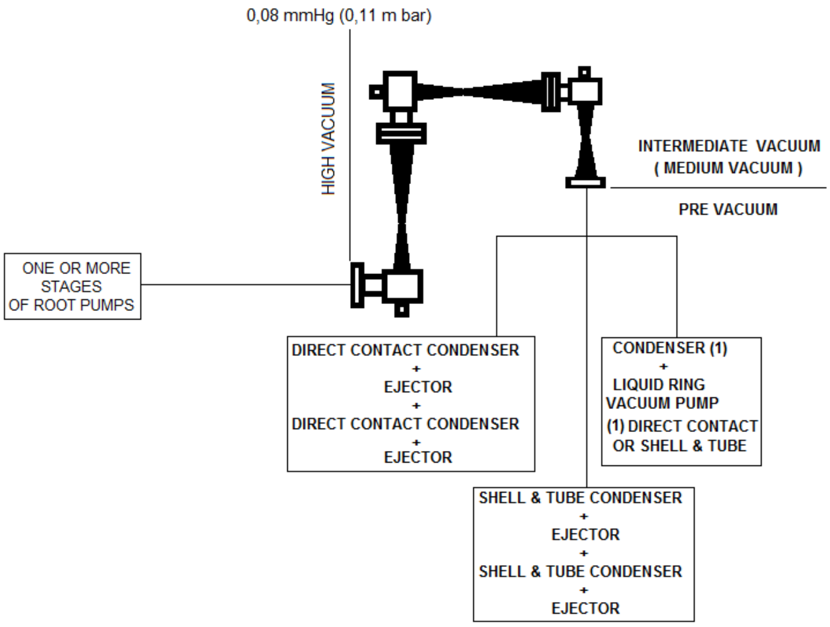


Vacuum Systems

Industrial Vacuum System

Industrial Vacuum system based in multi-stage ejectors, condenser and silencer

Economical analysis between Vacuum system with ejectors and VS with liquid ring pump



VMF STANDARD INDUSTRIAL VACUUM SYSTEM

Standard VMF vacuum systems are based on three booster ejectors with various combinations of pre-vacuum unit.
According available utilities, after the consequent study, are adopted the most economical application, which is different from case to case.
To improve the vacuum, to a high level, the most interesting equipment is the root pumps. The others pumps are not too good in case of industrial application.
With dry root pumps, you can achieve 5 x 10^{-4} mmHg.
This vacuum exceeds the needs of common industrial operations which require greater vacuum. Are exclude in this consideration ultra - high vacuum used in some specific applications: laboratory, Aerospatiale and singular industries, that use diffusion pump as the first stage.
Below common vacuum operations in industrial process with respective vacuum level requirements.

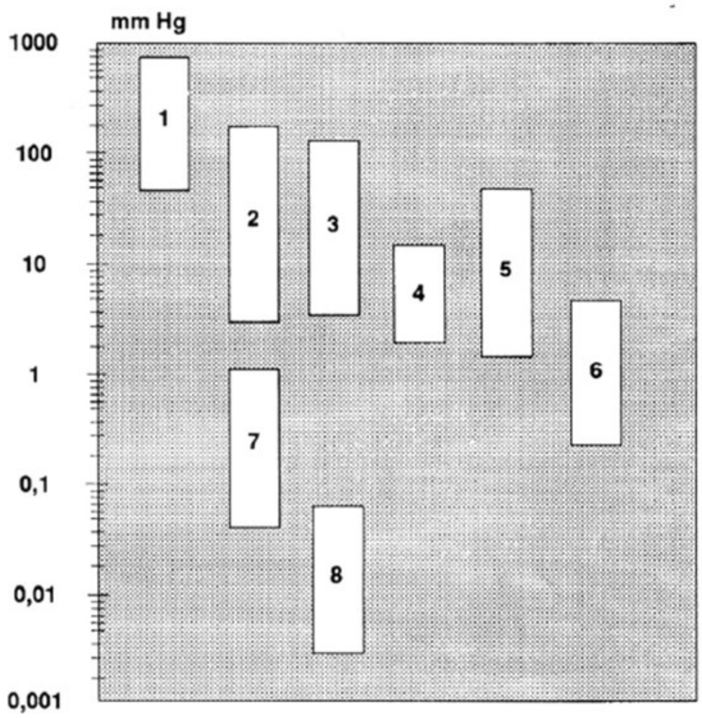
SOME INDUSTRIAL OPERATIONS UNDER VACUUM	VACUUM RANGE
Food Drying - Turbine Condensation Exhaust – Oil Degumming and Bleaching	20 to 50 mmHg (27 to 67 mbar)
Evaporation - Concentration - Crystallization	6 to 40 mmHg (8 to 55 mbar)
Oil Deodorization – Distillation –Mineral Oil Cracking – Colling Water	1 to 6 mmHg (1,3 to 8 mbar)
Lube oil Recuperation - Polymerization – Molecular Distillation	7,5 10^{-5} to 0,75 mmHg (10^{-4} to 10^{0} mbar)

STEAM CONSUMPTION ESTIMATION

To estimate steam consumption, we should define the vacuum unit configuration, based on the most interesting unit assemble to do de vacuum operation with a compensator operational lowest cost.

Through Fig. 1 we can select the appropriate configuration. To do this is necessary to know:

- More ejectors stages may have less steam consumption.
- Ejector compression rate (P(suction) / P(discharge)) must be limited to 10. For greater values the ejector is very inefficient.
- When there are overlay options should be studied cost benefit of a greatest investment versus operational cost, considering that the vacuum unit life is about 15 years. The trend of income is to opt for the higher cost of investment because will return soon.
- Presented curves are result of calculation to a specific operation point. Other points are note optimized. For this, therefore, consider only valid to studies, with good accuracy.



E - Ejector	C - Condenser
1 - E_1	5 - $E_1CE_2CE_3$
2 - E_1CE_2	6 - $E_1E_2CE_3CE_4$
3 - E_1E_2	7 - $E_1E_2E_3CE_4CE_5$
4 - $E_1E_2E_3$	8 - $E_1E_2E_3E_4CE_5CE_6$

Fig. 1 - Succion Pressure Versus Number of Stages.

EQUIVALENT AIR DETERMINATION:
Ejectors curves are based on equivalent air at standard temperature 70°F (21°C) is because the need of change all suction gases in equivalent air (EA). This is possible doing molecular and temperature corrections as follow:

Molecular Correction:	Temperature Correction:
MW = Molecular Weight. F (MW) = F (0,0345 (Mw))1/2 F = 1,00 IF MW= 1 TO 30; F = [1,076 – 0,0026 (MW)] WHEN MW= 31 TO 140	t = Temperature °C F (t) = 1,005 – 0,000432t

FIRST CONDENSER POSITION BETWEEN PRE VACUUM AND BOSTERS:
When it is possible to introduce the first condenser, depending from the cooling water temperature, we must to do. Then if it condensates all condensable gases, it relieves the load on the pre vacuum suction. Only some non condensable (air plus gases in equilibrium) go to the pre vacuum, that results in saving motive steam.

CRITERIUM TO FIT IN FIRST CONDENSER (C1)								
CONDENSER	BAROMETRIC				SHELL & TUBE			
COOLING WATER TEMPERATURE - °C	25	29	32	35	25	29	32	35
VACUUM IN WHICH THE CONDENSER C1 IS POSITIONED – mmHg	43	50	57	65	50	57	65	75
CORRECTION FACTOR (MOTIVE STEAM CONSUMPTION)	0,898	1,000	1,096	1,196	1,000	1,096	1,196	1,348
COOLING WATER DIFFERENCE BETWEEN IN AND OUT	3°C to 6°C (1)				5°C to 7°C (1)			

(1) The choose depends on the unit capacity and how much water available.

EXAMPLE OF APPLICATION: VACUUM UNIT TO OIL DEODORIZATION – BOOSTER COMSUMPTION

PROCESS DATA	EQUIVALENT AIR	STEAM CONSUMPTION	COOLING FLOW RATE
Suction: **- Pressure: 3 mmHg.** **- Temperature: 120°C** **- Flow Rate (kg/h):** **Air: 22,1** **Steam Water: 189** **FFA: 15,8** Cooling Water: **-Temperature in: 29°C** Type of Condenser: **- Barometric.** Boosters Selection: **- Fig.1: two stage.** Motive Steam: **- 7 bar g (Saturated).**	**Air F(Mw) factor:** Mw=29 => F=1 F(Mw) = F (0,0345 (Mw))1/2 F(Mw) =1 **Steam F(Mw) factor:** Mw=18 => F=1 F(Mw) = F (0,0345 (Mw))1/2 F(Mw) =0,788 T=120°C **FFA F(Mw) factor:** Mw > 140 => F(Mw)=1,6 **Mixture F(t) factor:** t=120° F(t) = 1,005 – 0,000432t F(T) = 0,95316 EA= (22,1+189/0,788+15,8/1,6)/0,95316 **EA= 285,18 kg/h**	**From Fig.3:** -Vacuum absolute: 3 mmHg -Discharge: 50 mmHg a. -Read on the curve: 2,9 W / 1 EA **Consumption Steam(W), 10 bar g (saturated):** W= 2,9 x EA W= 2,9 x 285,18 **W= 827,4 kg/h** Correction to Stated Motive Pressure (7 bar g): **From Fig.6: 1,124** $W_{(corrected)}$= 1,124 x 827,4 **$W_{(corrected)}$= 930 kg/h**	**Temperature:** -Inlet/outlet: 29 / 35 Steam Flow to Condensate: W + Steam Suction: 930 + 189 = 1.119 kg/h **Latent Heat at 50 mmHg:** 576 kcal/kg. **Cooling Water Flow:** Water $_{Cooling}$ Dt=6°C. Thermic Load: Q=576 x 1.119 Q=622.544 kcal/h **Mass Flow Rate (M):** M= Q / (cp x Dt) cp $_{(Specif.\ Heat)}$ = 1 kcal / (kg x °C) M=622544/(1x6) =103757 kg/h SG = 1 **Volumetric Flow: 104 m3/h**
IN CASE OF TYPE OF CONDENSER IS: **Shell & Tube**	**EA=285,18**	**Discharging Pr.: 50 mmHg** $W_{(CORRETED)}$ =930 kg/h **Discharging Pr.: 57 mmHg** $W_{(CORRETED)}$ =930 x 1,096 **$W_{(CORRETED)}$= 1019,3 kg/h**	**Latent Heat at 57 mmHg:** 574,6 kcal/kg. **Cooling Water Flow:** Water $_{Cooling}$ Dt=7°C. Thermic Load: Q=574,6 x (1019,3+189) Q=694.250,14 kcal/h **Mass Flow Rate (M):** **M=**694.250,14/7=99.178,6 kg/h. **Volumetric Flow: 99,2 m3/h**

PRE VACUUM MOTIVE STEAM CONSUMPTION:
Normally pre vacuum is performed with two stage ejectors and an inter condenser, which motive steam consumption is taken from the graph of Figure 5.

TABLE 2 – PRE VACUUM PARAMETERS

CONDENSER	BAROMETRIC				SHELL & TUBE			
COOLING WATER TEMPERATURE - °C	25	29	32	35	25	29	32	35
POSITION OF PRE CONDENSER C1–mmHg	43	50	57	65	50	57	65	75
CORRECTION FACTOR FOR STEAM CONSUMPTION	1,031	1,000	0,998	0,964	1,000	0,956	0,925	0,897
COOLING WATER FLOW RATE m3/h by 1 kg EA	0,0623	0,0627	0,0655	0,0683	0,13			
COOLING WATER CRITERIUM FLOW CALCULATION	TERMINAL TEMPERATURE DIFFERENCE: 3°C, NCOND. 25%				DIFFERENCE TEMP. IN TO OUT 5°C, NCOND. 25%			

EXAMPLE OF APPLICATION: VACUUM UNIT TO OIL DEODORIZATION – PRE VACUUM COMSUMPTION

PROCESS DATA	EQUIVALENT AIR	STEAM CONSUMPTION	COOLING FLOW RATE
Pre Vacuum Suction: **- Pressure: 50 mmHg.** **- Temperature: 38 °C** **- Flow Rate (kg/h):** **Air: 22,1** **Steam Water: ?** **FFA: trace.** Cooling Water: **-Temperature in: 29°C** Type of Condenser: **- Barometric.** Ejectors Selection: **- Fig.5: two stage.** Motive Steam: **- 7 bar g (Saturated).**	**Steam in equilibrium with air:** **W steam/ W air = Pv / (Pt – Pv) x Mws/Mwa** **Pv = 36,75 mmHg (32,5** °C) Wsteam/Wair= 36,75/(50-36,75)*18/29 Wsteam/Wair= 1,722 Steam Water = 1,722 x 22,1=38,05 **Air F(Mw) factor:** Mw=29 => F=1 F(Mw) = F (0,0345 (Mw))1/2 F(Mw) =1 **Steam F(Mw) factor:** Mw=18 => F=1 F(Mw) = F (0,0345 (Mw))1/2 F(Mw) =0,788 **FFA F(Mw) factor:** Mw > 140 => F(Mw)=1,6 **Mixture temperature F(t) factor:** t=32,5° F(t) = 1,005 – 0,000432t F(T) = 0,991 EA= (22,1+38,5/0,788)/0,991 **EA= 71,6 kg/h**	**From Fig.5:** -Vacuum absolute: 50mmHg -Discharge: 760 mmHg a. -Read on the curve: 4 W / 1 EA **Consumption Steam(W),** **10 bar g (saturated):** W= 4 x EA W= 4 x 71,6 **W= 286,4 kg/h** Correction to Stated Motive Pressure (7 bar g): **From Fig.6: 1,124** $W_{(corrected)}$= 1,124 x 286,4 **$W_{(corrected)}$= 321,9 kg/h**	**Inlet Temperature:** 29°C **EA Flow Rate:** 71,6 kg/h From table 2: Cooling water flow rate: 0,0627 x 71,6 = **4,49 m3/h** **Outlet Temperature:** - Out temp = Sat. Temp-3 °C. - Out temp = 49,57 °C. Note: Inter condenser position is choose to have constant saturation temperature in table 2 coverage.
IN CASE OF TYPE OF CONDENSER IS: **Shell & Tube**	**EA=71,6 kg/h**	**Suction Pr.: 50 mmHg** $W_{(CORRETED)}$ =321,9 kg/h **Suction Pr.: 57 mmHg** $W_{(CORRETED)}$ =321,9 x 0,956 **$W_{(CORRETED)}$= 307,7 kg/h**	**Inlet Temperature:** 29°C **EA Flow Rate:** 71,6 kg/h From table 2: Cooling water flow rate: 0,13 x 71,6 = **9,31 m3/h** **Outlet Temperature:** - Out temp = In temp.+ °C **Outlet temp. = 34 °C**

WATER RING PUMP PRE VACUUM ALTERNATIVE.
Water ring pump has limited application because vacuum performance is affected by water ring temperature due vapor pressure.
This alternative must be compared with two stages ejector with condenser to analyze coast benefit.
The study need to compare the investment of equipment and operational coasts.

VACUUM PUMP SELECTION			
EA (kg/h)	71,6	Pump Curve break power - kw	18,5
EA (m3/h), 12,64 m3/kg, (12,64 x 71,6)	905 m3/h	Break power – kw (corrected)	48
Water Ring temperature rise (steam condensation)	4°C	Ring water flow - m3/h	4,30
Corrected water Ring Temperature (°C)	29 + 4 =32°C	Water to cooling ring water flow - m3/h	5,40

ECONOMICAL PARAMETERS TO COMPARE TWO OPTIONS ANNUAL OPERATION 8664 h / 5 DAYS YEAR TO DO MAINTNANCE (OPERATION PERIODE 10 YEARS AND ALL COSTS PRORATED FOR 10 YEARS)		
	TWO STAGE EJECTORS WITH S&T CONDENSER	WATER RING VACUUM PUMP
INVESTED CAPITAL PRORATED 10 YEARS	€ 2.685,71	€ 5.000,00
MOTIVE STEAM CONSUMPTION	321,9 kg/h	---------------------
MOTOR DRIVE BREAK POWER	------------------	48 kw
UNIT COST OF ENERGY	€ 0,013 / kg (steam)	€ 0,119 / kwh
ENERGY COST YEAR	0,013 x 321,9 x 8664 = € 35.857,83	0,119 x 48 x 8664 = € 49.488,77
WATER UTILITY COST YEAR (€ 3,25/m3)	3,25 x 9,31x 8664 = € 262.151,00	3,25 x 9,7x 8664= € 273.132,60
ANNUAL MANUTENANCE COAST	€ 142,86	€ 1.514,29
TOTAL	**€ 300.837,40**	**€ 329.135,66**
SAVED VALUE CHOOSING EJECTORS	**ONE YEAR: € 28.298,26**	**TEN YEARS: € 282.982,60**

COMPARATIVE STUDY RESUME:

	STEAM JET EJECTOR	WATER RING PUMP
Size and Need of Stages:	Small charge on equipment cost.	Large charge on equipment cost.
Condensable Loads	Not Affect.	Affect because water ring is heated.
Equipment capital investment:	Smaller.	Larger.
Operational Cost:	Smaller (1).	Larger (1).
Maintenance Cost:	Smaller.	Larger.
High water temperature:	Without vacuum limitation.	There is vacuum limitation.

Notes:

1- Water ring pumps are usually competitive where there are available low water temperatures.
However, operating costs change from region to region. This costs are based in the European average cost.
Costs of steam, electricity and water are determinant to found the best option, where low water temperatures are available.
Always which is possible must be made a cost analysis.

2- The study was made based on Brazil reality, considering a low water temperature usually in south region a little portion of the country. The most common is 32°C and in the hotter regions it may achieve 42°C.

Industrial Energy Costs

EU-28 electricity prices for industrial consumers during the second half of 2015 averaged EUR 0.119 per kWh. The price of electricity for this category of consumers was highest in Italy, the United Kingdom and Germany, while relatively low prices were recorded for Finland and Sweden (which had the lowest price level, EUR 0.059 per kWh); in Serbia and in Bosnia and Herzegovina, industrial electricity prices were almost as low as in Sweden.

Source: eurostats

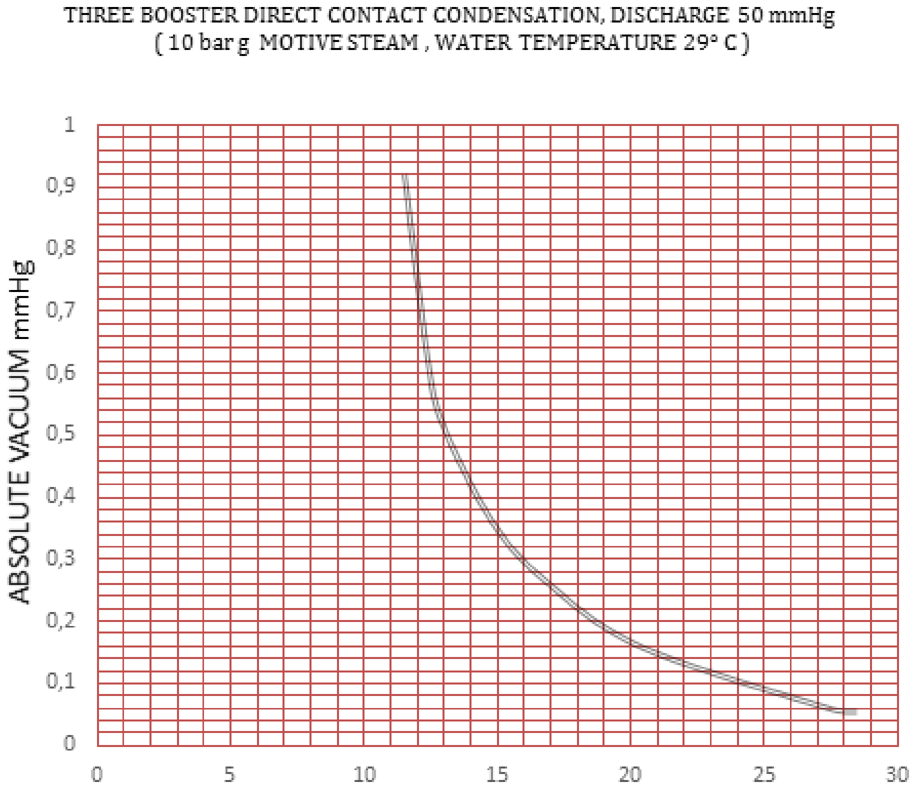


FIG.2 W- MOTIVE STEAM CONSUMPTION kg/h PER ONE kg/h OF EQUIVALENT AIR

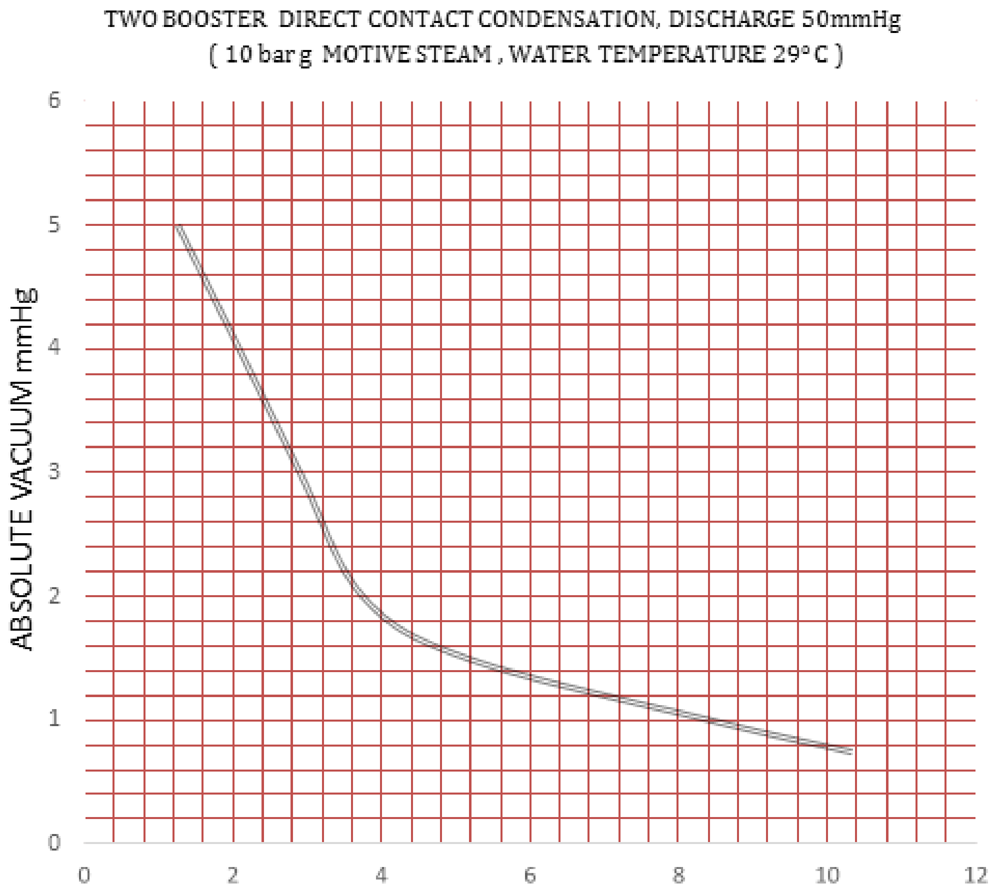


FIG.3 W-MOTIVE STEAM CONSUMPTION kg/h PER ONE kg/h EQUIVALENT AIR

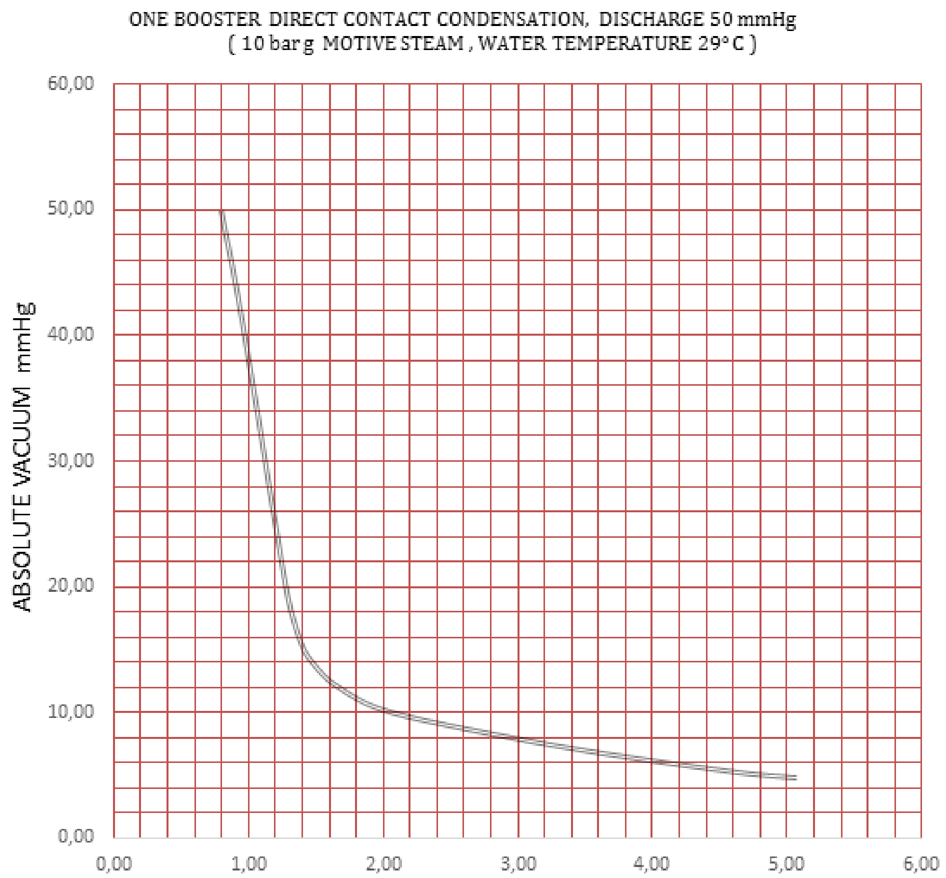


FIG.4 W- MOTIVE STEAM CONSUMPTION kg/h PER ONE kg/h OF EQUIVALENT AIR

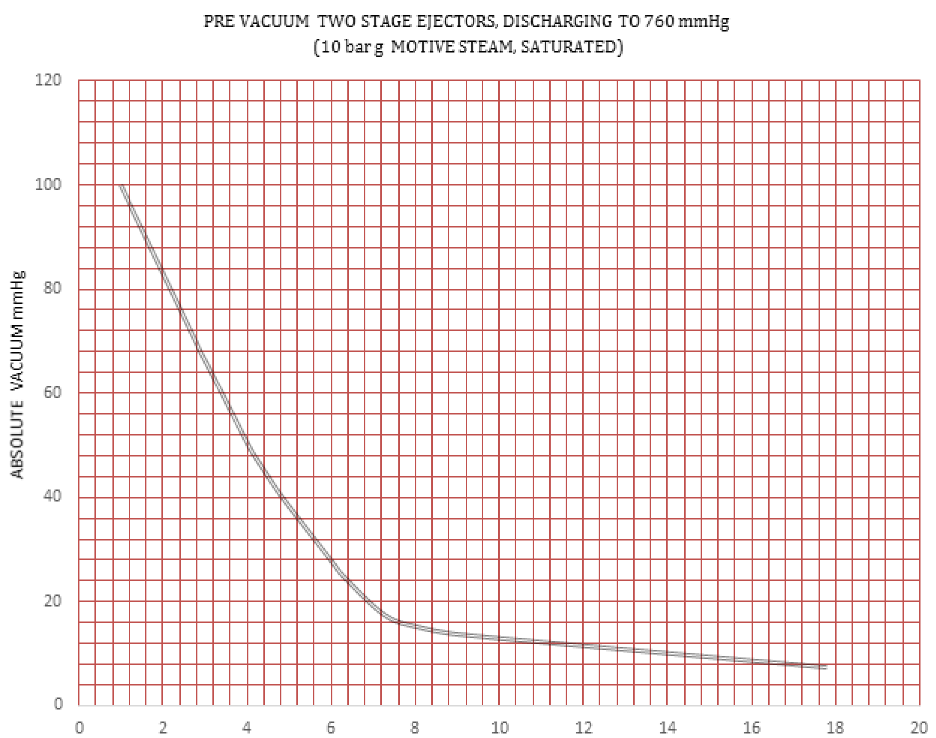
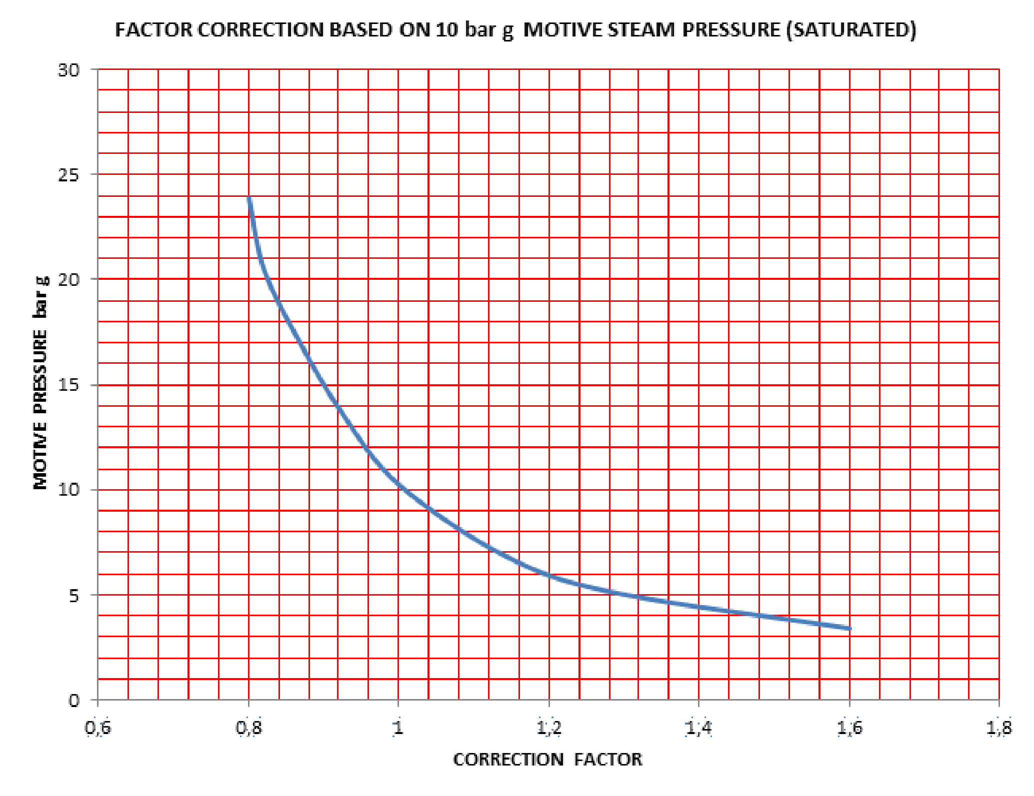


FIG.5 W-MOTIVE STEAM CONSUMPTION kg/h PER ONE kg/ h OF EQUIVALENT AIR

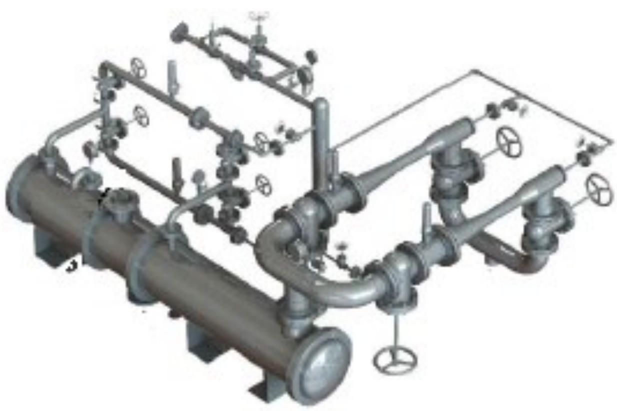


GALLERY OF VMF STEAM JET - CONDENSERS UNITS

FOUR STAGE EJECTORS UNIT – OIL DEODORIZING

TWO UNITS-THREE STAGE BOOSTERS OF A SIX STEPS SYSTEM
POLYESTER FIBRES, BASED ON *PTA – GLYCOL PROCESS*

HYBRID VACUUM SYSTEM TO GENERATE COLD WATER
EJECTOR AND WATER RING PUMP (WITH STAND-BY)



OPERATION STEAM JET VACUUM SYSTEM
STEAM TURBINE CONDENSATION UNDER VACUUM

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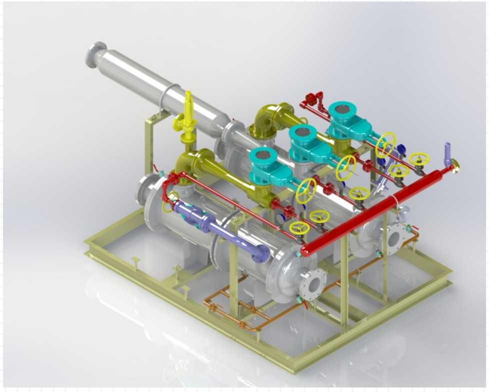

Brazil and Latin America market

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