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PIGGY BACK SEPARATOR DESIGN

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ABSTRACT

A PIGGY BACK separator is a device used in industrial oil and gas applications to separate a vapor-liquid mixture into its constituent phases. The aim of this study is to size the Piggy Back, a separator placed upstream of an electrostatic dehydrator to perform gas-liquid separation. In the course of this study, we sized the Piggy Back using manual calculations in accordance with the guidelines of the main standards and codes in force today, such as API 12J. To validate the manual assessment of the separator's dimensions, a static simulation was carried out using ASPEN HYSYS® software. Using the finally approved manual sizing methodology, and taking into account the Piggy Back separator's operational data, an economic evaluation was carried out to conclude that the design was cost-effective.

Keywords: Piggy Back, API 12J, ASPEN HYSYS®, manual sizing

1. INTRODUCTION

Before we start processing oil, we must first remove gas and free water from the well stream. This operation is essential to reduce the size of the liquids processing equipment. In this work, we will present the PIGGY BACK separator and detail the calculation procedures for sizing using the API 12J standard, and then compare the results obtained after simulation on ASPEN HYSYS software. The fluid produced at the wellhead generally consists of gas, oil, free water and emulsified water (water-oil emulsion), consists of gas, oil, free water and emulsified water (water-oil emulsion). [1],[2]

Piggy Back separators are equipment sometimes placed upstream of the dehydrator which enable the separation of quantities of gas or traces of gas in the liquid phase. It is often necessary to separate the liquid and gas phases at some point in an operation or process. Since both wet gas flow conditions (or more generally gas/liquid conditions) and the required efficiency can vary considerably, a separator must be carefully selected to suit the specific task at hand. [3],[4],[5]

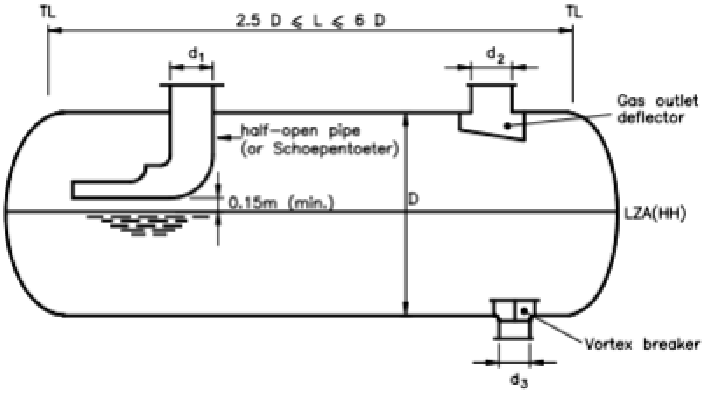


***Fig.1**. Piggy Back separator (Horizontal Knock Out Drum)* [1]

The Piggy Back separator ensures a clean, dry gas at the outlet, and protects sensitive downstream equipment such as pressure reducers, control valves and flowmeters. In the case of steam, it improves heat exchange efficiency. Gas from the production well contains inherent impurities which not only accelerate corrosion of standard separators and control or transmission equipment, but also reduce the calorific value of the gas. These impurities and the treated gas must be removed downstream, before the oil and water are sent to a treatment facility known as a dehydrator. [4],[6]

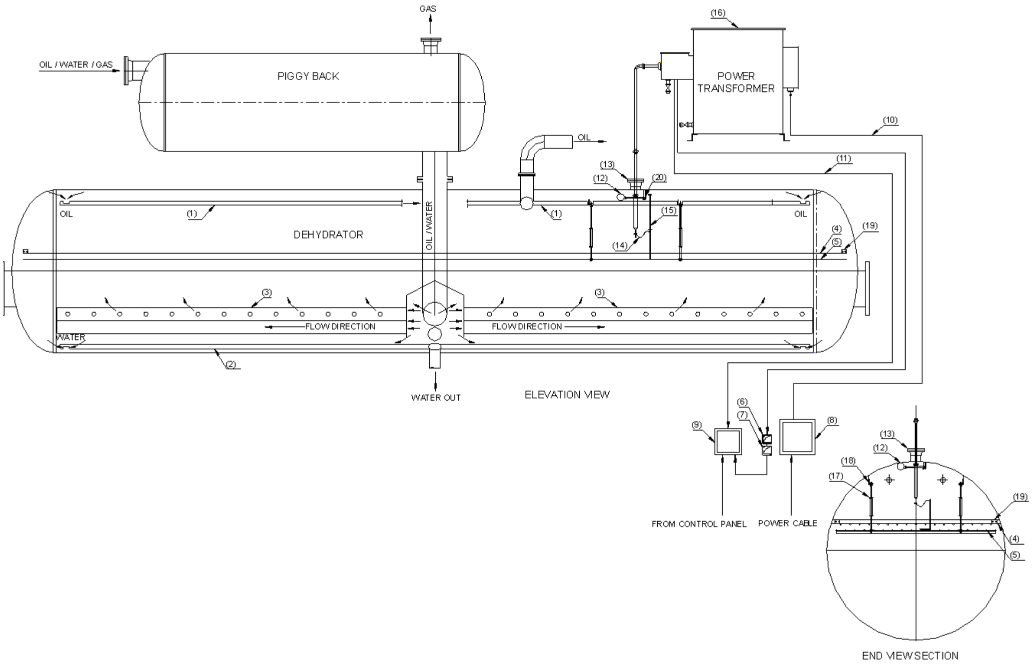


***Fig.2.** Piggy Back separator with electrostatic dehydrator* [10]

2. SIZING OF PIGGY BACK SEPARATOR USING API 12J

2.1. Calculation Method

STEP1: Collect data

Input parameters used for the Piggy Back calculation are summarized in Table 1 below.

***Table 1**. Input parameters of Piggy Back according API 12J*

Input parameters		
Gas flow rate Q_g	*3.8*	*MMSCFD*
Oil flow rate Q_o	*2544*	*BPD*
Operating pressure P	*1014*	*Psig*
Operating temperature T	*60.8*	*°F*
Gas specific gravity SG_g	*0.70*	
Oil density API	*40*	*°API*
Molecular weight MW	*56.3*	*lb/lb mol*
Gas compressibility Z	*0.92*	
Gas viscosity μ_g	*0.014*	*cp*
Retention time API>35 (according to API 12J Appendix C 1.7)	*1*	*Minute*
Typical factor range K (According to API 12J Appendix table C 1.1)	*0.5*	*ft/s*

STEP2: Gas operating density and Oil operating density

Using the API 12J standard (appendix D) standard we can calculate the gas operating density and oil operating density [7]:

$$\rho_g = 2.7 \times SG_g \times \frac{P}{TZ} \tag{1}$$

$$SG_{o=} \frac{141.5}{131.5+API} \tag{2}$$

$$\rho o = 62.4 \times SG_o \tag{3}$$

where:

SG_g : gas specific gravity

T : operating temperature, °R (°R= °F+460)

ρ_g : gas density, lb/ft^3

ρ_o : oil density, lb /ft^3

P : operating pressure, Psia

Z : compressibility factor

STEP3: The maximum allowable superficial velocity of the gas

Using API 12J Appendix C1.1 we can calculate the maximum allowable superficial velocity of the gas [7]:

$$Va = \sqrt{\frac{\rho_l - \rho_g}{\rho_l}} \tag{4}$$

where:

V_a : maximum allowable superficial velocity, ft/s

ρ_g : gas operating density, lb/ft^3

$\rho_{o=}\rho_l$: oil operating density, lb/ft^3

K : typical factor range, ft/s.

STEP4: Calculation of actual gas flow rate and gas area

Using API 12J (Appendix D) we can calculate the actual gas flow rate and the minimum gas area. [7],[8].

$$Q_{g,a} = \frac{Q_g \times MW}{379.5 \times 86400 \times \rho_g} \tag{5}$$

$$A_{gmin} = \frac{Q_{g,a}}{V_a} \tag{6}$$

knowing the minimum gas area we can deduce the minimum ID of separator:

$$D = \sqrt{\frac{4 \times A_{gmin}}{\pi}} \tag{7}$$

where:

1 day=86400sec

molar volume =22.4l=379.5 scf

$Q_{g,a}$: actual gas flow rate, f t^3/s

Q_g : gas flow rate, Scf/day

V_a : maximum allowable superficial velocity, ft/s

ρ_g : gas operating density, lb/ft^3

MW : Molecular weight, lb/lb.mol

A_{gmin} : gas minimum area, ft^3

D : the minimum Internal diameter of separator ft.(1ft=12inch)

STEP5: Calculation of liquid volume (excluding bottom head)

Using API 12J Appendix C 1.6, we can calculate Liquid volume [7]:

$$V = \frac{{}^{\pi D_{Selected}}/_{4} \times L \times NLL}{12^2 \times 5.614} \tag{8}$$

knowing the liquid volume we can deduce the liquid capacity of separator:

$$W = \frac{1440 \times V}{t} \tag{9}$$

where:

V : Liquid volume (excluding bottom head) in bbl,

$D_{selected}$: Next larger and appropriate size, inch

L : length seam to seam ft.

NLL : Normal liquid level

W : Liquid capacity of separator should be more than input value, in BPD (W>Qo).

t : retention time, minute

The slenderness ratio must be between 2.5 and 5 (2.5<L/D<5) (according to API 12J).

by choosing V = Vmin and L = Lmin, the minimum liquid capacity that must be available So we can calculate Vmin, the minimum liquid volume [7] :

$$V_{min} = \frac{W_{min} \times t}{1440} \tag{10}$$

with Wmin=Qo=2544 bpd

Knowing Vmin we can deduce Lmin:

$$L_{min} = \frac{V_{min} \times 144 \times 5.614}{\pi D^2/_4 \times NLL} \tag{11}$$

According to the calculations, there are several minimum lengths that meet the following criteria: W ≥ Qo and 2.5<L/D<5.

To match our results with those of the software, we choose L= 10ft which must be greater than Lmin which meets all the criteria. The table 2 illustrates the choice of L > Lmin

***Table 2**. Incrementing for the calculation of L_{min}*

Incrementing	
Lmin (ft)	**Dselected (in)**
7	36
7.42	35
7.64	34.5
7.86	34
8.35	33
8.61	32.5
8.88	32
9.16	31.5

3. SIZING OF FEED AND OUTLET NOZZLES

Using Shell DEP 31.22.05.11-Gen « Gas/Liquid Separators appendix II for sizing of Feed and Outlet Nozzles. [3]

STEP1: Calculation of mixture density

Referring to Appendix II we can calculate the mixture density.

$$\rho_m = \frac{Mg + Mo}{Qg + Qo} \tag{12}$$

where:

ρ_m : mixture density, kg/m^3

M_g : mass flow rate of gas, kg/s

M_o : mass flow rate of oil, kg/s

Q_g : volumetric gas flow rate, m^3/s

Q_o : volumetric oil flow rate, m^3/s

STEP2: Calculation of mixture velocity

Referring to Appendix II we can calculate the mixture velocity.

$$Vm = \frac{Qg + Qo}{\frac{\pi D^2}{4}} \tag{13}$$

where:

V_m : the velocity of the mixture in the inlet nozzle, m/s,

D : minimum internal diameter of vessel, m,

Q_g : volumetric gas flow rate, m^3/s

Q_o : volumetric oil flow rate, m^3/s

***Table 3**. Type of nozzle according to their criterion*

Criterion	***Type***
For $\rho_m V^2_{m,in} \leq 1400$	*Horizontal pipe*
For $\rho_m V^2_{m,in} \leq 2100$	*Open half hose*
For $\rho_m V^2_{m,in} \leq 8000$	*Schopentoeter*

STEP3: Calculation of feed inlet diameter

Referring to Appendix II we can calculate feed inlet diameter using the following equation:

$$d_1 = \sqrt{\frac{4Q_o}{\pi V_m}} \tag{14}$$

where:

d_1 : feed inlet diameter, m.

V_m : the velocity of the mixture in the inlet nozzle, m/s

STEP4: Calculation of gas velocity

Referring to Appendix II we can calculate the gas velocity using the following equation:

$$V_g = \sqrt{\frac{4500}{\pi \rho_g}} \tag{15}$$

where:

V_g : gas velocity, m/s.

ρ_g : gas density, kg/m^3

STEP5: Calculation of gas outlet diameter (m)

Using Appendix II we can calculate the gas outlet diameter:

$$d_2 = \sqrt{\frac{4Q_g}{\pi V_g}} \tag{16}$$

where:

d_2 : gas outlet diameter, m

V_g : gas velocity, m/s

Q_g : volumetric gas flow rate, m^3/s

STEP6: Calculation of liquid outlet diameter

Using Appendix II we can calculate the liquid outlet diameter.

$$d_3 = \sqrt{\frac{4Q_o}{\pi V_l}} \tag{17}$$

where:

d_3 : liquid outlet diameter, m

V_l : liquid velocity, m/s

Q_o : volumetric oil flow rate, m^3/s.

The diameter of the liquid outlet nozzle, d_3, shall be chosen such that the liquid velocity does not exceed 1 m/s. (According to DEP 31.22.05.11-Gen «Gas/Liquid Separators» appendix II).

4. ASPEN HYSYS® SIMULATION

Aspen HYSYS is the industry leading simulation software for oil and gas, refining, and engineering process. With an extensive array of unit operations, specialized work environments, and a robust solver, modeling in Aspen HYSYS enables the user to: [9]

- Improve equipment design and performance;
- Monitor safety and operational issues in the plant;
- Identify energy savings opportunities;
- Optimize processing capacity and operating conditions;

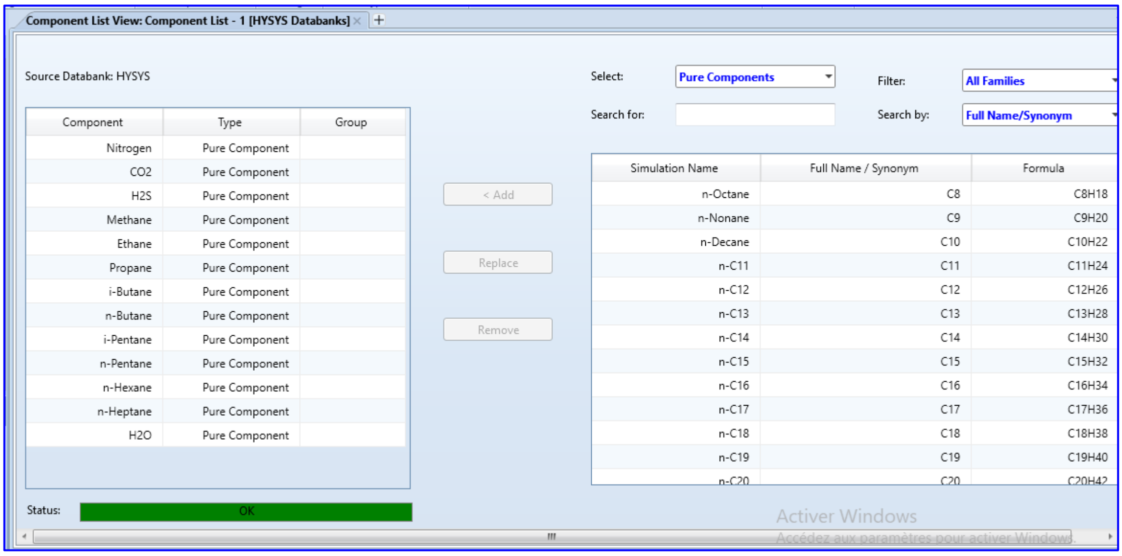
- Perform economic evaluation to realize savings in the process design Aspen Hysys builds upon the legacy modeling environment, adding increased value with integrated products and an improved user experience. [9]

4.1. Procedure for creating an Aspen HYSYS model

1. Start the program, From Start Menu, Select All Programs » Aspen Tech » Process Modeling V9.x » Aspen HYSYS » Aspen HYSYS [9]

2. First, Start a new case

3. Add the Components (fig. 3)



Component List View: Component List - 1 [HYSYS Databanks]

Source Databank: HYSYS

Component	Type	Group
Nitrogen	Pure Component	
CO2	Pure Component	
H2S	Pure Component	
Methane	Pure Component	
Ethane	Pure Component	
Propane	Pure Component	
i-Butane	Pure Component	
n-Butane	Pure Component	
i-Pentane	Pure Component	
n-Pentane	Pure Component	
n-Hexane	Pure Component	
n-Heptane	Pure Component	
H2O	Pure Component	

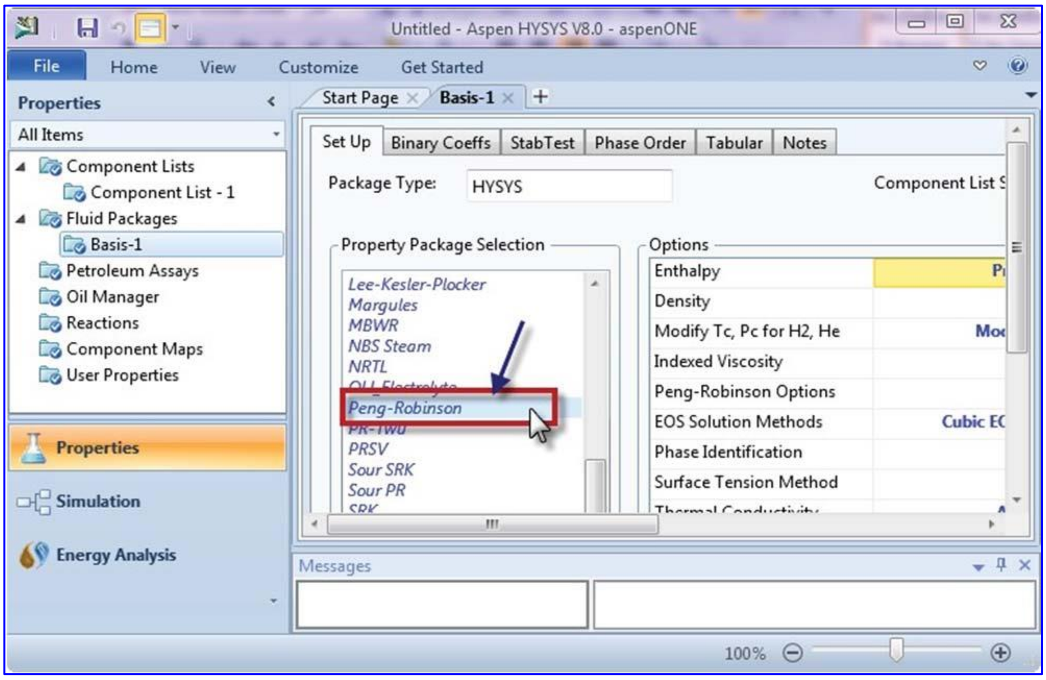
Status: OK

Select: Pure Components
Filter: All Families
Search for:
Search by: Full Name/Synonym

Simulation Name	Full Name / Synonym	Formula
n-Octane	C8	C8H18
n-Nonane	C9	C9H20
n-Decane	C10	C10H22
n-C11	C11	C11H24
n-C12	C12	C12H26
n-C13	C13	C13H28
n-C14	C14	C14H30
n-C15	C15	C15H32
n-C16	C16	C16H34
n-C17	C17	C17H36
n-C18	C18	C18H38
n-C19	C19	C19H40
n-C20	C20	C20H42

***Fig.3**. Adding the Components with Aspen HYSYS.*

4. Select the fluid package; in this case, select Peng-Robinson (fig. 4)



Package Type: HYSYS

***Fig.4**. Select the fluid package in Aspen HYSYS simulation* [9]

5. Drawing the flow sheet (fig. 5, 6 and 7)

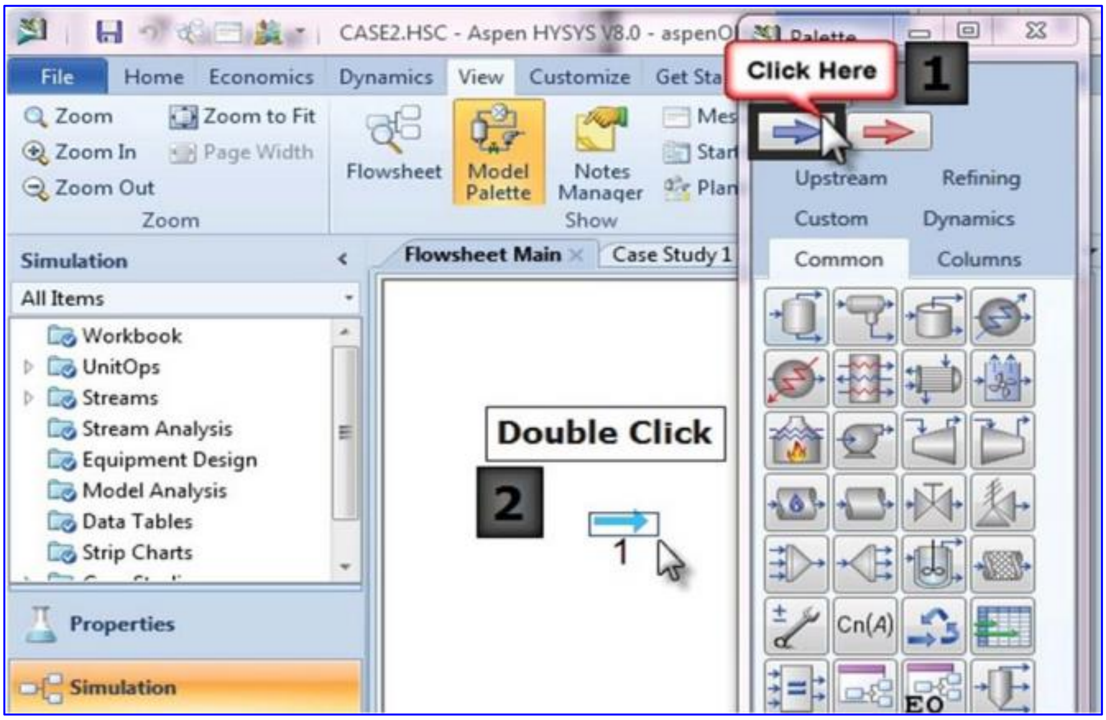
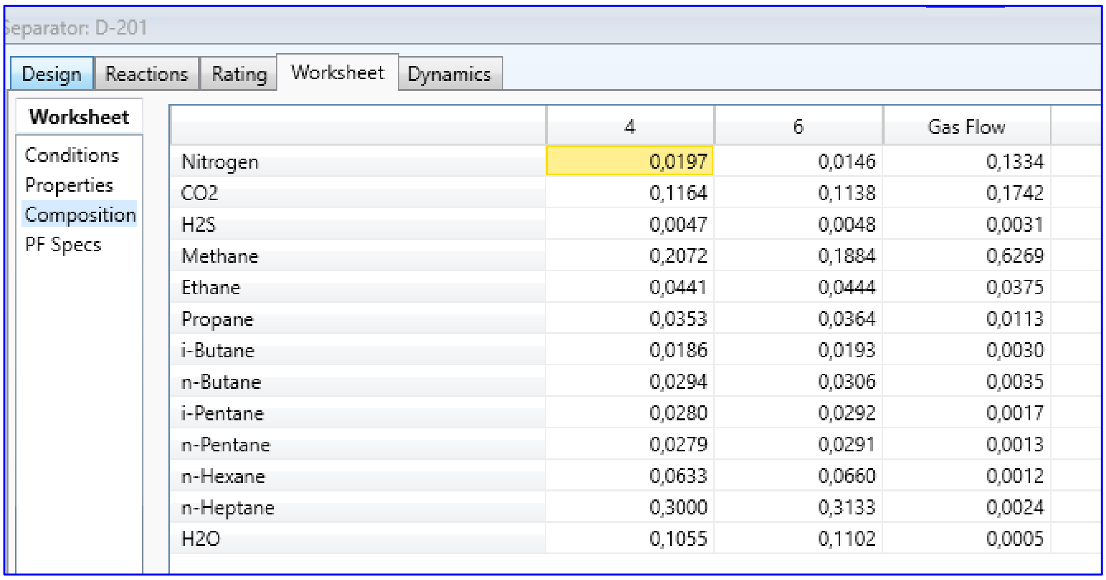


Fig.5. Drawing the flow sheet with Aspen HYSYS simulation.



	4	6	Gas Flow
Nitrogen	0,0197	0,0146	0,1334
CO2	0,1164	0,1138	0,1742
H2S	0,0047	0,0048	0,0031
Methane	0,2072	0,1884	0,6269
Ethane	0,0441	0,0444	0,0375
Propane	0,0353	0,0364	0,0113
i-Butane	0,0186	0,0193	0,0030
n-Butane	0,0294	0,0306	0,0035
i-Pentane	0,0280	0,0292	0,0017
n-Pentane	0,0279	0,0291	0,0013
n-Hexane	0,0633	0,0660	0,0012
n-Heptane	0,3000	0,3133	0,0024
H2O	0,1055	0,1102	0,0005

Fig.6. Composition of crude oil in Aspen HYSYS simulation

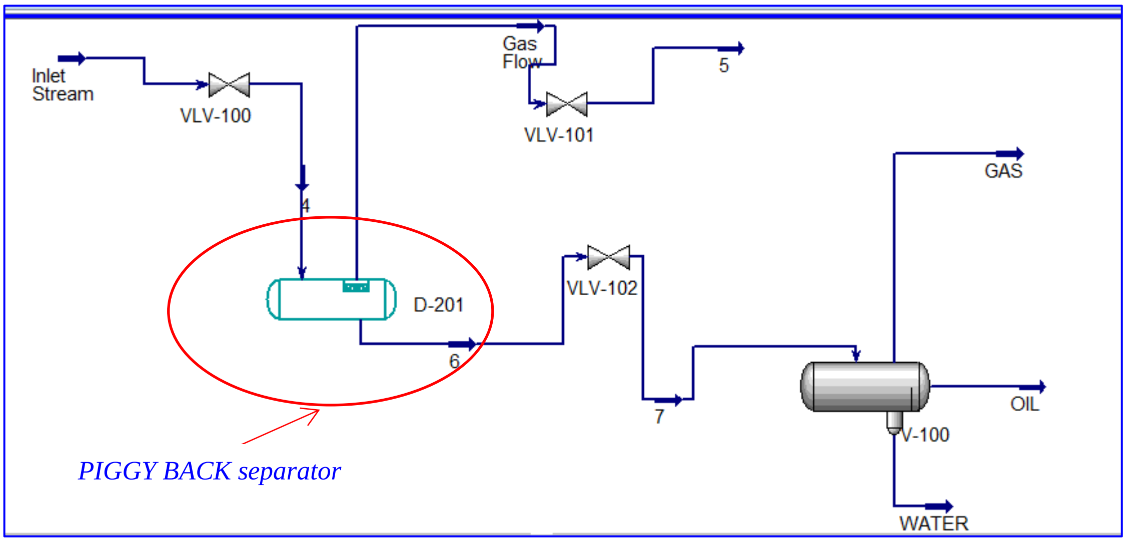


Fig.7. *Process diagram flow using Aspen HYSYS simulation.*

5. RESULTS AND DISCUSSIONS

Results of Piggy Back separator sizing according API 12J are presented in table 4.

Table 4. *Results of Piggy Back separator sizing according API 12J*

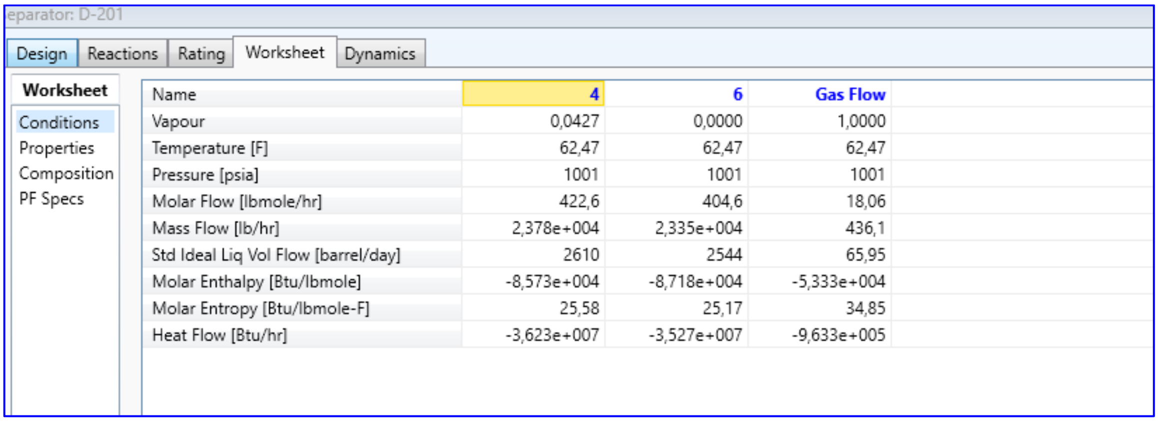
Results		
Gas operating density ρ_g	*4*	*lb/ft3*
Oil operating density ρ_o	*51.5*	*lb/ft3*
Maximum allowable superficial velocity V_a	*1.722*	*ft/sec*
Actual Volume Flow of gas $Q_{g,a}$	*1.63*	*ft3/sec*
Minimum gas flow area $A_{g,min}$	*0.95*	*ft2*
D minimum diameter of separator	*13.16*	*in*
Next larger and appropriate size $D_{selected}$	*34*	*in*
Tangent to tangente L	*10*	*ft*
Liquid volume (excluding bottom head) V	*1.93*	*bbl*
Liquid capacity of separator W	*2786.85*	*BPD*
ratio L/D	*3.3*	*-*

5.1. Sizing of Feed and Outlet Nozzles

Using Shell DEP 31.22.05.11-Gen, Gas/Liquid Separators appendix II for sizing of Feed and Outlet Nozzles.

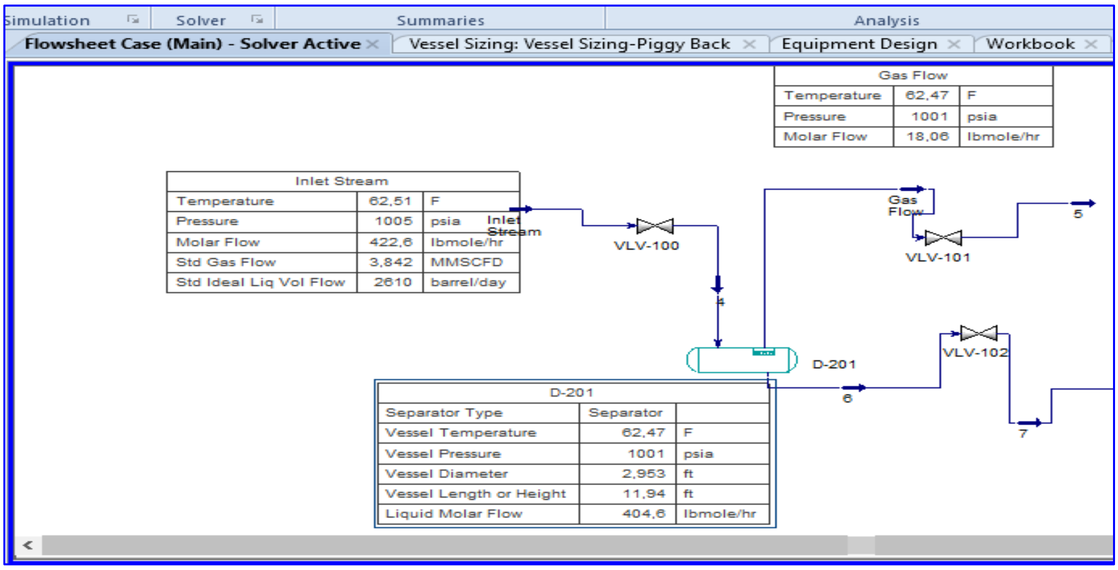
***Table** 5. Results of Nozzles using Shell DEP*

Results		
Mixture density, ρ_m	*5.77*	*kg/m3*
Mixture velocity, V_m	*0.328*	*m/s*
Feed inlet diameter,d_1	*0.13*	*m*
Gas velocity, V_g	*22.70*	*m/s*
Gas outlet diameter, d_2	*0.26*	*m*
liquid outlet diameter, d_3	*0.08*	*m*



Name	4	6	Gas Flow
Vapour	0,0427	0,0000	1,0000
Temperature [F]	62,47	62,47	62,47
Pressure [psia]	1001	1001	1001
Molar Flow [lbmole/hr]	422,6	404,6	18,06
Mass Flow [lb/hr]	2,378e+004	2,335e+004	436,1
Std Ideal Liq Vol Flow [barrel/day]	2610	2544	65,95
Molar Enthalpy [Btu/lbmole]	-8,573e+004	-8,718e+004	-5,333e+004
Molar Entropy [Btu/lbmole-F]	25,58	25,17	34,85
Heat Flow [Btu/hr]	-3,623e+007	-3,527e+007	-9,633e+005

***Fig.8**. Fluids properties using Aspen HYSYS.*

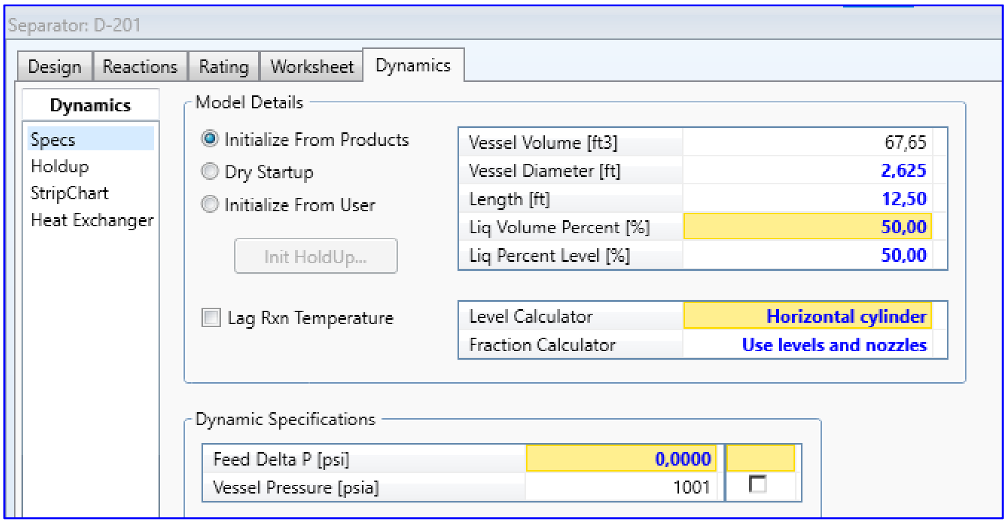


Gas Flow		
Temperature	62,47	F
Pressure	1001	psia
Molar Flow	18,06	lbmole/hr

Inlet Stream		
Temperature	62,51	F
Pressure	1005	psia
Molar Flow	422,6	lbmole/hr
Std Gas Flow	3,842	MMSCFD
Std Ideal Liq Vol Flow	2610	barrel/day

D-201		
Separator Type	Separator	
Vessel Temperature	62,47	F
Vessel Pressure	1001	psia
Vessel Diameter	2,953	ft
Vessel Length or Height	11,94	ft
Liquid Molar Flow	404,6	lbmole/hr

***Fig.9**. Fluids properties with PFD using Aspen HYSYS.*



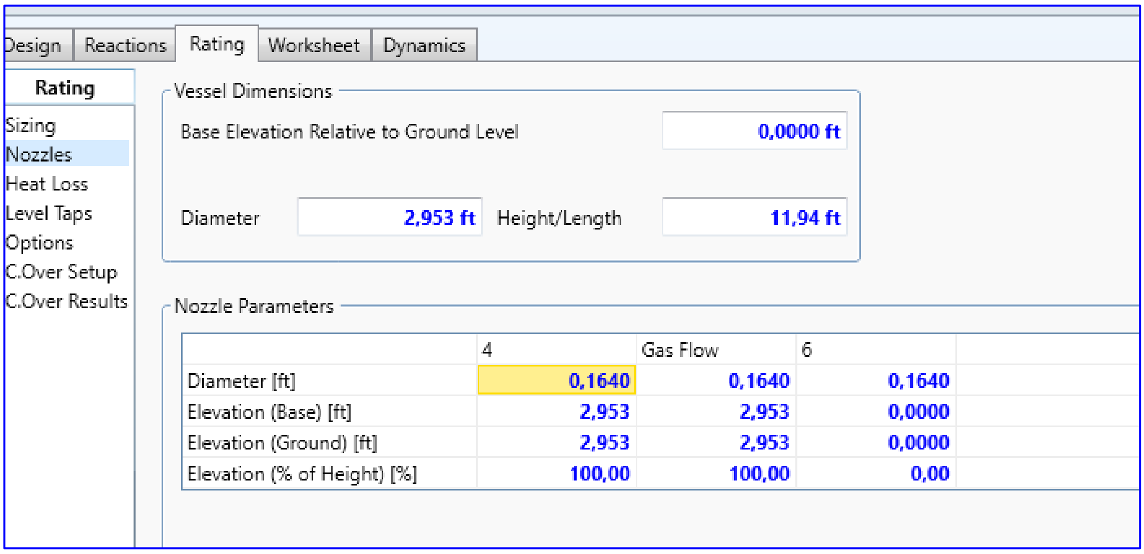
● Initialize From Products
○ Dry Startup
○ Initialize From User
☐ Lag Rxn Temperature

Vessel Volume [ft3]	67,65
Vessel Diameter [ft]	2,625
Length [ft]	12,50
Liq Volume Percent [%]	50,00
Liq Percent Level [%]	50,00

Level Calculator	Horizontal cylinder
Fraction Calculator	Use levels and nozzles

Feed Delta P [psi]	0,0000	
Vessel Pressure [psia]	1001	☐

Fig.10. *Dynamic specifications using Aspen HYSYS.*



Base Elevation Relative to Ground Level 0,0000 ft

Diameter 2,953 ft Height/Length 11,94 ft

	4	Gas Flow	6
Diameter [ft]	0,1640	0,1640	0,1640
Elevation (Base) [ft]	2,953	2,953	0,0000
Elevation (Ground) [ft]	2,953	2,953	0,0000
Elevation (% of Height) [%]	100,00	100,00	0,00

Fig.11. *Output of sizing Piggy Back using ASPEN HYSYS.*

Table 6. *Comparative Result of Piggy Back separator sizing*

	°API 12J	***ASPEN HYSYS®***
L length seam to seam (ft)	*10*	*11.94*
D Minimum of separator (in)	*34*	*35.43*

Comparing the results found in the API 12J standard and those of the software, we can see that the values found with the Aspen HYSYS simulation are higher than those calculated manually using the API 12J standard.

6. ECONOMIC EVALUATION USING ASPEN HYSYS

As part of an economic study for the same flow rate, several diameters were simulated in order to choose the optimum design. As the diameter determines the flow rate and capacity of the separator, we can deduce that the choice of diameter influences the price of the Piggy Back separator.

Table 7*. Economic Assessment Outcomes.*

Length(ft)	*D(in)*	*Price (US$)*
8	36	15020
8.5	**35**	**14730**
9	34.5	14870
10	34	15360
10.5	33	15030
11	32.5	15320
11.5	32	15030
12.5	31	15490

Referring to the result of the table above (Table 7), the cost effective design is:

Length(ft)	*D(in)*	*Price (US$)*
8.5	35	14730

7. CONCLUSION

The paper presents sizing calculations of the Piggy Back separator using API 12J standard. The dimensions obtained are realistic and experimental, with a few corrections to satisfy the slenderness ratio. In addition, we dimensioned the various nozzles of the Piggy Back and evaluated the fluid flow velocities. To validate the manual sizing, we will use the Aspen HYSYS simulation. We presented the procedures and methods for sizing the Piggy Back for gas-liquid treatment. Next, a comparison was made between theoretical results and those obtained with Aspen HYSYS®. Differences in length and diameter were observed, some of them minimal.

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