IBP1044_**05**

FUEL CONSUMPTION IMPACT ON GAS PIPELINE PROJECTS

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Resumo

Um projeto otimizado de gasoduto requer não apenas um bom gerenciamento, planejamento e engenharia, como também boas estimativas de investimento de capital e custos de operação e manutenção. As estações de compressão desempenham um papel importante na viabilidade de um projeto de gasoduto e uma seleção criteriosa dos compressores centrífugos e acionadores é de fundamental importância para o sucesso do projeto. O estado da arte em projeto disponível atualmente para esses equipamentos provê altos valores globais de rendimento termodinâmico e conseqüentemente permite minimizar os requisitos de potência instalada e uso de energia com ganhos expressivos nos custos operacionais ao longo da vida econômica do projeto. Este trabalho apresenta um roteiro para um bom projeto de estação de compressão e seleção adequada de unidades turbocompressoras dando ênfase no impacto do consumo de combustível num projeto de gasoduto.

Abstract

An optimized Gas pipeline design requires not only a qualified management of good engineering and planning, but also accurate estimates of capital investment and O&M. Compressor stations play a very important role on the success of a gas pipeline design and a careful selection of centrifugal compressors and drivers are key aspects for the success of the project. The state of the art design available nowadays for these kind of equipment provides overall high thermodynamic performance and consequently minimizes installed power requirements and energy usage with expressive savings on operating expenses along the economic life of the project. This paper will present a guideline for proper station design and selection of its turbo-compressors giving emphasis on the impact of fuel consumption on the economics of a gas pipeline project.

1. Introduction

The gas business industry in Brazil has faced a significant change and growth due to the following happenings:

1. The Bolivia-Brazil Gas Pipeline Project that started operation in July, 1999;
2. The law Nº 9478, of August 6, 1997 address the Brazilian energy policy, the activities related to petroleum monopoly, establish the Conselho Nacional de Política Energética – CNPE (*National Council of Energy Policy*) and the Agência Nacional do Petróleo – ANP (National Petroleum Agency);
3. ANP is entitled to authorize the practice of exploration and production, refining, processing, transportation, supply, importation and exportation of petroleum products and natural gas and also to establish criteria for transportation rate for pipelines and other related subjects;
4. New Local Distribution Companies;
5. The Plano Prioritário de Termelétricas – PPT (*Priority Plan for Thermo Power Plants*) of the Ministério de Minas e Energia – MME (*Ministry of Mines and Energy*) started in 2002;

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6. Gas reserves discoveries in Bolivia and Brazil
7. Development of the bas business market in different sectors such as automobile, industrial, cogeneration, electricity generation, commercial and residential.

Under this scenario PETROBRAS has started in line with its strategic planning to implement expansion projects for its gas pipeline networks in Brazil. These projects have adopted the state of the art in designing gas pipeline projects. Compressor Station design has been attracting attention since plays a very important role on the feasibility of the gas pipeline projects.

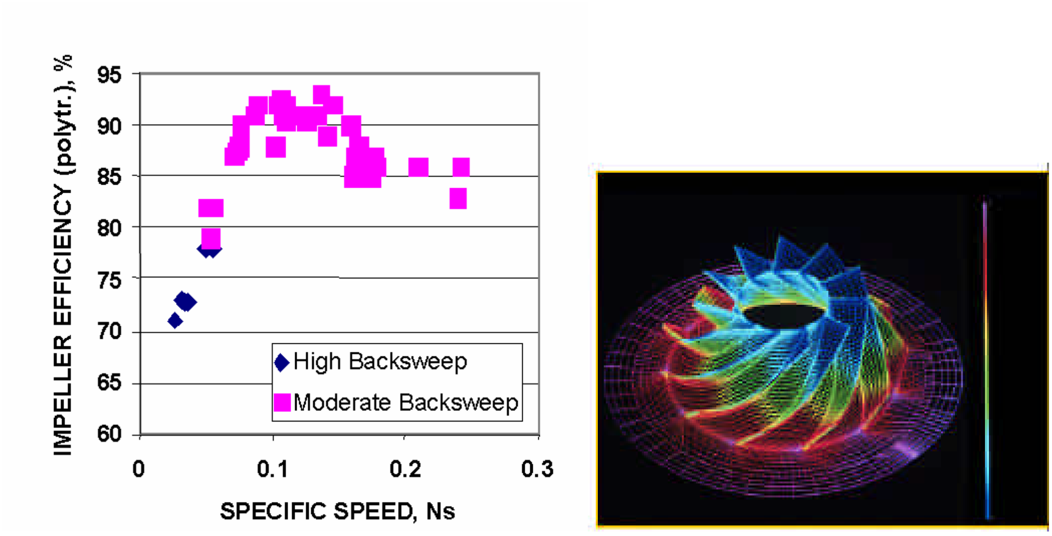

Figure 1: Impeller efficiency is influenced by the specific speed of the impeller. The impeller on the right shows significant backsweep of the blades.

The development on centrifugal compressor and gas turbine design through the last 20 years has been impressive. Pipeline compressors now routinely achieve or exceed 85% isentropic efficiency, while exhibiting wide operating ranges. The study of operating scenarios suggests certain requirements for the compression system. Beyond the quest for higher compressor peak efficiencies, the operating requirements set forth in this study, as well as in other references (Kurz, 2001) require a compressor capable of operating over a wide operating range at high efficiency.

Wide operating range in a centrifugal compressor (figure 1) can be achieved by a combination of means. Aerodynamic theory suggests a strong relationship between operating range, efficiency and impeller backsweep[1]. However, there is a practical limit to the amount of backsweep. In particular, increasing backsweep reduces the capability of an impeller of given tip speed to make head. With the capability to use two impellers in a casing, this perceived disadvantage can be eliminated. The operating range is further increased by the use of vaneless diffusers.

The aerodynamic aspects can be considered with the following:

$$N_s = N \frac{Q^{1/2}}{H^{3/4}} \qquad (1)$$

Equation (1), and the subsequent discussion use N in min-1, H in J/kg, and Q in m3/s.

The question whether a station should be equipped with compressor units in series or in parallel cannot be answered universally. While the series approach can have advantages in case one of the units fails (Ohanian et al., 2001), the decision process has to take into account issues such as further expansion, back-up strategies, operational strategy and aerodynamic performance.

Centrifugal impellers can be described by their specific speed, where a high specific speed depicts a low head, high flow impeller. There is a range of specific speeds where centrifugal impellers tend to exhibit good aerodynamic performance, while both very low and very high specific speeds penalize the performance. Specific speeds between 0.09 and 0.14 tend to yield good efficiency. Mixed flow impellers can extend this range to higher specific speeds.

[1] Backsweep: Impeller blade geometry such, that the blades at the impeller exit, point into a direction against the rotation of the impeller. The flow (in a coordinate system rotating with the impeller) therefore leaves the impeller in a more tangential direction.

It must be noted that the actual running speed (N) is determined by the power turbine speed of the gas turbine, unless a gearbox is used. For aerodynamic and mechanical reasons, power turbine speeds are lower for larger gas turbines than for smaller ones. For example, a typical 15-MW (20,000-hp) class gas turbine may have a power turbine speed of about 8500 rpm, while a typical 3.5-MW (5000-hp) class gas turbine may run at about 16,000 rpm.

For any given pipeline compressor station, two units in series will yield a higher specific speed than two units in parallel. Thus, once the driver size (and thus the power turbine speed) and the desired head and flow through the station are known, one can conceptually decide whether the series or the parallel approach would lead to better aerodynamic performance. With modern compressors and stages with a wide operating range, it is usually possible to have identical stages for both the low pressure and the high pressure compressor in a series application. Intercooling is usually not necessary nor does it typically yield significant savings in power demand.

2. Gas Turbine Requirements

Certain gas turbine operating characteristics need to be considered (The gas turbine used to drive mechanical equipment is usually of the two-shaft design. The power turbine thus allows variable speeds in the range of at least 50-to-100% speed.):

- Gas turbine power and heat rate depend on ambient temperature and pressure.
- Driven equipment speed has an impact on power turbine efficiency. The impact of different speeds can be described by the difference between the operating speed and the optimum power turbine speed. This optimum power turbine speed is a function of engine load and ambient temperature.
- Gas turbine efficiency is reduced at part load (Figure 2).

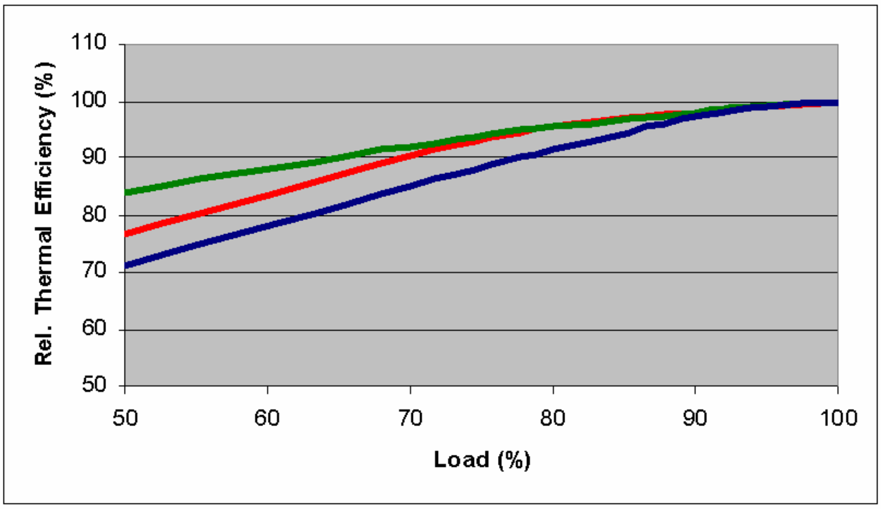

Figure 2: Part load efficiency of three different, typical gas turbines for use in pipeline applications

3. Gas Pipeline Design

As far as we have a clear definition of the pipeline route linking gas reserves or pipeline interconnection to the consumer market the technical and economic evaluation of the gas pipeline project starts.

A long distance gas pipeline transmission system is basically formed by a pipeline, compressor stations, gas custody transfer stations and a supervisory system.

Designers must optimize the project so as to provide the lowest transportation rate taking into consideration capital investment – Capex and operation and maintenance costs – Opex.

The transportation capacity ramp up and the compressor stations installation schedule are taken into account for the project evaluation.

During this design phase we normally try a range of configuration of diameter versus compressor station quantities that provide the same transportation service to select the one that will give the best overall economic result.

4. Compressor Station Design

The design of a compressor station is closely related to the gas volumes to be transported, the gas quality, maximum allowed operation pressure – MAOP, compression ratio, power requirements and the configuration of compressor units whether in series or parallel. A technical and economic approach must also be applied in selecting the best arrangement for the gas pipeline project (Santos, 2004; Kurz et al, 2003), as well as an availability study for all the stations and units including failure analysis to allow the definition of standby units. When planning a compressor station or, for a new pipeline, a number of stations, certain considerations have to be made. These include:

- Steady-state and transient capabilities and requirements of the system
- Growth requirements and capability
- Total cost of ownership and delivered cost to shippers and customers

The first consideration involves the capability to cope with changes in flow capacity on all time scales (i.e., hourly, daily, seasonally). The pipeline hydraulics relate pressure losses to the flow through the pipeline, determine the compressor operating conditions in terms of head and actual flow, and subsequently determine the required power from the driver. Contractual requirements and obligations, such as pressures and volumes at transfer points, have to be considered.

The second consideration deals with the fact that the nominal capacity of a pipeline may grow when additional customers demand a higher supply of natural gas. In fact, many new pipelines start out with 50% and less capacity and grow to full capacity over several years, or are sized for easy expansion. Often, the prediction of the rate of growth shows a significant degree of uncertainty. The growth scenarios, if foreseeable, drive a station layout to allow additional power to be installed at the station or additional stations along the pipeline. The alternative scenario, where the pipeline usage declines over the years (e.g., because the gas supply from the field declines), is also a possibility.

We have to distinguish between growth scenarios that increase pipeline capacity by adding power along the pipeline and scenarios that add power and loop the pipeline. The former scenario will always require an increase in pressure ratio in the station. It is often necessary to replace single-stage compressors with two-stage compressors or install compressors in series to meet the higher pressure ratio. The latter scenario will usually increase the flow though the station and will be covered by installing additional units parallel to the existing ones. For new gas pipeline projects the capacity ramp up will be taken into account to define the best feasible combination of solutions and to avoid future additional investments that would affect negatively the economics of the project. Compressor stations with high compression ratio would not be an economical solution when compared to enlarging the gas pipeline diameter as can be seen from the case study presented onward.

Fuel gas plays an important role in compressor station and gas pipeline design. Fuel gas will have to be transported through the pipeline to serve the stations and therefore will take away transportation capacity that would be used for transporting gas to the market and providing revenue for the project. Fuel gas saved by an optimum compressor station design will also lower operation costs.

Another important aspect is related to the installation of stand by units that normally are required to provide the gas pipeline an appropriate level of availability for the compressor units to guarantee contractual firm transportation capacity to the shippers - the companies that contract transportation capacity.

Depending on the compressor station arrangements, compressor units' size and the installed power percentage of the stand by units per station, the effect of the Capex and Opex for the station may overcome the advantage of having larger compressor units with better thermodynamic performance that require less fuel gas for their operation.

The fuel gas cost is also very important to be taken into account while doing the feasibility analysis for the gas pipeline project.

5. Economic Assumptions

The following assumptions where adopted for the case study evaluation:

- Capital investment requirements for each configuration
- Investment done in two years time – 50% each year.
- O&M cost (overhaul and spare parts included) as 5% of the total station investment
- Transportation rates in US$/MMBTU

- Fuel price at 1.25 US$/MMBTU
- Cost of the pipes at 2,300 US$/ton
- Taxes of 40%
- Return rate of 12% a year un-leveraged.
- Project life of 20 years

6. Case Study

The case study is based on the Bolivia-Brazil Gas Pipeline Project – Gasbol as detailed by Santos (1997). The evaluation of the Gasbol has considered only the main line from Rio Grande –Bolivia to Campinas – Brazil with 1813 km of extension considering all the capacity available delivered at gas pipeline end point in Campinas. Some economic assumptions have been changed to reflect the ongoing costs of Capex and Opex. We considered a stand by unit for all the stations to provide availability to the transportation system due to contractual reasons..

The study evaluated only parallel arrangement for the compressor units.

6.1. Technical Assumptions

Gas Specific Gravity	0.635
Pipeline	
Diameter:	DN 30, 32, 34 and 36”
Design code:	ANSI B31.8
Max. Allowed Working Pres. – MAOP:	1440 PSIG (101.24 kgf/cm2 man.)
Pipe material:	API 5L X70
Pipe internal roughness (epoxy painted):	350 μ inches (0.009 millimeters)
Pipeline Inlet Pressure:	1420 psig (99.84 kgf/cm2 man.)
Minimum Pipeline Delivery Pressure:	900 psig (63.27 kgf/cm2 man.)
Pipeline overall heat transfer:	0.39 Btu/h.ft2.F
Soil temperature:	61 to 86 F (16 to 30 C)
Depth of burial:	3.28 feet (1 meter)
Compressor Station	
Maximum Compression ratio:	1.55
Compressor adiabatic efficiency	85%
Suction and Discharge Header pressure drop:	5 psi (0.35 kgf/cm2)
After cooler pressure drop:	5 psi (0.35 kgf/cm2)
After cooler outside temperature:	126.7 F (52.6 C)
Site elevation	344.5 feet (105 meters)
Site Temperature	86 F (30 C)
Flow Equation:	General equation with Colebrook

6.2. Thermo-Hydraulic simulation Results for the Station Configurations

The simulations results for all the arrangements can be seen on table 1, below.

Nominal Diameter ND	Capacity PPL End Point	Pipeline Length	MAOP	Discharge Pressure (At Flange)	Compression Ratio (Pd/Ps)	Stations Quantity	Total Required Power	Mean Required Power per Station	Fuel required
inches	MMm3/d	km	kgf/cm2	kgf/cm2	-	Qty.	hp	hp	MMm3/d
30	11.95	1813	100	99.84	1.50	2	16,787	8,394	0.1085
	16.79				1.50	5	59,038	11,808	0.3293
	22.27				1.51	10	161,672	16,167	1.0452
	30.00				1.50	20	455,584	22,779	2.5411
32	11.58	1813	100	99.84	1.52	1	8,427	8,427	0.0545
	16.26				1.50	3	33,906	11,302	0.1891
	22.72				1.48	7	113,183	16,169	0.6313
	30.00				1.48	14	296,687	21,192	1.6549
34	13.49	1813	100	99.84	1.50	1	9,490	9,490	0.0592
	18.82				1.48	3	37,962	12,654	0.2366
	23.11				1.50	5	81,376	16,275	0.5880
	30.00				1.46	10	201,042	20,104	1.2532
36	15.65	1813	100	99.84	1.50	1	10,988	10,988	0.0685
	18.95				1.48	2	25,562	12,781	0.1652
	24.56				1.50	4	69,051	17,263	0.4989
	30.00				1.46	7	138,832	19,833	0.8654

Table 1 – Simulations Results for Gas Pipelines with 30 to 36 ND

6.3. Compressor Station Costs

The Capex and Opex adopted for the installed Compressor Station are as table 2 below (Santos, 2004):

Compressor Station		Station	Engineering & Management	Taxes & Transportation	Total	O&M
Units	hp	(US$)	(5%)	(17%)	(US$)	(US$)/year
4	7800	28,800,179	1,440,009	4,896,030	35,136,218	1,756,811
5	7800	33,769,979	1,688,499	5,740,896	41,199,374	2,059,969
2	15000	28,005,517	1,400,276	4,760,938	34,166,731	1,708,337
3	15000	37,399,612	1,869,981	6,357,934	45,627,527	2,281,376

Table 2 – Capex and Opex for Compressor Stations

For the purpose of this paper it was considered the O&M costs as a function of the total Capex required for the compressor stations. Reader must be aware that when a stand by unit is installed the operational cost will not be affected by its installation but only the maintenance cost will change. Fuel gas has been considered just for the running units. This will not impact the conclusion presented in this paper since this effect on the maintenance cost will influence positively to a certain amount the adoption of smaller compressor units that proportionally will have a lower cost for maintenance.

7. Economic Evaluation

The economic evaluation for each pipeline diameter can be summarized on figure 3, 4, 5 and 6 below and allows us to visualize the contribution of the Capex and Opex for the Pipeline, Compressor Stations and Fuel on the transportation ratios.

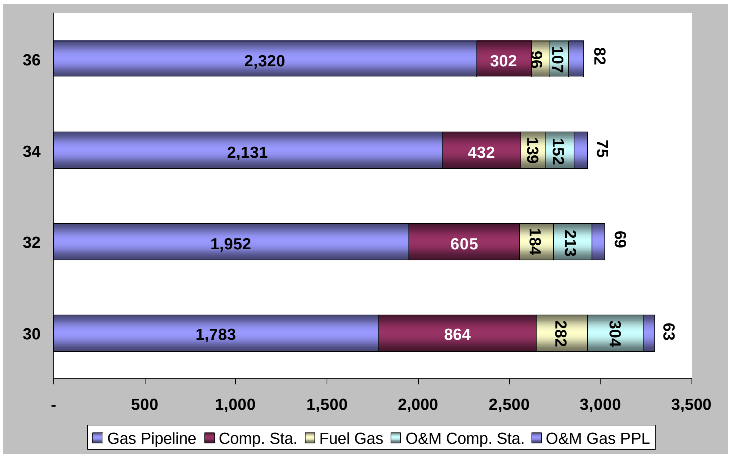

Figure 3 – Cost Structure for All Gas Pipeline Alternatives from Nominal Diameter 30 to 36" for 15000 hp ISO units

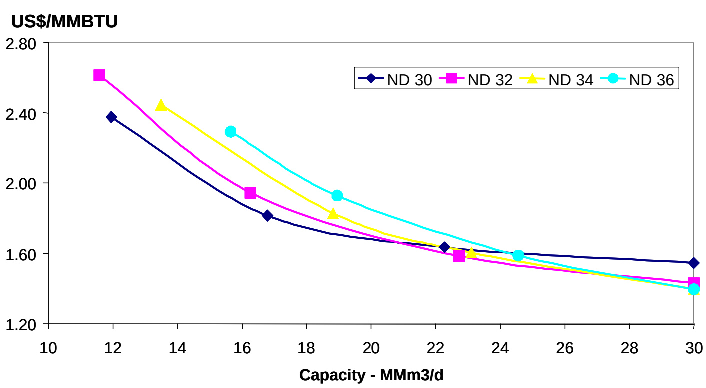

Figure 4 – Gas Pipeline Transportation Rate versus Capacity and Nominal Diameter for 15000 hp ISO units

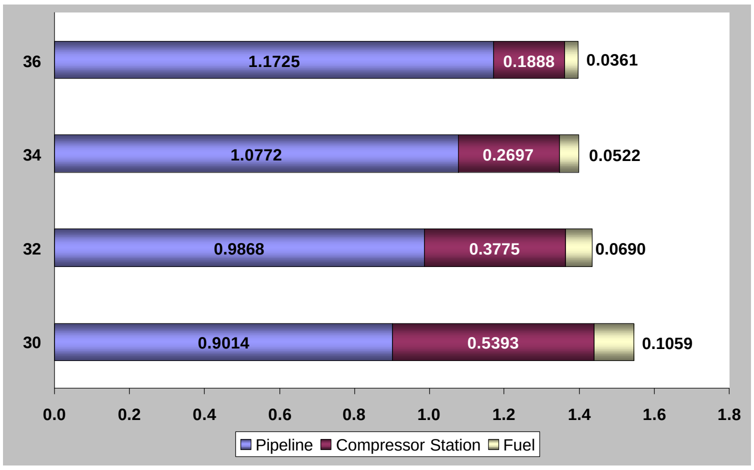

Figure 5 – Transportation Rate Share – Pipeline, Compressor Station and Fuel using 15000 hp ISO per Unit

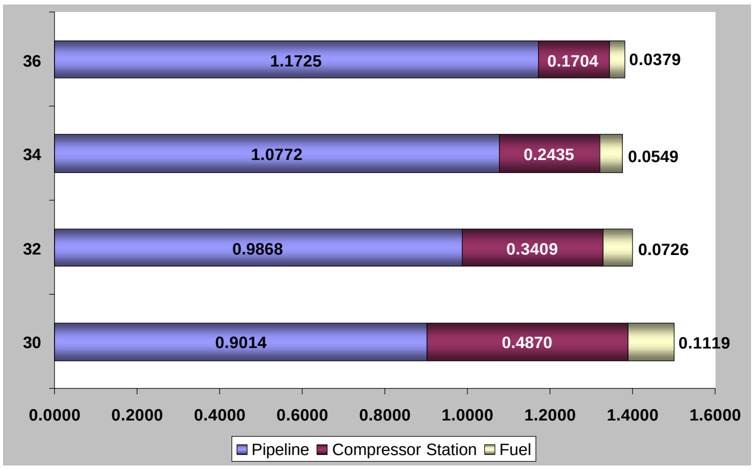

Figure 6 – Transportation Rate Share – Pipeline, Compressor Station and Fuel using 7800 hp ISO per Unit

8. Fuel Consumption Impact

The fuel gas consumption is a function of the gas pipeline diameter, transportation capacity compression ratio, installed compression power and running units. As seen from previous figures 3, 5 and 6 for the capacity of 30 MMm3/d and gas pipeline with diameters of 30, 32, 34 and 36" fuel gas decreases as we select larger diameters that require fewer compressor stations.

Stand by compressor units play also an important role since for larger units the capital cost for those units will be higher and will impact the economic evaluation negatively while, in the other hand, the thermodynamic performance of the larger compressor units will benefit the economic evaluation.

In this case study the overall benefit that produced a lower transportation rate was the alternative of a gas pipeline with ND 34" and 10 compressor stations with 5 units of 7800 hp ISO per station. The table 3 shows the comparison results for the capacity of 30 MMm3/d with compressor units of 7800 against 15000 hp ISO. This result is a reminder that the designer must evaluate some gas pipeline alternatives to come to an optimal selection and size for the project. The fuel gas assumed to be 1.25 US$/MMBTU has impacted the transportation rate from 2.6 to 7.5% and representing a present value from around US$ 95 to 102 millions.

Nominal Diameter ND	Capacity PPL End Point	Pipeline Length	Compression Ratio (Pd/Ps)	Stations Quantity	Total Required Power	Mean Required Power per Station	Unit Size	Available Power per Unit at Site Condition	Compressor Units per Station	Fuel required	Transportation Rate US$/MMBTU
inches	MMm3/d	km	-	Qty.	hp	hp	hp ISO	hp		MMm3/d	
30	30.00	1813	1.51	20	464,501	23,225	7,800	6,405	4+1	2.6857	1.5003
			1.50		455,584	22,779	15,000	12,778	2+1	2.5411	1.5466
32	30.00	1813	1.48	14	301,417	21,530	7,800	6,405	4+1	1.7427	1.4003
			1.48		296,687	21,192	15,000	12,778	2+1	1.6549	1.4333
34	30.00	1813	1.46	10	203,935	20,393	7,800	6,405	4+1	1.3178	***1.3756***
			1.46		201,042	20,104	15,000	12,778	2+1	1.2532	1.3991
36	30.00	1813	1.46	7	140,659	20,094	7,800	6,405	4+1	0.9089	1.3809
			1.46		138,832	19,833	15,000	12,778	2+1	0.8654	***1.3974***

Table 3 – Economic Evaluation Results for All Gas Pipeline Configuration Alternatives

9. Conclusion

As can be seen from tables 3 and figures 1, 2 and 4 the fuel impact on gas pipeline projects as well as the stand by units (depending on the quantity and size of units adopted for the compressor stations) play an important role on gas pipeline projects. The designer must well plan and evaluate all possible scenarios and configuration so as to guarantee that the configuration adopted will present the best economic result and will provide for future expansions that will require lower investments

10. References

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