# An Energy Harvesting Alternative to Wellhead Gas Chokes

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## Abstract

Current practices utilize chokes in the wellhead to induce a pressure drop in high production gas wells to produce at a constant rate. Consequently, in this setup, the potential for this pressure to be made useful is lost. In contrast, the use of a turbo-expander could induce this same necessary pressure drop while simultaneously utilizing it to generate energy. To estimate the potential benefits of this modified system, some assessments were made.

All tests conducted in this investigation utilized the thermodynamic property tables of pure methane to model the performance of produced reservoir gases. The first test conducted attempted to model the amount of mechanical energy lost across a typical choke at varying pressure ratios and flow rates. The second test modelled the theoretical energy that could be harvested across a turbo-expander. Using the relationships deduced between pressure ratio and power generated across a turbo-expander an equation relating the two parameters was derived. This equation was then applied to a case study representing a high producing gas well in the Middle East region to appraise the effectiveness of turbo-expander use on wells of this caliber. Reservoir parameters were estimated based upon parameters typically found in the region and were then used to create a production forecast for one well. The results of this case study indicate that expansion use in gas wells with production rates of roughly 100 MMSCFD/well show an average power generation of 2.2 MW/D/well in a five-year span towards the middle of the plateau production region. Over an entire production plateau and at some different wells, the power generation benefits of turbo-expander use could greatly improve the energy efficiency of gas production wells.

## Keywords
Gas wells, Wellhead choke, Turbo-expander, Power generation, Energy alternative

## Introduction
Energy demands worldwide continue to grow at a staggering rate. In fact, in the past three decades, global energy use has doubled (Chauvin, 2008). The oil and gas industry has a major role to play in response to this growing need. Therefore, it is imperative that the industry achieves this in the most energy-efficient manner possible. It is often overlooked that the oil and gas industry itself is a major consumer of energy. Large amounts of energy are spent in the exploration, extraction, refining, and delivery of oil and gas (Chauvin, 2008). This process, in its current state, is certainly economical with roughly "10 percent of gross oil and gas production" consumed by the industry. However, with the poor current market price of oil, at the moment, any efficiency improvement, at any scale of operations, would be of great value to the industry. Also, the relatively negative stigma surrounding oil and gas operations sparked by a growing climate change concern incentivize the need to become more energy efficient.

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Having said that, one potential area of improvement is the use of a choke in the wellhead to control production rates. A wellhead choke is installed in gas wells to control downstream system pressures. The benefits of using a choke are a controlled production rate and economic surface facility layout due to the lower pressure ratings required. As mentioned, in gas wells, choke valves are used at early stages where high wellhead pressures are expected. As a result, the pressure drop induced across a choke can be very high and, with current configurations, this pressure and a potential source of mechanical energy are simply lost. Figure 1 shows the typical wellhead choke installed in a gas well.

**Figure 1. Gas wellhead choke (http://www.iceweb.com.au/Technical/choke-valve.htm)**

However, if a turbo-expander or expansion unit was used in place or combination with a choke, as illustrated in Figure 2, the required pressure drop can be achieved and made useful by creating mechanical energy.

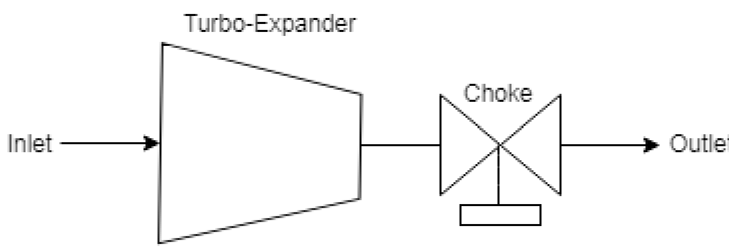


**Figure 2. Series configuration for a turbo-expander and choke combination**

**Thermodynamic Background**: The governing theory behind these processes must be introduced before any analysis on the amount of energy lost across the choke or the potential energy to be harvested through the use of a turbo-expander can be conducted. Both cases can be analyzed through Equation 1, the law of conservation of energy under steady-state conditions.

$$\left(u + \frac{P}{\rho} + \frac{v^2}{2} + gz\right)_1 + q = \left(u + \frac{p}{\rho} + \frac{v^2}{2} + gz\right)_2 + w \tag{1}$$

Eq. 1 describes the flow of a fluid through a control volume from inlet conditions, 1, to outlet conditions, 2, using the following parameters: $u$ is the internal energy of the fluid, $P/\rho$ (pressure over density) is the transport energy, $v^2/2$ is the kinetic energy, $gz$ is the potential energy, $q$ describes the heat transfer, and $w$ accounts for any work done by the fluid. In this form of the law of conservation of energy these parameters are in the units *kJ*/*kg*.

**Analysis of a typical choke**: In the case the fluid flows across a typical choke some simplifications to Eq. 1 can be made. Firstly, since there is no turbine or compressor in the control volume, the work done by the fluid is zero. Furthermore, since the fluid velocity in gas wells is high, heat transfer '$q$' can be neglected. Also, a lack of elevation change and the minimal change in velocity means the potential and kinetic energy terms can be neglected. This reduces Eq. 1 to Eq. 2 below,

$$\left(u+\frac{P}{\rho}\right)_1=\left(u+\frac{p}{\rho}\right)_2 \quad (2)$$

Based on the definition for enthalpy 'h' this can be further reduced to Eq.3:

$$(h)_1=(h)_2 \quad (3)$$

In other words, the enthalpy remains constant throughout the process making the choking process isenthalpic. However, as the transport energy component of enthalpy ($P/\rho$) goes down the internal energy ($u$) goes up. Though energy has been conserved through this control volume, the transfer of energy into internal energy makes it no longer useful. Essentially the energy loss that occurs across a choke can be determined from the difference in transport energy between the inlet and outlet of the choke. An interesting observation to be made is the fact that, across a choke, temperature and pressure drop are observed yet it has been concluded that there is an increase in internal energy across the choke. This phenomena can be explained by the fact that the gas behaves as a real gas and consequently the 'internal energy is a function of both temperature and pressure' (Xiao, 2015). It is worth noting that a decrease in pressure results in an increase in internal energy while a decrease in temperature results in a decrease in internal energy. Across the choke, the pressure drop generated an increase in internal energy that accounted for the drop in internal energy from the pressure drop resulting in a net increase in internal energy. Again, this internal energy increase is a robust fractional representation of the energy to be harvested in this process.

**Turbo-Expanders**: In the case that a turbo-expander is used in place of a choke, a minor change can be made to Eq. 3 to reflect the flow of energy. The main component of a turbo-expander is a flow turbine. The flow turbine utilizes the high-pressure fluid at the inlet to produce work. The process is known as a reverse running centrifugal process where the gas works on the wheel of the turbine as it is expanded (Maddox). As a result, energy is produced while still creating the necessary pressure drop to control the gas production rate. This phenomenon is reflected by the inclusion of the work term in Eq. 3. That is, the change in enthalpy between the inlet and outlet conditions is equal to the work done by the turbo-expander as illustrated in Eq. 4 below. In reality, this exchange in energy is not 100% efficient and therefore an efficiency term, n is inserted ahead of the work term to compensate for this unfortunate circumstance. Because this process is considered to be both reversible and adiabatic, it can be modeled as an isentropic process (constant entropy). The assumption of no heat transfer is a common assumption to make as its impact is small. However, the reversible assumption implies no irreversibilities such as friction. This model the process under the ideal conditions and, therefore, comparisons with actual performance can be used to calculate the efficiency. The efficiency term can be manipulated to give a range of expected energy output as well as reflect the actual performance of the turbo expander.

$$h_1-h_2=n*w \quad (4)$$

One may question the feasibility of implementing a turbo expander in the system. In practice, a variety of turbo expander is available including direct drive, external gearbox, internal gearbox, and multi-stage turbo-expanders. The multi-stage variation seems to be the most promising due to its high pressure and flow rate rating. Another issue with the use of a turbo expander is the enhanced Joule Thomson effect on the fluid through the expansion. The temperature drop observed across a turbo-expander will be slightly greater than that observed across a choke. This phenomenon will have unwanted implications such as hydrate formation or the condensation of heavier hydrocarbon components (Nazir, 2015). As a result, the turbo-expander system would have to include either a post or preheating mechanism to prevent this from happening.

**Types of Turbo-Expanders**: Turbo-expanders are axial flow turbines that are capable of expanding gas to produce work. Though the main expansion component of the design remains the same, the turbo-expanders come in three main forms that satisfy different functions (Garcia-Gutierrez, 2013):

- Expander- Compressor
- Expander-Generator
- Expander-Brake

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These three types vary in the loading device that comes attached to the expander. Compressor systems utilize the driving power to run a compressor and increase the flow rate of another gas line. Similarly, generator systems utilize the drive power to generate electricity. A schematic of both systems can be found in Figure 3. Utilizing a hydraulic brake instead of the compressor or generator essentially wastes the drive power of the turbo-expander but is used in scenarios where the low-temperature outputs of turbo-expanders are desired at lower costs (Garcia-Gutierrez, 2013).

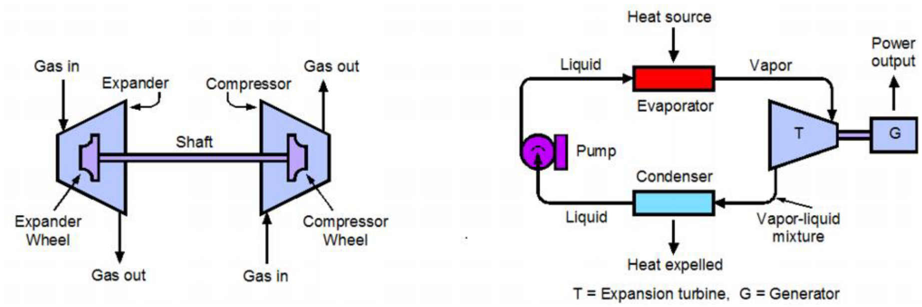


**Figure 3. Schematic for a turbo-expander compressor (left) and turbo-expander generator (right) (Garcia-Gutierrez, 2013)**

## Analysis for the energy can be harvested through choke

**Energy loss across a Choke**: In order to better understand how much energy can be harvested through the use of a turbo expander the amount of energy lost across a typical choke must be quantified. As discussed earlier, across a choke energy is conserved however it is converted from mechanical energy (transport energy) to internal energy. The fact energy is conserved is represented through a constant enthalpy at inlet an outlet conditions as expressed in Eq. 3. The change in the pressure over density term in this equation will aid in quantifying the amount of mechanical energy lost. As an exercise, thermodynamic data for pure methane was extracted from the NIST Web Book of Chemistry. To simulate the effect of a typical choke on a gas, thermodynamic properties were extracted at inlet and outlet conditions summarized in Table 1. The only condition kept constant across the inlet and outlet was enthalpy. Inlet temperatures were fixed at 200 degrees Fahrenheit while the outlet pressure was fixed at 1500 psi. Sensitivity analysis on this data was conducted by examining the effect of pressure drop and flow rate on the energy lost across the choke.

**Table 1. Input parameters utilized in the sensitivity analysis for the energy loss across a choke**

| | |
|---|---|
| **Inlet Temperature (°F)** | 200 |
| **Outlet Pressure (psi)** | 1500 |
| **Outlet Temperature (°F)** | 140 - 180 |
| **Inlet Density (kg/m$^3$)** | 115 - 200 |
| **Outlet Density (kg/m$^3$)** | 40 - 85 |
| **Pressure Ratio** | 2.7 - 3.1 |
| **Flow Rate (kg/s)** | 5 - 40 |
| **Enthalpy (kj/kg)** | 900 - 950 |
| **Gas Composition** | Pure Methane |

The first sensitivity analysis was conducted on the pressure ratio and observing the resulting power generated. The mass flow rate in this scenario was kept at a constant 30 kg/s in order to reflect that of a typical gas well in the region. The inlet conditions for pressure and density were found from isothermic data for pure methane at 150 degrees

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Fahrenheit at varying pressures. The outlet conditions for density and temperature were found from isobaric data for pure methane at 1500 psi. The mechanical energy for the inlet and outlet were both calculated and the difference was used to estimate the energy loss induced. This was done for a pressure ratio range available from the data. The results of this analysis can be found in Table 2 and Figure 4.

**Table 2. Energy loss observed at varying pressure ratios for pure methane flowing at 30 kg/s.**

| Pressure Ratio | Inlet P (psi) | Outlet P (psi) | Outlet T (°F) | Enthalpy (kJ/kg) | Inlet ρ (kg/m3) | Outlet ρ (kg/m3) | ΔMech. Energy (J/kg) | Power (MW/d) |
|---|---|---|---|---|---|---|---|---|
| 3.5 | 5200 | 1500 | 140 | 910 | 180.9 | 65.9 | 41.3 | 1.24 |
| 2.9 | 4400 | 1500 | 146 | 920 | 159.9 | 65.0 | 30.6 | 0.92 |
| 2.6 | 3900 | 1500 | 154 | 930 | 145.0 | 63.7 | 23.1 | 0.69 |
| 2.3 | 3400 | 1500 | 160 | 940 | 128.9 | 62.8 | 17.3 | 0.52 |
| 2.0 | 3000 | 1500 | 166 | 950 | 115.0 | 62.0 | 13.0 | 0.39 |
| 1.8 | 2700 | 1500 | 172 | 960 | 104.1 | 61.1 | 9.7 | 0.29 |
| 1.6 | 2400 | 1500 | 178 | 970 | 92.8 | 60.3 | 6.9 | 0.21 |

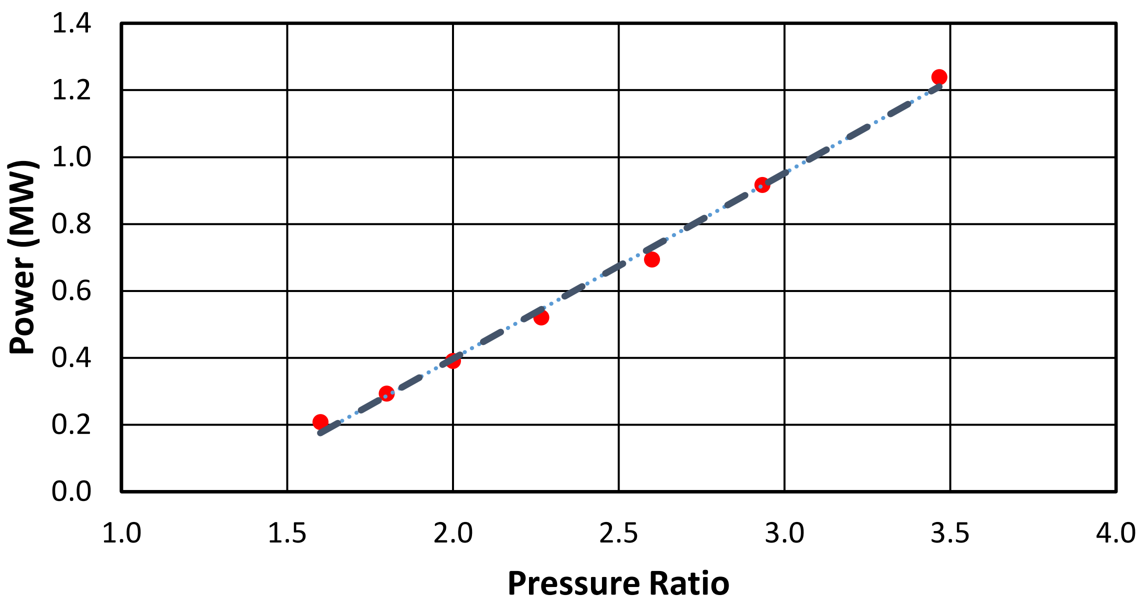


**Figure 4: Energy loss induced across a choke for varying pressure ratios.**

**Table 3. Energy loss observed for pure methane at varying pressure ratios and flowrates**

| Flow Rate (kg/s) | Power (MW/d) | | | | | | |
|---|---|---|---|---|---|---|---|
| | **3.5** | **2.9** | **2.6** | **2.3** | **2.0** | **1.8** | **1.6** |
| 5 | 0.206 | 0.153 | 0.116 | 0.087 | 0.065 | 0.049 | 0.001 |
| 10 | 0.413 | 0.306 | 0.231 | 0.173 | 0.130 | 0.097 | 0.002 |
| 15 | 0.619 | 0.458 | 0.347 | 0.260 | 0.195 | 0.146 | 0.003 |
| 20 | 0.826 | 0.611 | 0.462 | 0.347 | 0.260 | 0.195 | 0.004 |
| 25 | 1.032 | 0.764 | 0.578 | 0.433 | 0.326 | 0.244 | 0.005 |
| 30 | 1.239 | 0.917 | 0.693 | 0.520 | 0.391 | 0.292 | 0.006 |
| 35 | 1.445 | 1.070 | 0.809 | 0.607 | 0.456 | 0.341 | 0.007 |
| 40 | 1.651 | 1.222 | 0.925 | 0.693 | 0.521 | 0.390 | 0.008 |

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In addition to conducting a sensitivity analysis on pressure, the flow rate was also varied to analyze its effect on the energy loss across a choke. This was done for flowrates varying from 5 to 40 kg/s. The results obtained from this analysis can be found in Table 3 and Figure 5.

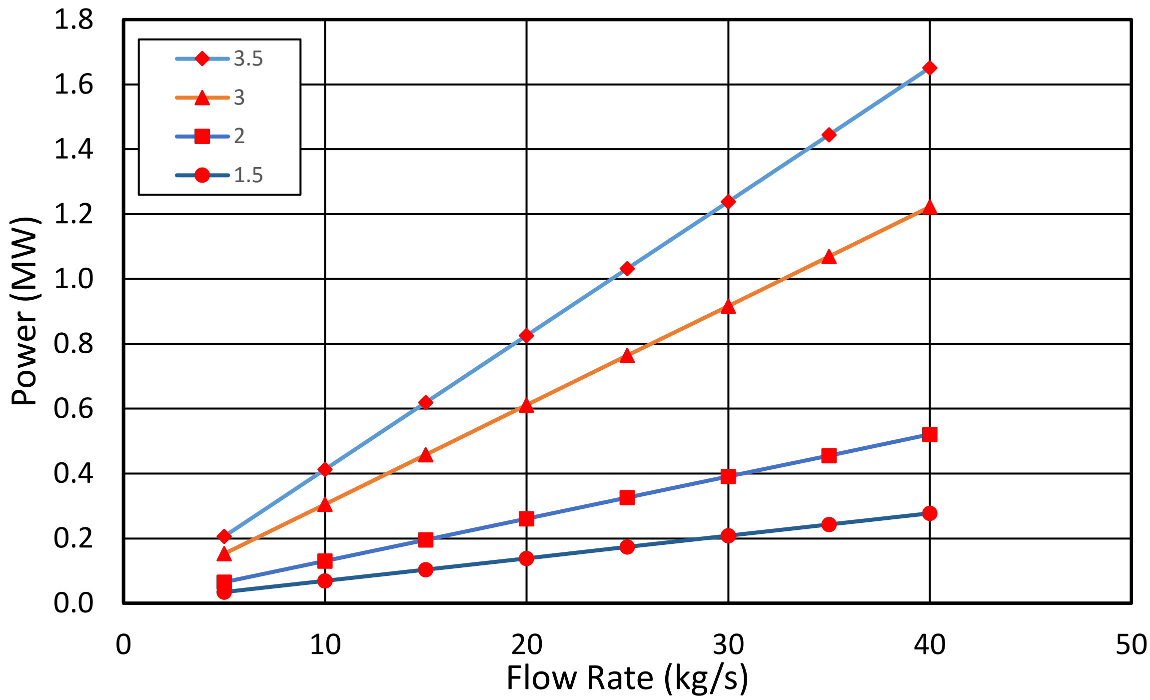


**Figure 5. Energy loss induced across a choke at varying flowrates and pressure ratios**

**Energy Generated through a Turbo-Expander**: Similarly, an energy analysis was conducted to simulate the potential energy that can be harvested through the use of a turbo expander in place of a conventional choke. Typically, the expansion process that is commonly observed in using a turbo expander can be approximated by an isentropic process (constant entropy). A similar experimental setup was used in this analysis as the one used for the choke. However in this case, the governing equation is Eq. 3. Similar to the choke analysis, the inlet and outlet conditions are extracted from isothermal and isobaric data for pure methane respectively. However, in the case for the outlet conditions a wider range of temperatures were used to account for the larger temperature drops observed in the expansion process. From the two sets of data, matching entropies were extracted and used to identify inlet and outlet properties. The main parameter used in the energy analysis was the enthalpy drop as required by Equation 3. An efficiency term of 60% was used to account for turbo-expander efficiency. A summary of the parameters used in this analysis can be found in Table 4. The results of this analysis can be found in Table 5 and Figure 6.

**Table 4. Input parameters utilized in the sensitivity analysis for the energy harvested**

| | |
|---|---|
| **Inlet Temperature (°F)** | 200 |
| **Outlet Pressure (psi)** | 1500 |
| **Outlet Temperature (°F)** | 30 - 180 |
| **Inlet Enthalpy (kg/m$^3$)** | 980 - 900 |
| **Outlet Enthalpy (kg/m$^3$)** | 930 - 720 |
| **Pressure Ratio** | 2.7 - 3.1 |
| **Flow Rate (kg/s)** | 5- 40 |
| **Entropy (J/g*K)** | 4.5 – 3.6 |
| **Gas Composition** | Pure Methane |

**Table 5. Potential energy harvested from the use of a turbo expander for pure methane at a 40 kg/s flowrate and varying pressure ratios**

| Pressure Ratio | Inlet P (psi) | Outlet P (psi) | Outlet T (°F) | Entropy (kJ/kg) | Inlet h (kJ/kg) | Outlet h (kJ/kg) | Δ.h (kJ/kg) | Power (MW/d) | Power Actual (MW/d) |
|---|---|---|---|---|---|---|---|---|---|
| 1.33 | 2000 | 1500 | 154 | 4.41 | 983.2 | 930.8 | 52.4 | 1.57 | 0.94 |
| 1.40 | 2100 | 1500 | 148 | 4.38 | 979.5 | 921.4 | 58.1 | 1.74 | 1.05 |
| 1.47 | 2200 | 1500 | 142 | 4.35 | 975.9 | 911.9 | 64.0 | 1.92 | 1.15 |
| 1.67 | 2500 | 1500 | 124 | 4.26 | 965.7 | 883.3 | 82.4 | 2.47 | 1.48 |
| 1.80 | 2700 | 1500 | 112 | 4.20 | 959.3 | 864.0 | 95.4 | 2.86 | 1.72 |
| 2.07 | 3100 | 1500 | 94 | 4.10 | 945.1 | 844.4 | 100.7 | 3.02 | 1.81 |
| 2.40 | 3600 | 1500 | 74 | 4.00 | 940.1 | 804.4 | 135.7 | 4.07 | 2.44 |
| 2.73 | 4100 | 1500 | 58 | 3.90 | 925.5 | 773.4 | 152.1 | 4.56 | 2.74 |
| 3.67 | 5500 | 1500 | 30 | 3.70 | 907.6 | 722.1 | 185.5 | 5.57 | 3.34 |

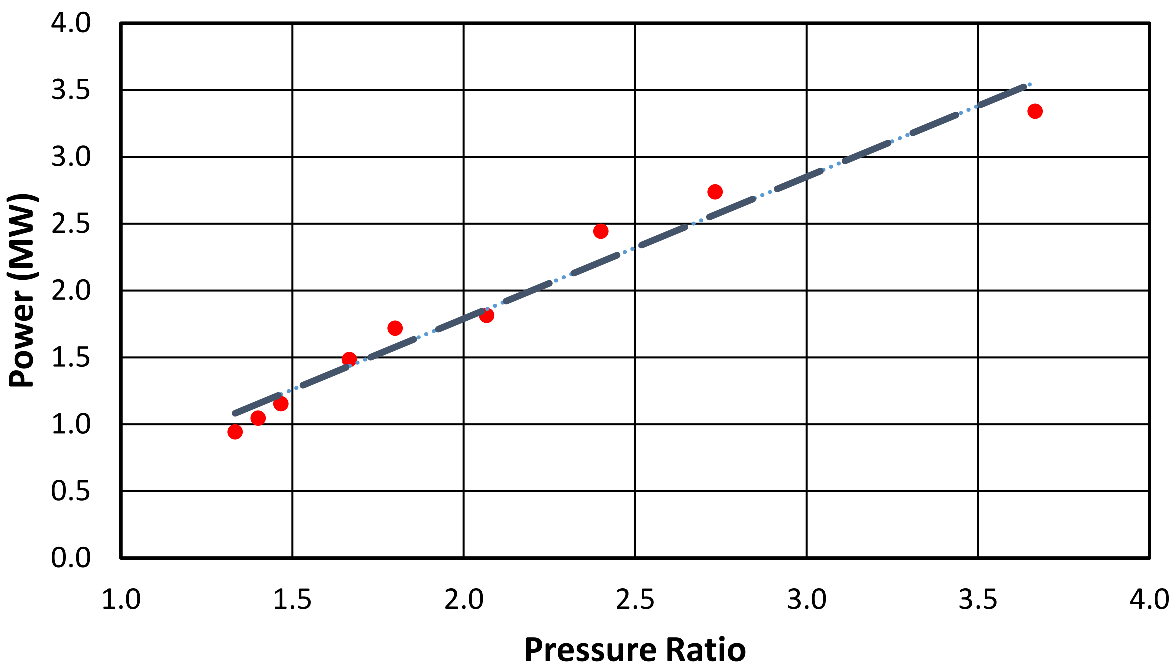


**Figure 6. Energy harvested through the use of a turbo-expander for varying pressure ratios**

In addition to conducting a sensitivity analysis on pressure, the flow rate was also varied to analyze its effect on the energy loss across a choke. This was done for flowrates varying from 5 to 40 kg/s. The results obtained from this analysis can be found in Table 6 and Figure 7.

In analyzing the energy lost across the choke, the process was considered to be isenthalpic. As mentioned enthalpy consists of internal and flow energy. Though the enthalpy remains constant between inlet and outlet conditions, internal energy increases across the control volume as the mechanical (transport energy) decreases. The flow energy decrease and net internal energy increase is characterized by a pressure and temperature drop. By assuming the flow across the choke as isenthalpic, the change in pressure over density terms (transport energy) was used as an estimation of mechanical energy loss. This was done for a variety of inlet pressure scenarios with the outlet pressure kept constant at 1500 psi. A range of thermodynamic data at these conditions was extracted for pure methane. From this, a number of observations were made after tabulating the results in Table 2. Firstly, across all scenarios a temperature drop was observed. The outlet temperatures ranged from 140-180 degrees Fahrenheit. The maximum temperature drop of 60 degrees Fahrenheit was observed at the highest pressure ratio included of 3.47. Consequently, this pressure ratio also resulted in the highest loss in mechanical energy. Furthermore, as pressure ratio decreases so does the loss in

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mechanical energy. This relationship is linear as illustrated by Figure 3, with the data points almost perfectly aligning to the data points.

**Table 6. Energy harvested for pure methane at varying pressure ratios and flowrates**

| Flow Rate (kg/s) | Power(MW/d) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | 3.7 | 2.7 | 2.4 | 2.1 | 1.8 | 1.7 | 1.5 | 1.4 | 1.3 |
| 5 | 0.557 | 0.456 | 0.407 | 0.302 | 0.286 | 0.247 | 0.192 | 0.174 | 0.157 |
| 10 | 1.113 | 0.913 | 0.814 | 0.604 | 0.572 | 0.495 | 0.384 | 0.349 | 0.314 |
| 15 | 1.670 | 1.369 | 1.221 | 0.906 | 0.859 | 0.742 | 0.576 | 0.523 | 0.471 |
| 20 | 2.226 | 1.826 | 1.628 | 1.209 | 1.145 | 0.989 | 0.768 | 0.698 | 0.629 |
| 25 | 2.783 | 2.282 | 2.035 | 1.511 | 1.431 | 1.237 | 0.961 | 0.872 | 0.786 |
| 30 | 3.340 | 2.738 | 2.442 | 1.813 | 1.717 | 1.484 | 1.153 | 1.047 | 0.943 |
| 35 | 3.896 | 3.195 | 2.849 | 2.115 | 2.003 | 1.731 | 1.345 | 1.221 | 1.100 |
| 40 | 4.453 | 3.651 | 3.257 | 2.417 | 2.289 | 1.979 | 1.537 | 1.396 | 1.257 |

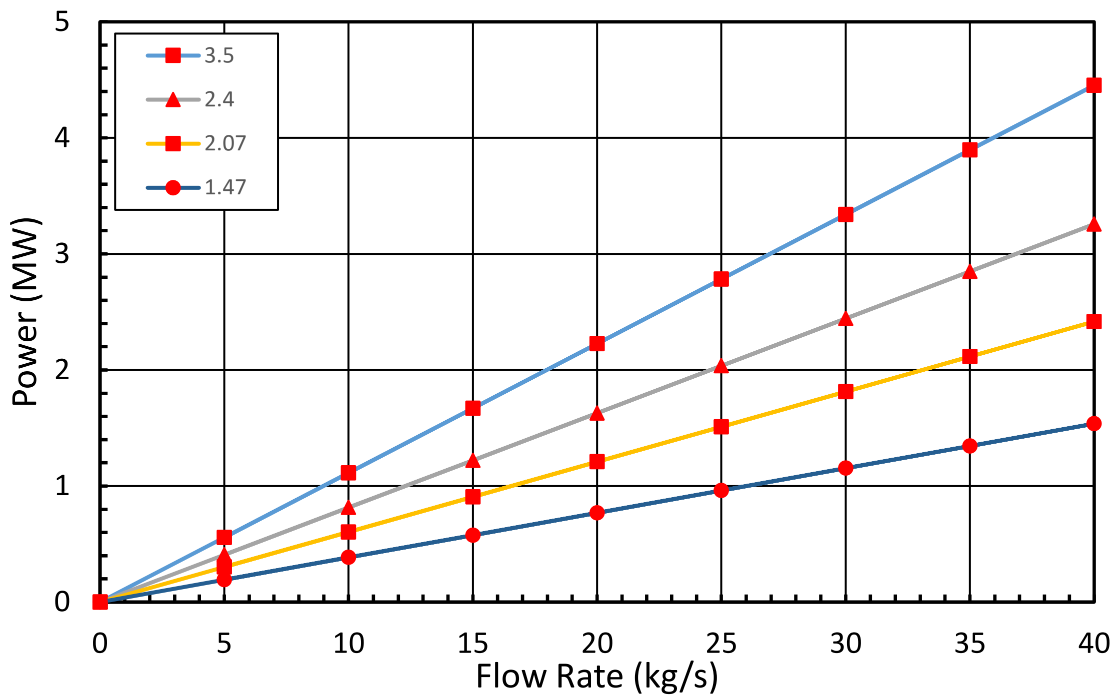


**Figure 7. Energy harvested across a turbo-expander at varying flowrates and pressure ratios**

The flowrate was then varied to see the effect on energy loss at various pressure ratios as plotted in Figure 5. From this plot, it can be seen that increasing the flow rate will also increase the mechanical energy, therefore there is more energy to be harvested at high producing gas wells. A similar analysis was conducted to investigate how this lost energy could be harvested through the use of a turbo-expander. This was process was modeled to be isentropic (constant entropy) and therefore reversible and adiabatic. This model assumes no irreversibility's such as friction and therefore is an ideal case. In order to account for real world scenarios an efficiency of 60% was introduced into the model. Through this model the work produced from the turbo-expander shaft can be estimated from Eq. 4. This equation was utilized through a number of scenarios based again on thermodynamic data for pure methane. Inlet temperature was fixed at 200 degrees Fahrenheit while the outlet pressure was set at 1500 psi. After finding matching entropy conditions at both the inlet and outlet the difference in enthalpy between the inlet and outlet was calculated and used to estimate the power output at 60% efficiency. A number of observations can be made from the tabulated results in Table 5. To begin with, a much larger range of outlet temperatures were observed for the turbo-expander system when compared to the conventional choke system – minimum temperature of 30 and maximum of 180 degrees Fahrenheit. These temperature ranges were observed for a very similar range in pressure ratio as that analyzed in the choke scenario. This confirms the enhanced Joule Thompson effect that occurs in this expansion process. In terms of the relationship between pressure ratio and power generated, as illustrated in Figure 6, a similar linear relationship is observed with power generated increasing with increased pressure ratio. The trend however does not match the trend line perfectly which seems to be the result of the increased number of assumptions introduced in this model.

In comparing the estimations of energy lost and energy generated, the range of values, at 60 % efficiency, for power generated (0.94 – 1.34) are consistently larger than those estimated to be lost (0.21 – 1.24 MW) at similar pressure ratio values. This phenomena can explained through the fact that choke model estimates mechanical energy lost and assumes it to be equal to the change in internal energy. As an isentropic process, the model used to estimate power generated equates generated work to change in enthalpy – the sum of both internal and mechanical energy drops. With the increased temperature drop observed the change in enthalpy and therefore the power generated through expansion is greater than the mechanical energy lost in earlier estimations. The cost to this greater power output is lower outlet temperature conditions which can lead to undesirable consequences such as hydrate formation or condensation of heavier hydrocarbon components inconvenient stages of the production stream.

## Typical High Production Gas Wells

In order to gauge the potential benefit of turbo-expander implementation Eq. 5 was applied to a scenario representing the gas wells in the region. This case study uses reservoir properties describing a typical field in the Middle East region, an ideal candidate for energy generation due to the high production rates expected form the gas wells in this region.

The main goal of the case study was to forecast wellhead pressure values over time. Based on this wellhead pressure and the set choke outlet surface pressure. The pressure rate of the well and therefore the potential energy to be harvested can be found over time. The reservoir performance was modeled through application of simple dry gas material balance. Under the assumption of a closed volumetric reservoir, the production and cumulative production as reservoir pressure is depleted was found.  The well rate was set at 100 MMSCF/D in order to replicate wells found in the region. This plateau rate and production was used to find time past as a function of depleting reservoir pressure. Consequently, the inflow performance was estimated and the bottom hole flowing pressure was calculated. The average TZ correlation was used to estimate the wellbore performance and the wellhead pressure. The fixed surface facility intake pressure was set at 1000 psi - a common value in high pressure scenarios. This led to a plateau time of roughly 29 years and the production forecast illustrated in Figure 8 where Pr, Pwf, and Pwf are reservoir pressure, wellbore flwoing pressure, and wellhead pressure, respectively.. Though turbo-expander application could be applied at any point during the plateau time, for the purpose of this study the power generated was estimated from the 10th to the 15th year. Throughout this five year interval the pressure ratio – wellhead pressure over the constant surface facility intake pressure of 1000. These pressure ratios combined with Eq. 5 were used to find the power generation potential over this five year interval. The maximum, minimum and average power generated in this interval can be found in Table 7.

In examining the pressure ratio depletion of the case study its clear to see that turbo-expander application is a highly viable option. The average power harvested of 2.19 MW can have a number of benefits on the economic performance of similar fields. The case study examined explores a highly ideal scenario where the flow rate is considerably high – around 30 kg/s. Though the portion of the plateau analyzed was in an intermediate pressure ratio, due to the high flow rate, turbo-expander implementation could lead to economic scenarios throughout the majority of the plateau time. This however, may not be the case for lower producing fields. Figures 4 and 6 support this fact by illustrating the low power generation at varying pressure ratios when the production rate is found to be low. Based on the cost of implementation and running costs of the turbo-expander system, there exists a certain flowrate where the system becomes economic therefore the viability of this system will vary depending on the area and corresponding performance. However, as illustrated by the results of this case study, application in this region and areas such as the Middle East are highly promising.

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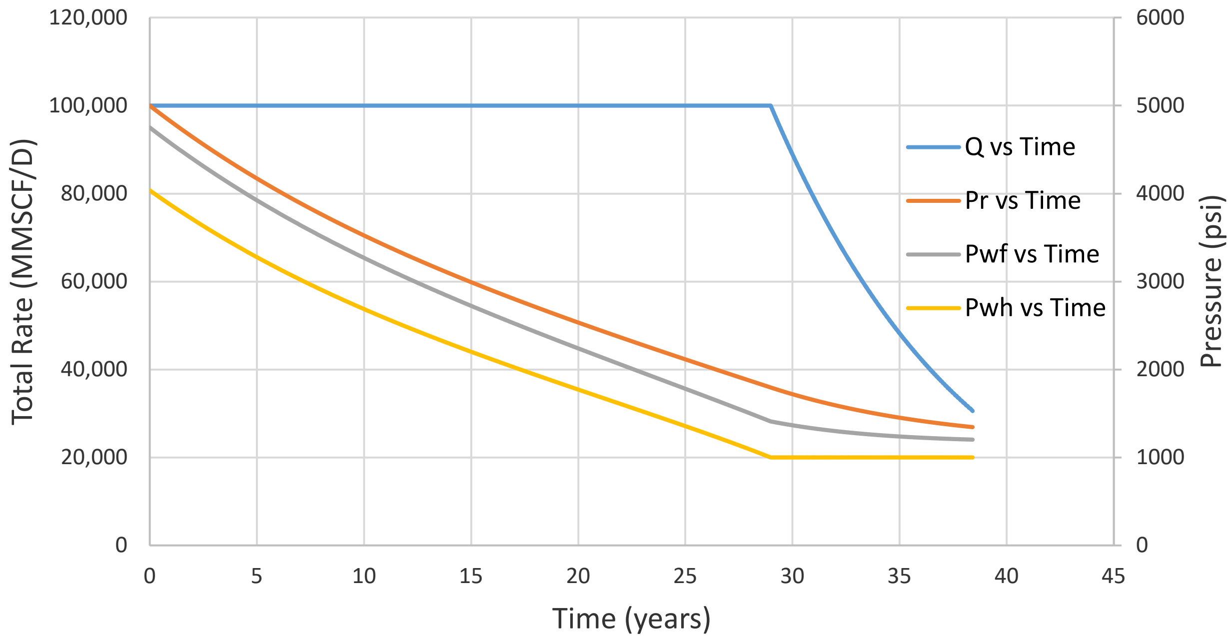


**Figure 8. Production forecast replicating the performance of a typical gas field in the region**

**Table 7. Summary of power generation results in Years 5-10 of the production forecast**

| | Pressure Ratio | Power (MW/D) |
|---|---|---|
| Maximum (at 10 years) | 3.28 | 2.49 |
| Minimum (at 15 years) | 2.49 | 1.89 |
| Average | 2.98 | 2.19 |

## Conclusion

Based on the models tested, the mechanical energy lost across a choke is less than the energy that can be harvested in a turbo-expander. This is a result of the fact that the choke model only accounts for the transport energy lost and does not quantify the energy that is transformed into internal energy. An increase in pressure ratio and flow rate will increase energy loss and consequently the amount of energy that can be harvested through expansion.

Turbo-expander outlets are subject to an increased temperature drop than usual due to the enhance Joule Thompson effect. In the industry this can lead to complications such as hydrate formation and condensate drop out. In order to avoid this the fluid needs to be pre or post heated. In high producing gas wells such as those in the Middle East, in a five year span at a constant plateau rate of roughly 100 MMSCF/D/well the average power generated is 2.19 MW/D/well.

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## Biographies

**Dr. Albertus Retnanto** is Professor of the Practice of Petroleum Engineering at Texas A&M University at Qatar and has been in the Petroleum Engineering program since 2009. He received his Ph.D. degree in Petroleum Engineering (1998) from Texas A&M University. He teaches undergraduate courses in numerical methods, well testing, petroleum production system, production engineering, petroleum technical presentation, natural gas engineering, and integrated asset development and makes significant curriculum enhancements to several courses. He held a Principal position with Schlumberger and has more than 18 years of experience worldwide in both technical and management positions in the area of well testing, field development, and production enhancement. He has received the Performed by Schlumberger Bronze Award four times. He has served as the Review Chairman of SPE Drilling & Completion Journal and chair on several committees on SPE. He received the A Peer Apart SPE Award, which is dedicated to the technical excellence of authors to the industry. He received the AFS College-level Distinguished Achievement Award in Teaching in 2016, SGA Educator Award, SEC Best Faculty Award, and the Faculty of the Year Award in five times, and the Distinguished Teaching Award. He has authored and co-authored over 35 papers. He is a PETE undergraduate advisor, and ABET/SAC coordinator. He serves as an ABET Program Evaluator (PEV) for the Engineering Accreditation Commission representing the Petroleum Engineering.

**Mohamed Idris** is a graduate student at the University of Calgary pursuing a Masters of Engineering degree in Chemical and Petroleum Engineering with a Petroleum Engineering specialization. He received his undergraduate Bachelor of Science degree in Petroleum Engineering from Texas A&M University at Qatar (TAMUQ) in 2018. During his time as an undergraduate student, Mohamed was heavily involved in research through his role as undergraduate research assistant sponsored by the Qatar National Research Fund. Some of his other notable research interests include the use of nanoparticles in EOR and ultrasonication as a means of separating crude oil emulsions – the latter of which earned him 2nd place in the Annual Undergraduate Research Experience Competition hosted by the Qatar National Research Fund in 2018. In addition, Mohamed was an active member of the Society of Petroleum Engineering student chapter at TAMUQ as an undergraduate student serving as the chapter's membership officer in his senior year. Mohamed is also a member of a few academic honor societies including Tau Beta Pi, Pi Epsilon Tau, and Phi Kappa Phi. In his pastime, Mohamed enjoys reading, running, and watching a variety of sports.

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