POWER GENERATION FROM PRESSURE REDUCTION IN THE NATURAL GAS SUPPLY CHAIN IN BANGLADESH

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Abstract: Power can be generated from the pressure energy of natural gas along its supply chain at various pressure reduction points by using turbo-expanders. This technology is being applied in different countries around the world. This paper attempts to asses the potential of using this technology for Bangladesh. A number of producing wells and pressure reduction stations are investigated. It is found that pre-heating before expansion is almost always necessary to avoid hydrate formation. The power obtainable at the wellheads range from 150-500 kW, and that from pressure reduction stations range from 200 kW to 5 MW.

Key Words: Power Generation, Pressure Reduction, Turbo Expander,

INTRODUCTION

Natural gas is produced at high pressures from the wells, but the pressure is deliberately reduced at different points along the supply chain (Figure 1). Usually throttle valves or pressure control valves are used to reduce the pressure, where energy of the gas is spent without doing any work. This lost energy can be recovered as electricity if turbo-expanders coupled with generators are used instead of throttle valves.

Turbo-expanders are usually used in the gas processing plants or in deep-cut straddle plants to recover natural gas liquids (NGL). The idea of using them for power generation is not new; however, such use has been limited. The power recoverable from expansion is small compared to the power that would be gained from a gas fired power plant. The flow rates along the supply chain may vary widely, which makes it difficult to maintain a steady power output. Besides, the well head stream contains a mixture of gas, condensate and water. Therefore turbo-expanders may not work efficiently at the well heads with un-processed gas.

WORLD SCENARIO

Application of turbo-expanders for power generation is gaining more attention due to the recent global trend of extracting energy from every conceivable source, addressing the growing concerns over environment and energy conservation. Turbo-expanders are relatively small and compact, and are usually coupled with a generator in one power pack. The entire assembly is mounted on a skid, which can be relocated if required. The power output mainly depends on the pressure ratio, inlet temperature, and the flow rate. The power usually ranges from hundreds of kW to several MW. For lower end application 30 kW power packs are also available.

There is an emerging market for this type of applications. This technology is implemented in several countries such as the USA, UK, Italy, and Russia. Early installations were made in the 1980's in San Diego (California), Memphis (Tennessee), Stockbridge (Georgia), and Hamilton (New Jersey). In 2008, a combined turbo expander-fuel cell facility was opened to produce 2.2 MW in Toronto, Canada.

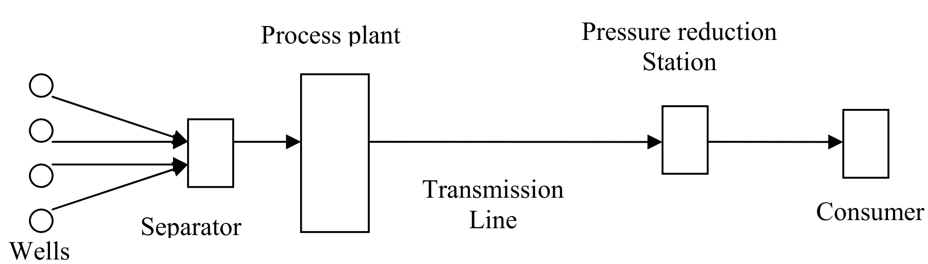

Figure 1. Simplified Schematic of Natural Gas Supply Chain

Another project to install turbo expanders throughout London's natural gas distribution system was initiated in 2009. This project would combine turbo expanders with bio-fuel burning generators to produce 20 MW [1].

LITERATURE REVIEW

Mirandola and Minca [2] presented detailed analysis of power generation from high pressure natural gas. They provided guidelines for designing such plants, considering thermodynamics, number of expansion stages, gas glow rates, and pre-heating requirements. They suggested design conditions for 8 plants in Italy. The number of stages varied from 1-3, while the inlet pressures ranging from 51-11.3 bar, and outlet pressure ranging from 6-1.5 bar. It was shown that the specific production of electrical energy can be 0.028-0.0644 kWh/Nm^3 of gas. With design flow rates ranged from 5,000-30,000 Nm^3/hour, resulting power output varied from 300-1400 kW. In a subsequent paper, Mirandola and Macor [3] presented experimental results and analysis of real data from a prototype plant built in 1987 in Ravenna, Italy. At initial stages the plant showed some operational problems which were rectified later. In two separate periods totaling 84 days, it produced 971 MWh of electricity. The heat input for pre-heating the gas was taken into account. The electrical power thus obtained is a combined effect of the heat input and the pressure energy of the gas. If only the heat is considered as input (as pressure is 'free'), then the output electrical power was 85% of the heat input required for pre-heating. It indicates that even though preheating adds to the expense, most of the heat energy is recovered as electricity.

Poživil [4] reported simulation results for a gas transmission station at Velké Němčice, Czech Republic. It is mentioned that temperature drop in the throttle valve can be about 0.45-0.6^{o}C per bar of pressure drop, whereas with turbo-expanders it can be much higher, around 1.5-2^{o}C per bar, depending on the gas composition. Such cooling can cause detrimental effects like hydrate formation and liquid production. For the simulation study, gas was pre-heated such that the outlet temperature was always 3^{o}C, where inlet pressure varied from 63-45 bar, and the outlet pressures varied from 23-14 bar. The gas composition was fixed, and the flow rate was kept constant at 60,000 Nm^3/hour. The effect of isentropic efficiency of the expander on the power output was also investigated. It is pointed out that the rotational speed of the turbine will be quite high (about 40,000 rpm), which must be reduced by gearbox to about 3,000 rpm to work with the alternator to produce electricity at 50 Hz. The author mentioned that the heat required for preheating would come from the waste heat produced at the generator, gearbox, frequency converter, etc.

Ardali and Heybatian [5] published simulation results for a 120,000 Nm^3/hour-capacity City Gate Station (CGS) in Shahrekord, Iran. Over a 12-month period, the monthly flow rates varied from 40 MMNm^3 to 5 MMNm^3, and the inlet pressures varied from 49-55 bar. The outlet pressure was reduced and kept at 18 bar. The authors assumed constant inlet and outlet temperatures to be 83^o C and 3^{o}C respectively, and estimated the fuel requirement for pre-heating. The power output thus estimated ranged between 1.18-0.15 GWh per month. The amount of gas required for heating is about 0.32% of the total flow. A cost-benefit analysis stated that the payback period for the project would be less than 3 years. The authors further stated that replacing throttle valves with suitable turbo-expanders in the domestic gas sector throughout Iran would be a profitable venture, with potential annual income of more than US$160 million. They also pointed out that application of this technology in conjunction with the thermal power plants would be more profitable, since the exhaust from gas turbines can be used for preheating.

Mansoor and Mansoor [6] presented a study on the prospects of using natural gas pressure in Bangladesh. They mentioned 5 specific locations where this technology could be used, but did not provide any figures regarding the expected power generation. They suggested using chart published by a manufacturer to estimate the power output. Preheating is not considered. They mainly emphasized on the advantages of this technology, and outlined an action plan for adopting this technology for Bangladesh.

BANGLADESH SCENARIO

Pressure reduction along the natural gas supply chain happens at several places:

Wellhead to Separator*:* A survey of 45 wells in 7 producing gas fields in Bangladesh shows that most wells have average wellhead pressures in two ranges of 1500 - 2000 psig (103-138 bar-g) and 2000 – 3000 psig (138-207 bar-g). Just before introducing the gas into the process plants, the gas is expanded using pressure control valves (throttling process) into a separator in order to separate the liquid phase from gas. The separator pressures vary from field to field, but usually range from 1200 psig to 900 psig (83-62 bar-g). Power generation potential from single wells varies from 150 to 500 kW. However, it is not clear whether the commercially available power packs are able to handle unprocessed gas, which is a mixture of gas and liquid.

Process Plant: Some pressure drop occur while passing through the process plant but it depend on the plant type. The glycol dehydration plants create small pressure drop- usually in the range of 20-200 psi (1.4-14 bar). There is not much to be done in terms of efficiency or energy recovery with these plants.

Pipe line: Pressure loss in the pipeline, mainly due to friction, depends on the gas property as well as the pipe configuration such as diameter, surface roughness, flow rate etc. In Bangladesh the average loss is about 1.2-4.6 psi/mile along the GTCL transmission system except the Rashidpur-Hobigonj segment, where the loss is about 6.7 psi/mile. This loss is inevitable, and happens over the entire length of the pipe. Therefore improving flow efficiency by means of friction reduction measures may be beneficial. But it does not offer any power generation potential.

Downstream locations: These include City Gate Stations (CGS), Regulating and Metering Stations (RMS), etc. Pressure is deliberately cut at these places to meet the customer requirement. There are some stations dedicated to a single bulk customer such as a power plant or a fertilizer plant. Others serve a combination of domestic and industrial customer base. The combinations of pressure ratio and flow rate through some of these stations offer attractive opportunities for energy recovery. Potential power generation at single locations varies from 200 kW to 5 MW.

WORKING PRINCIPLE

Figure 2 shows a schematic of a simple arrangement with pre-heating. Figure 3 shows the work on a pressure-enthalpy (p-h) diagram.

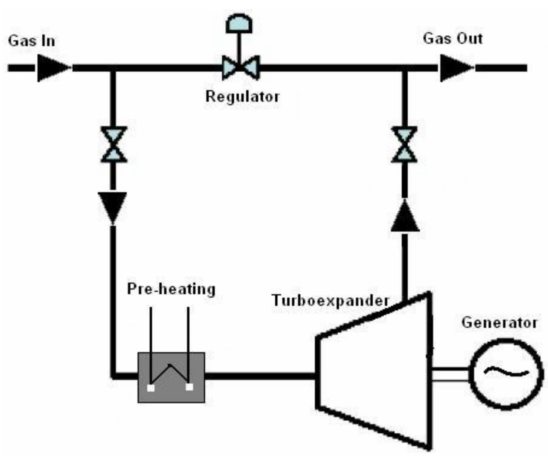

Figure 2. Simplified Schematic with pre-heating

From Figure 3, the inlet condition of gas in A. If it is expanded with throttle valves, the outlet state is B. In that case the work done by gas is 0. If it is expanded isentropically, without pre-heating, the outlet condition is C, and the work done is ($h_A - h_c$). If the gas is heated at constant pressure before expansion, the inlet condition is D, and after isentropic expansion, the outlet condition is E. The work done is ($h_D - h_E$). The work from expansion is given by Eq. 1.

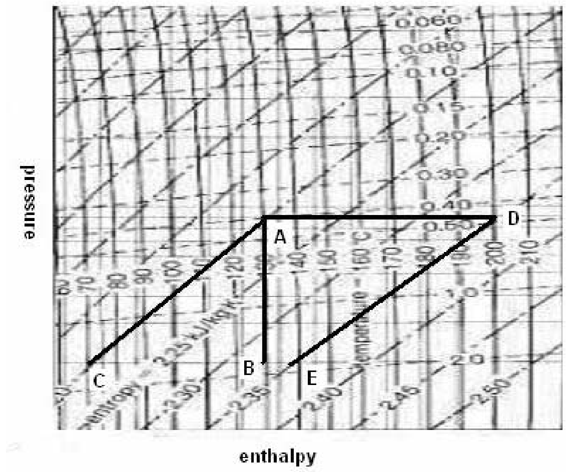

Figure 3. p-h diagram

$$w = C_p T_1 \left[1 - \left(\frac{p_2}{p_1} \right)^{\frac{k-1}{k}} \right] \quad (1)$$

The inlet and outlet temperatures are related by:

$$T_2 = T_1 \left(\frac{p_2}{p_1} \right)^{\frac{k-1}{k}} \quad (2)$$

Where, w is work done by gas per unit mass, C_p is Specific heat of gas, T_1, T_2 are Inlet and outlet temperatures, p_1, p_2 are Inlet and outlet pressures, and k is Isentropic exponent

From the equations, it is clear that the most important factors are the pressure ratio (p_1/p_2) and the exponent k. Eq. 1 is for per unit mass, therefore the work will linearly increase with flow rate. Again, for a given pressure ratio, the work is linearly related to the inlet temperature.

ESTIMATION OF POWER GENERATION

The theoretical output at the generator terminal is calculated by the thermodynamic equations presented in the previous section. No assumptions on isentropic, mechanical or generator efficiencies are made. Rather, 5 samples from 2 different manufacturers [7, 8] are consulted to estimate an "*overall efficiency*". The theoretical output is calculated for these samples from Eq. 1, and compared with the rated output claimed by the manufactures. Table 1 shows that the ratio of the two outputs vary from 0.49 – 0.57. Thus an average of 53% *overall efficiency* is assumed for estimating the expected output from the installations. Data from two gas distribution companies and six gas fields were used for the analysis. Tables 2-4 show the results.

Table 1. Estimation of Overall Efficiency from Manufacturer Data

Manufacturer	Inlet Pr. p1 (bar-a)	Outlet Pr. p2(bar-a)	Pr. Ratio (p1/p2)	Flow Rate (Nm^3/hr)	Theoretical Power from Generator (kW)	Rated Power Output (kW)	% overall efficiency
Atlas Copco	165.48	68.95	2.4	165,250	4,853	2,750	57
	177.55	68.95	2.6	35,411	1,113	550	49
	144.80	68.95	2.1	125,118	3,172	1,775	56
	137.56	68.95	2	28,329	673	350	52
Electratherm	21.01	6.90	3.	1,598	57	30	52
	42.38	7.91	5.4	23,796	1,203	650	54
Inlet Temp = 38°C				**Average Overall Efficiency = 53%**			

Table 2. Power Generation Potential from Downstream Stations, Titas Gas T&D Franchise Area

	Station	Inlet pipe dia D1 (inch)	Avg Inlet Pr p1 (bar-g)	outlet pipe dia D2 (inch)	Avg Outlet Pr,p2 (bar-g)	Pr ratio (p1/p2)	Combined Avg Flow Rate Nm^3/hr	Power from Generator (kW)	Outlet Temp, C
1	Demra CGS (Titas)	20	45.51	12	20.00	2.21	79	1,333	-25.43
2	Demra CGS (Titas)	14	45.51	14	20.00	2.21	-	-	-17.78
		16	45.51	14	20.00	2.21	62	1,046	-25.43
3	Demra CGS (GTCL)	20	45.51	12	18.27	2.41	140	2,585	-31.42
4	Demra CGS (GTCL)	20	45.51	12	10.00	4.22	203	5,688	-67.22
5	Tarabo TBS	14	48.27	12	10.34	4.34	-	-	-17.78
		14	48.27	8	10.34	4.34	67	1,905	-68.79
6	HPL 360 MW RMS	20	17.24	16	11.72	1.43	54	438	7.38
7	MPL 450 MW RMS	20	22.06	16	12.07	1.76	76	945	-8.81
8	Monohordi TBS	14	58.61	4	3.45	13.36	34	1,477	-125.01
9	Ashuganj Power Station	10	55.16	8	42.40	1.29	-	-	-17.78
		10	55.16	12	42.40	1.29	-	-	-17.78
		10	55.16	6	42.40	1.29	138	813	15.70
10	ZFCL RMS	10	56.19	6	44.82	1.25	-	-	-17.78
		10	56.19	6	44.82	1.25	48	245	18.68
11	Ghorashal + Polash Fertilizer	14	34.48	8	27.58	1.24	-	-	-17.78
		14	34.48	8	27.58	1.24	648	3,220	19.16
12	Ghorashal Power Station	16	27.58	8	12.41	2.13	-	-	-17.78
		16	27.58	8	12.41	2.13	53	855	-22.67
13	Ghorashal Power Station	14	27.58	8	12.41	2.13	-	-	-17.78
		14	27.58	8	12.41	2.13	-	-	-17.78
		14	27.58	8	12.41	2.13	129	2,081	-22.67
14	Joydevpur CGS	14	20.69	12	12.41	1.62	-	-	-17.78
		14	20.69	8	12.41	1.62	68	724	-2.10
15	Joydevpur CGS	14	20.69	10	5.52	3.32	-	-	-17.78
		14	20.69	10	5.52	3.32	28	675	-52.58
16	JFCL RMS	12	34.48	10	24.13	1.41	40	311	8.61

Table 3. Power Generation Potential from Downstream Stations, Jalalabad Gas T&D Franchise Area

	Station	Avg Inlet Pr, p1 (bar-g)	Pressure after 1st cut (bar-g)	Final Outlet Pr, p2 (bar-g)	Pr ratio (p1/p2)	Avg Flow Rate (N^3/hr)	Power from Generator (kW)	Outlet Temp, C
1	90 MW CMS Unit 1	72.40	-	24.13	2.92	18,886	350	-44.26
2	90 MW CMS Unit 2	72.40	24.13	10.34	6.46	18,886	549	-90.80
3	Lafarge Cement CMS	31.03	-	10.34	2.82	18,886	341	-42.02
4	Shahjibazar TBS	68.95	34.48	10.34	6.16	53,116	1514	-88.28
5	Shahjibazar (PDB) Power Station	27.58	13.10	13.10	2.03	41,313	531	-19.05
6	Shahjibazar 86 MW (Pvt.) Power Station	6.90	24.13	4.14	1.54	23,607	191	1.90
7	Kumargaon 50 MW Rental Power	34.48	10.34	2.76	9.41	14,164	471	-109.37
8	KTLDRS	74.47	-	34.48	2.13	59,018	805	-22.56
9	Devpur Chevron RMS	75.85	-	34.48	2.17	59,018	822	-23.86
10	Chatak Cement CMS	34.48	10.34	4.14	6.89	6,492	194	-94.10
11	Kumargaon DRS	34.48	13.79	4.14	6.89	5,902	176	-94.10
12	Khadim DRS	34.48	13.79	4.14	6.89	7,082	211	-94.10

Table 4. Power Generation Potential from Producing Gas Wells

Gas Field	Well	Avg FWHP, p1 (bar-g)	seperator pr, p2 (bar-g)	Pr ratio (p1/p2)	Avg Flow Rate Nm^3/hr	Power from Generator (kW)	Outlet Temp, C
Titas Gas Field	1	129.97	68.95	1.87	38,008	470	5.32
	2	126.18		1.82	38,952	461	7.67
	4	133.42		1.92	37,771	485	3.26
	5	128.25		1.85	38,952	472	6.38
	6	131.01		1.89	41,313	517	4.70
	7	128.59		1.85	38,952	474	6.16
	8	110.32		1.59	23,607	221	18.57
	9	110.32		1.59	27,148	254	18.57
	11	137.90		1.99	29,509	396	0.68
	12	117.90		1.70	25,968	275	13.12
	13	133.07		1.92	35,411	453	3.46
	15	129.28		1.86	37,771	463	5.74
	16	128.94		1.86	37,771	462	5.95
Hobiganj Gas Field	1	111.01	68.95	1.60	23,607	224	18.05
	2	111.08		1.60	23,607	224	18.00
	3	108.60		1.57	42,493	386	19.87
	4	108.39		1.56	42,493	384	20.03
	5	103.84		1.50	36,591	301	23.61
	7	103.36		1.49	47,214	384	24.00
	10	101.70		1.47	47,214	370	25.36

Table 4 (Contd.). Power Generation Potential from Producing Gas Wells

Gas Field	Well	Avg FWHP, p1 (bar-g)	seperator pr, p2 (bar-g)	Pr ratio (p1/p2)	Avg Flow Rate Nm3/hr	Power from Generator (kW)	Outlet Temp, C
NGF	1	119.63	68.95	1.72	21,010	228	11.95
	2	110.87		1.60	19,122	181	18.16
KTL Gas Field	1	183.75	81.36	2.24	26,558	413	-8.70
	2	159.62	87.57	1.81	25,968	306	7.87
	3	173.75	87.57	1.97	17,705	235	1.18
	4	182.72	87.57	2.07	17,705	251	-2.72
	6	183.41	87.57	2.08	23,607	336	-3.01
BBGF	2	220.64	82.05	2.67	14,164	261	-21.51
FGF	2	179.27	77.91	2.28	16,525	262	-10.1

Legend: NGF = Narsingdi Gas Field, BBGF = Bianibazar Gas Field, FGF = Fenchuganj Gas Field

It should be noted that, in some cases, there are more than one pipeline controlled at a single station, with same inlet and outlet pressures, even though the pipelines may differ in diameter. In such cases a combined flow from the different lines is assumed. In reality this may not be implemented due to practical constraints.

It should be noted here that the data used in the above analysis are monthly average, one-time data. In reality these numbers will vary round the year. Therefore a more rigorous analysis will require data for several years. This technology may not be successfully implemented at locations where the rates and/or pressures fluctuate significantly.

PRE-HEATING REQUIREMENT

It can be seen from tables 2, 3, and 4, that the outlet temperatures, in most cases are very low. Such low temperatures will almost ensure hydrate formation, liquid production, icing, and similar undesirable effects. Therefore extraction of power from natural gas pipelines is not a straight forward project like simply buying and installing a turbo-expander-generator power pack. Some heating arrangement must be there to keep the outlet temperature and pressure above the hydrate formation range. Thus careful design and installation of heat exchangers become integral part of such a project. Even though it seems extra energy input to the system, a significant part of the heat input is actually recovered.

Gas heaters are routinely used in the gas processing plants. These are gas fired, multi-pass water-bath or oil bath heat exchangers. Fuel gas is usually tapped from the produced gas stream. These are also equipped with blowers to facilitate efficient combustion. In this paper however, energy consumption by blowers is not considered. A complete design and analysis with a heat exchanger for all the stations is beyond the scope of this paper. Hammerschmidt correlation [9] (Eq. 3) is used to predict the hydrate formation temperature at the outlet pressure:

$$T = 8.9\ p^{0.285} \qquad (3)$$

Where T is gas temperature (^oF), and p is gas pressure (psi). These are converted to ^oC and bar for consistent reporting. Assuming Isobaric process, the heating requirement is calculated from Eq. 4.

$$Q = m\ C_p\ \Delta T \qquad (4)$$

Where m is mass flow rate of gas (kgm/sec), C_p is specific heat of gas (kcal/kgm ^oK), and ΔT is temperature raised at inlet by heating (^oK).

Calculations for 3 different stations are presented in table 5. Options 1 and 2 are without and with pre-heating respectively, for the same station. For example, for the Demra CGS, the hydrate formation temperature is calculated from Eq. 3, which is about 44.8^oF (7.1^oC). A safe temperature of 55^oF (12^oC) is assumed at the outlet, and corresponding upstream temperature is calculated from Eq. 2, which is about 186^oF (85.5^oC). Thus ΔT is 45^oC. The heating requirement is estimated from Eq. 4. The heat exchanger efficiency is assumed 80%.

It can be seen that, to operate safely above the hydrate zone, 0.18-0.25% of the gas should be used as fuel for pre-heating. The power extracted at the generator is equivalent to 80-94% of this heat input. This however, *should not be considered as "thermal efficiency"* in the normal sense. Another way of looking at it is to consider the power that could have been obtained if the pre-heating fuel gas was used in a thermal power plant instead. Assuming 35% thermal efficiency of a power plant, the fuel gas would produce 668, 922, and 94 kW of electricity for the three examples respectively. It is also possible to use the exhaust or waste heat from the two power plants in the example for pre-heating purpose, thus eliminating the need for burning any additional gas.

Table 5. Heating Requirement at different locations

Station	Option	Avg Inlet Pr, p_1 (bar-g)	Inlet Temp T_1 C	Avg Outlet Pr, p_2 (bar-g)	Pr ratio (p_1/p_2)	Avg Flow Rate Nm^3/hr	Power from Generator (kW)	Hydrate Formation Temp, C	Outlet Temp, C	Δ T at inlet, C	Heating requirement, kW	% heat recovery	Fuel Gas req. Nm^3/hr	Fuel gas as % of Total flow	Power from fuel gas, kW
Demra CGS	1	45.51	38	20	2.21	93,300	1,332	7	-25.4	-	-	-	-	-	
	2	45.51	85.5	20	2.21	93,300	1,540	7	12	47.5	1908	80	236	0.25	668
GPS	1	27.6	38	12.4	2.13	152,266	2080	4	-22.7	-	-	-	-	-	-
	2	27.6	78	12.4	2.13	152,266	2350	4	10	40	2633	90	319	0.21	922
SPP (PDB)	1	27.6	38	13	2.03	41313	530	4	-19	-	-	-	-	-	-
	2	27.6	73	13	2.03	41313	590	4	10	35	630	94	71	0.18	94

Legend: GPS = Ghorashal Power Station, SPP = Shahbazpur Power Station

CONCLUSIONS AND RECOMMENDATIONS

There exists good potential for power generation from natural gas supply chain in Bangladesh. Although the power obtainable at individual locations is not very large compared to the conventional thermal power plants, the sum of all locations can be substantial. It should be noted that only six gas fields out of the eighteen producing gas fields, and the franchise areas of only two gas marketing companies out of four in Bangladesh, were covered in this study. Including all gas fields and franchise areas will increase the total power generation potential. It is also noted that, pre-heating is almost always necessary.

Turbo-expanders which are able to handle un-processed gas must be available for tapping the energy at the well heads. For downstream locations, power packs are available. This technology is being applied in different countries.

The results presented in this paper are based on monthly average data for a particular month. However, a real project design must take into account the variations of the pressure, temperature, and flow rates throughout the year, as well as the possible growth in future. Since this technology has never been used in Bangladesh, a pilot project can be undertaken. The electricity thus generated can be used by the facilities, and sold to the nearby localities.

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