Estimation of Power Production Potential from Natural Gas Pressure Reduction Stations in Pakistan Using ASPEN HYSYS

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ABSTRACT

Pakistan is a gas rich but power poor country. It consumes approximately 1, 559 Billion cubic feet of natural gas annually. Gas is transported around the country in a system of pressurized transmission pipelines under a pressure range of 600-1000 psig exclusively operated by two state owned companies i.e. SNGPL (Sui Northern Gas Pipelines Limited) and SSGCL (Sui Southern Gas Company Limited). The gas is distributed by reducing from the transmission pressure into distribution pressure up to maximum level of 150 psig at the city gate stations normally called SMS (Sales Metering Station). As a normal practice gas pressure reduction at those SMSs is accomplished in pressure regulators (PCVs or in throttle valves) where isenthalpic expansion takes place without producing any energy. Pressure potential of natural gas is an untapped energy resource which is currently wasted by its throttling. This pressure reduction at SMS (pressure drop through SMS) may also be achieved by expansion of natural gas in TE, which converts its pressure into the mechanical energy, which can be transmitted any loading device for example electric generator.

The aim of present paper is to explore the expected power production potential of various Sales Metering Stations of SSGCL company in Pakistan. The model of sales metering station was developed in a standard flow sheeting software Aspen HYSYS®7.1 to calculate power and study other parameters when an expansion turbine is used instead of throttling valves. It was observed from the simulation results that a significant power (more than 140 KW) can be produced at pressure reducing stations of SSGC network with gas flows more than 2.2 MMSCFD and pressure ration more than 1.3.

Key Words: Pressure into Power, Sales Metering Station, Turbo Expanders, Natural Gas.

1. INTRODUCTION

Currently Pakistan is facing power crisis. Natural Gas and Oil have a major share in energy mix of Pakistan. Pakistan, being the larger consumer of the natural gas, has total resource potential of 282 trillion cubic feet with recoverable reserves 24 trillion cubic feet and production of almost 4 billion cubic feet per day [1]. During 2012 total production remained 1,559 billion cubic feet that is equivalent to 32 million TOE which shows a growth of 6% when compared to last year in billion cubic feet while in TOE it shows a growth of 4.5% [1]. In Pakistan, currently Natural Gas transmission and distribution is exclusively operated by two state owned companies, namely SSGCL and SNGPL. Pakistan has one of the largest well developed transmission and distribution infrastructures, supplying Natural Gas to consumers through 9843 km of transmission networks and 71863 km

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of distribution system [2]. So there is a huge amount of hidden power potential in natural gas.

Natural gas in transmission networks is transported for longer distances at high pressure ranges 600-1000 psig to main cities and end users. High pressure throughout the transmission network is maintained by means of compression stations. A brief process of an integrated gas company is presented in Fig. 1. As per Oil and Gas Regulatory Authority Ordinance, 2002, the pressure for domestic or industrial use must be reduced to 300 psig or less [3]. Pressure is reduced at a Sales Metering Station or City Gate Station.

An schematic diagram of SMS is shown in Fig 2. In Fig. 2, Natural gas is first filtered from any dust/condensate (heavier hydrocarbons). Then pressure of gas is reduced up to the desired limits through throttling valves or pressure control valves. Finally low pressure gas is measured and being odorized by injection of some odorant so that it can be detected at the time of leakage.

In throttling process gas pressure is reduced from a higher level to a lower level which leads a drop in temperature of natural gas. During throttling, most gases cool down because of isenthalpic expansion. The temperature drop in natural gas during throttling lies in a range of about 4.5-

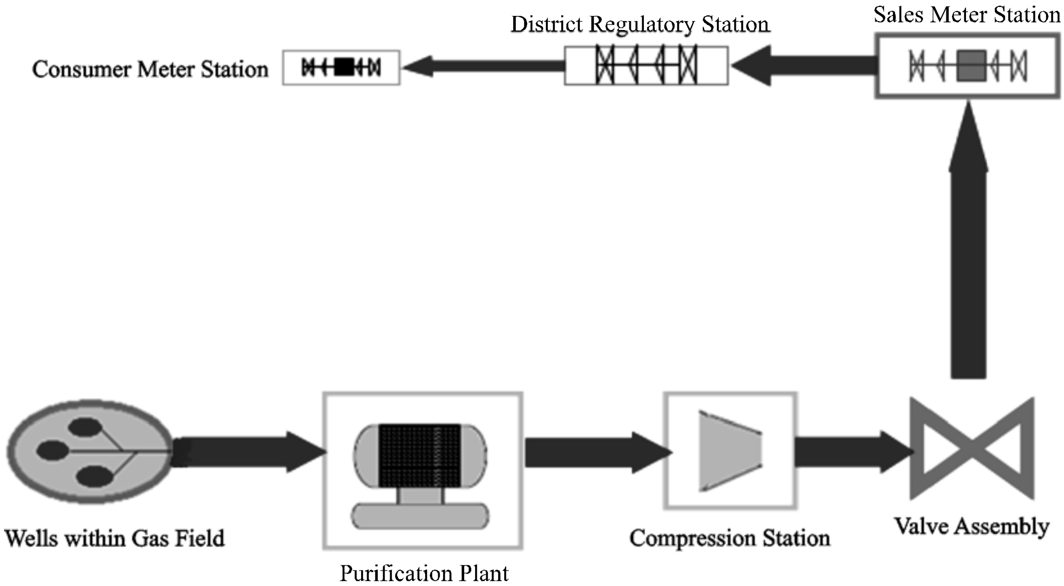

FIG. 1.PROCESS FLOW DIAGRAM OF AN INTEGRATED GAS COMPANY

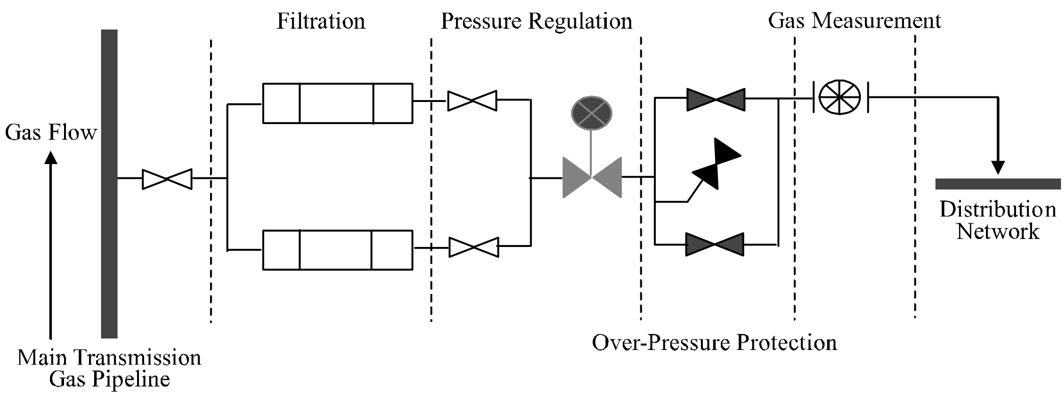

FIG. 2. SCHEMATIC DIAGRAM OF A SALES METERING STATION

5°C per 1 MPa [4]. So in the cases of greater temperature drop, natural gas must be preheated before throttling/ expansion in order to avoid hydrate formation or condensation of heavier hydrocarbons that may cause the blockage of distribution lines [5]. With these conventional methods of pressure reduction through expansion valves/throttle valves, mechanical Exergy is destroyed. Replacement of gas throttling process by the process of its expansion in Turbo-expander converts the pressure of natural gas/enthalpy of natural gas into mechanical energy which can be transmitted to a loading device [6] for example an electric generator, compressor or pump. A significant amount of cold is also generated as the gas is expanded in turbo-expander to lower pressure. In this way low pressure gas may also be used as a coolant in a cooling system.

The complete PIP (Pressure into Power)unit may take various models for various purposes depending on the site conditions and the desired outputs. It would be more suitable to install TEs (Turbo Expanders) parallel to existing pressure reduction throttle valves for assuring the reliability of the system. Simply PIP may be installed to derive electric generator to produce electricity and sold to local grid station. The flow and pressure of natural gas may vary seasonally, ultimately rate of power production will vary (fluctuate) so it will be more suitable to transfer recovered energy in any energy carrier which may be stored and used rather than supplying to a local grid station. Because of large annual variation in Natural Gas flow and the impact of season on pressure and flow results a fluctuated power generation, and the system behaves like a solar or wind renewable source.

A proposed model of power generation system is shown in Fig. 3 in which turbo-expander is installed parallel to the existing pressure reduction station assuring the reliability of the system. Natural Gas cools rapidly during expansion in TE, temperature drop in a TE is approximately 15-20°C per MPa [4]. The temperature of gas at outlet of TE must be maintained above the hydrocarbon dew point and also water dew point to avoid condensation and hydrate formation. That is why a pre-heater is required to maintain outlet temperature of gas.

Several researchers worked on the recovery of pressure potential from natural gas transmission lines. Ebrahim and Esmaeil [5] developed a computer simulation in

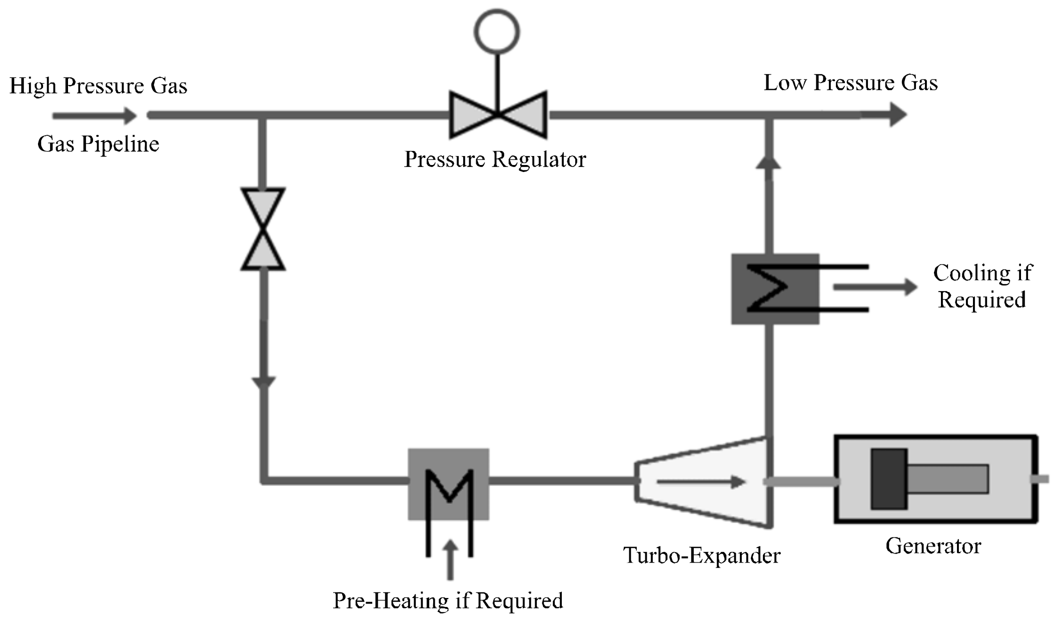

FIG. 3. EXERGY RECOVERY IN A PRESSURE REDUCTION STATION USING TURBO-EXPANDER

HYSYS to estimate the power generation potential for the natural gas transmission network in Iran. Power generation opportunities were also estimated in Bangladesh from pressure reducing stations using standard statistical curve fitting method [7]. Unar, et. al. [8] estimated the power from the industrial SMSs in SNGPL network of Pakistan using standard statistical curve fitting. Maddaloni and Rowe [9] investigated for the production of hydrogen using turbo expanders for power generation at pressure reducing stations. Howard, et. al. [10] investigated the performance of hybrid TE-fuel cell system for power recovery at natural gas pressure reduction stations.

The aim of present work is to estimate the expected power generation at SMSs of SSGCL network of Pakistan with PIP system (that is being wasted currently) through simulations developed in Aspen HYSYS®7.1. The study also focuses on the seasonal effects of natural gas flow at those SMSs.

2. METHODOLOGY

A simulation of a system is the operation of a model, which is a representation of that system. The model is amenable to manipulation which would be impossible, too expensive, or too impractical to perform on the system which it portrays. Modeling and simulation are the modern tools to conducted the several scientific and engineering. The present study was conducted through the simulation on the model of proposed PIP system developed in standard flow sheeting software Aspen HYSYS®7.1. The work was divided in two parts. The first part was to collect the necessary data from the natural gas transmission companies whereas the second part was to develop the model in Aspen HYSYS®7.1. Both the steps are briefly discussed as follows:

2.1 Data Collection

Model development and simulation of proposed PIP system requires following input data:

- Natural gas flow rate and its composition
- Gas Pressures at inlet and outlet of an SMS
- Inlet temperature of natural gas
- Isentropic efficiency of expander

Statistical records/Data Sheets were taken from SSGC Pakistan for the years 2010-2011.Average capacity (NG flow in MMSCFD), average pressure and temperature of inlet gas and outlet pressure of different SMSs operated by SSGC were given in these data sheets.

2.2 Development of Model in Aspen HYSYS®7.1 and Simulations for Various SMSs

Aspen HYSYS is a powerful engineering simulation tool, has been uniquely created with respect to the program architecture, interface design, engineering capabilities and interactive operations. The integrated steady state and dynamic modeling capabilities, where the same model can be evaluated from either perspective with full sharing of process information, represent a significant advancement in the engineering software industry. Aspen HYSYS serves as the engineering platform for modeling processes from Upstream, through Gas Processing and Cryogenic facilities, to Refining and Chemicals processes [11].

In present work a model of proposed system (Fig. 3) was developed in Aspen HYSSYS®7.1 to calculate the power generation capacity and the impact of different factors on rate of power production using real site data obtained from SSGCL. PR (Peng-Robinson) equation of state as described by Equation (1) was solved to calculate the specific volume of a gaseous mixture of chemicals at a specified temperature and pressure.

$$P = \frac{RT}{\hat{v} - b} - \frac{a}{\hat{v}(\hat{v} + b) + b(\hat{v} - b)} \qquad (1)$$

where P is Pressure, T is Temperature, R is General gas constant, $\hat{v}$ is Specific volume, and Z is Compressibility factor of real gas.

PFD (Process Flow Diagram) of the model developed in the software is shown in Fig. 4.

The main simulation results were:

- Power required for pre-heating of Natural Gas
- Required temperature of inlet gas
- Power generated

3. RESULTS AND DISCUSSION

The domestic and industrial natural gas requirements of Sindh province are fulfilled by SSGC Company through a huge transmission system having various SMSs (pressure reduction stations) at different locations in the region (Sindh and Balochistan). Statistical records showing average NG flow (MMSCFD), average pressure and temperature of inlet gas and outlet pressure of all SMSs for the month of September 2011 were taken from SSGCL Pakistan.

Computer simulations for expansion turbines were developed for different SMSs operated by SSGCL to calculate the power that may be recovered by using turbo-expander in place of throttling valve in a pressure reduction station.

SMSs with less gas flow rates and pressure drops were neglected due to very low power generation. Finally 7 SMSs were analyzed to produce reasonable power for the month of September 2011 shown in Table 1.

It is seen from the Table 1 that a significant amount of power may be produced at various SMSs operated by natural gas transmission companies in Pakistan.

Highest estimated power production is 1727 kW from a domestic SMS (Karachi SMS) because of high natural gas flow and pressure reduction ratio. While industrial SMSs that are ACPL, FJFC and FFBL also have a good power potential of 1518, 1262 and 944 kW respectively. However, the rate of power generation from Karachi Terminal SMS

TABLE 1. MONTHLY ESTIMATED POWER RODUCTION FROM DIFFERENT SMSS

SMS Location	Pressure Ratio (High/Low)	Natural Gas Flow (MMSCFD)	Energy Required For Pre-Heating (KW)	Estimated Power Production from Simulations (KW)
ACPL	1.3	193.3	0	1518
FJFC	1.3	196.5	0	1262
FFBL	1.25	120	0	944
Karachi	3	239	6478	1727
Malir	3.5	95	3206	536
Pak Steel	3.8	38	1475	188
Hyd Main	2.2	22	374	141

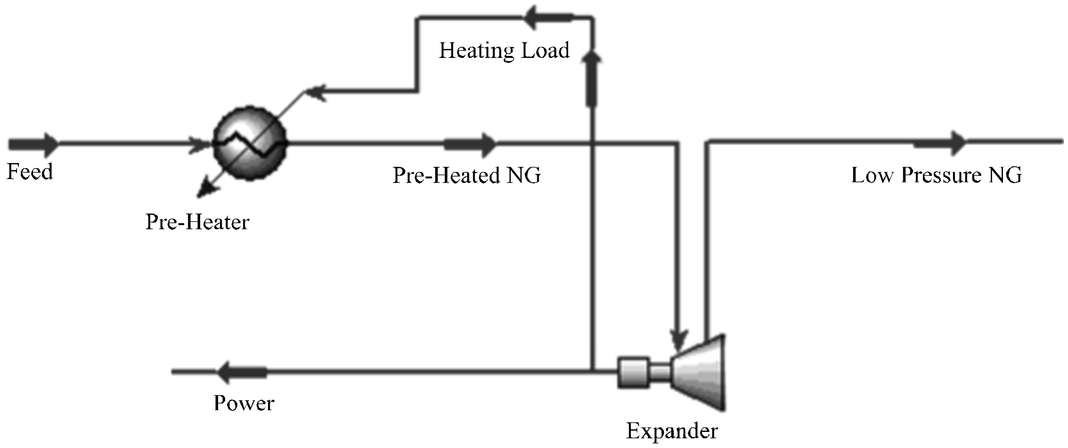

FIG. 4. SIMULATION OF PROPOSED MODEL IN ASPEN HYSSYS®7.1

is analyzed for various months where the maximum power generation was up to 2 MW. The power production estimations are in the similar range as compared with the SMSs in SNGPL as per our previous studies [8]. Necessary amount of energy required to pre-heat natural gas in order to keep its outlet temperature above the dew point is also presented in Table1. In first three SMSs there is no need of pre-heating natural gas because at related gas flow rate and pressure drop the outlet temperature of natural gas remains above dew point or condensation temperature. It is also evident from the calculations that power production directly varies with gas flow as per conclusions of earlier studies [10,12-13].

Similarly using statistical records for KT (Karachi Terminal) SMS, impact of gas flow rate on the rate of power production was analyzed and the results are tabulated in Table 2.

Maximum estimated power produced from KT SMS is 2.19 MW in the month of February, 2011 and minimum is 1.27 MW in May, 2011.

TABLE 2. MONTHLY ESTIMATED POWER PRODUCTION FROM KT SMS (FROM SEPTEMBER 2010 TO JUNE 2011)

Location	Month	Pressure Ratio (High/Low)	KT SMS Sale (MMSCFD)	Estimated Power Production (KW)
KT SMS	September 2010	2.77	264	1818
	October 2010	2.79	245	1805
	November 2010	3.034	239	1727
	December 2010	2.71	286	2082
	January 2011	2.87	299	2026
	Feburary 2011	2.65	297	2194
	March 2011	2.6	259	1883
	April 2011	3.32	216	1370
	May 2011	3.66	211	1275
	June 2011	3.47	215	1359

3.1 Impacts of Gas Flow on the Rate of Power Production

The gas flow over an SMS may vary seasonally due to domestic/industrial consumption variations thought the year. Table 2 represents the monthly power production of KT SMS in different months (from September 2010 to June 2011) with different gas flow rates. It is seen that power production varies with change in gas flow and pressure reduction ratio. The impact of gas flow on the rate of power generation is shown graphically in Fig. 5.

From Fig. 5 it is clear that the rate of power production directly varies with change in gas flow. With decreasing gas flow, rate of power production also decreases while an increase in gas flow cause an increase in power production. In graph at 264 MMSCFD power generation is 1818 kW, as in next month when the gas flow is decreased to 245 MMSCFD power generation is also decreased to 1805kW. This may also be quoted as seasonality impact on the power production as studied by Maddaloni, *et .al.* [9]. This is because of the gas consumption variations for summer and winter season at domestic SMS.

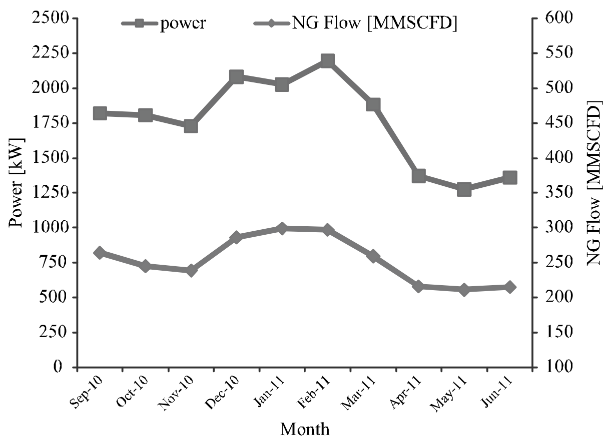

FIG. 5.ESTIMATED POWER PRODUCTION AT VARIOUS GAS FLOW RATES FROM KT SMS

3.2 Dependence of Power output on TE's Isentropic Efficiency

Isentropic efficiency is the ratio of the real turbine output in which losses of mechanical energy through friction happens to the theoretical ideal turbine output [12]. The developed model has further used to investigate the impact of the TE's isentropic efficiency on the rate of power production, heat consumption and temperature at expander inlet. Table 3 shows the estimated rate of power generating and pre-heating load at different isentropic efficiencies.

It is a common understanding that in any system the overall performance of the system depends on the working efficiency of different components. Main component in our proposed model is a Turbo-Expander. In order to estimate the rate of power generation from the system first we have to specify the efficiency of Turbo-Expander. In our work we have evaluated the estimated rate of power generation from different SMSs at different isentropic efficiencies of Turbo-Expander. The results are graphically represented in Fig.6.

Fig. 6 shows that the inlet temperature and heat consumption increases linearly with increase in isentropic efficiency. While power production shows a dual nature with change in Isentropic efficiency of TE because of TE design.

4. CONCLUSIONS

Pakistan consumes approximately 38.41 billion m^3 of natural gas annually. Gas is transported around the country in a system of pressurized pipelines. In Pakistan NG transportation system is operated by two giant integrated gas companies i.e. SNGPL and SSGCL operating more than 200 SMSs (Metering and pressure reduction stations) throughout the Pakistan. Long distance pipelines are operated at high pressure, which is lowered at various junctions called SMSs. At these SMSs pressure regulating devices (control valves or regulators) drops the pressure to the appropriate pressure for the low pressure network according to the requirement of end users.

When these pressure regulators are replaced by a TE (Expansion Turbine) the pressure potential currently which is wasted during pressure reduction process is captured in the form mechanical power or electricity.

Pakistan has a well-developed NG transmission system so there is a great hidden potential to develop systems for power generation.

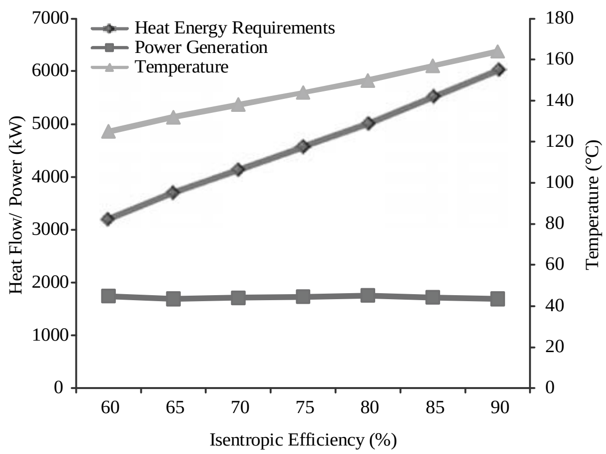

FIG. 6. DEPENDENCE OF POWER OUTPUT ON TURBO-EXPANDER'S ISENTROPIC EFFICIENCY

TABLE 3. ESTIMATED POWER GENERATION AND ENERGY REQUIRED FOR PRE-HEATING AT DIFFERENT ISENTROPIC EFFICIENCIES OF TURBO-EXPANDER

Isentropic Efficiency of TE (%)	60	65	70	75	80	85	90
Temperature at TE inlet (°F)	125	132	138	144	150	157	164
Energy Required for Heating (kW)	3214	3718	4151	4585	5020	5529	6040
Power Generation (kW)	1746	1696	1714	1734	1757	1720	1694

(i) The proposed cases were simulated through Aspen HYSSYS®7.1 and validated by comparing the results with the findings of previous researches.

(ii) It was observed that a significant power can be produced at pressure reducing stations of SSGC network with gas flows more than 2.2 MMSCFD and pressure ration more than 1.3.

(iii) The maximum estimated power generation was calculated to be 2194 kW from KT SMSwith an average pressure ratio 2.65 and natural gas flow 299 MMSCFD (February 2011).

(iv) Relationship between the rate of power production and natural gas flow was observed from the simulation results. Power production was observed to vary directly with change in natural gas flow.

(v) Low pressure and low temperature gas may be used for an efficient cooling system (cooling potential is also present).

(vi) The inlet temperature and heat consumption increases linearly with increase in isentropic efficiency.

The proposed idea for power production needs no fuel and additionally there is no danger of environment pollution. It will require a coordinated approach from the private and public sector with the help from donor agencies to make PIP a reality in Pakistan and help it to come out from energy crisis.

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