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Energetika v Sloveniji v luči finančne krize

Stanje na področju energetike v Sloveniji se zaostruje praktično na vseh področjih energetike. Tudi ali pa predvsem na področju električne energije z višanjem cen. Z višanjem standarda v Sloveniji, se veča tudi poraba električne energije. Tako se že precej približujemo povprečju porabe razvitih članic EU. Proizvodnja električne energije v Sloveniji ne dosega porabe, saj danes uvažamo že skoraj četrtino potrebne električne energije. Zato bo nujno sočasno delovanje v večih smereh – v smeri učinkovite rabe električne energije, - v smeri večjega varčevanja z energijo (sprememba odnosa do energije), – v smeri izgradnje novih kapacitet in posodabljanja starih elektroenergetskih sistemov ob sočasni izgradnji novih kapacitet. Morda je prav sedanja finančna kriza čas za nova vlaganja na področje energetike v Sloveniji in tako zastaviti pot do nadaljnjega, še uspešnejšega razvoja Slovenije.

Energy Technology in Slovenia in the light of financial crisis

The situation in the energy sector in Slovenia becoming more strained in practically at all areas, even (or especially) in the field of electricity price increases. With the increasing living standards of Slovenia, the consumption of electricity is growing; it is already approaching the average consumption of the developed EU member states. Production of electricity in Slovenia does not meet consumption, meaning that currently almost a quarter of all necessary electricity is imported. It will, therefore, be essential to co-operate in several directions: toward the effective use of electricity, in the direction of greater energy savings (change in attitude to energy), in the building new facilities and modernizing old power systems, while building new capacity. Perhaps the current financial crisis is the time for new investment in energy in Slovenia and also for setting the new path to further, more effective development of Slovenia.

Krško, February 2009

Andrej PREDIN

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COMPARISON OF MEASUREMENT SHAFT DISPLACEMENT, BEARING CASING VIBRATIONS AND AXIAL FORCES IN THREE DIFFERENT KAPLAN TURBINES

PRIMERJAVA PREMIKOV GREDI, VIBRACIJ OHIŠJA LEŽAJEV IN AKSIALNIH SIL NA TREH RAZLIČNIH KAPLANOVIH TURBINAH

B. GREGORC[ℜ] , A. PREDIN[1]

Keywords: shaft vibrations, shaft displacement, Kaplan turbine, measurements;

Abstract

This paper deals with the vibrations and displacements of turbine shafts at different aggregate loads in hydroelectric power stations. Measurements have been made at three different power plants with Kaplan turbines. The first part contains theoretical starting points for the evaluation of the measurement signals of displacements and of vibrations. The results of the evaluation measurements are shown in the experimental part accompanied by comments. The findings of the treated results of measurement are introduced.

Povzetek

V prispevku so opisane vibracije in pomiki turbinske gredi pri različnih obremenitvah elektro generatorja v hidroelektrarni. Meritve so izvedene na treh različnih hidroelektrarnah z Kaplanovimi turbinami. Prvi del zajema izhodišča za ocenjevanje merilnih signalov premikov in

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vibracij. Rezultati teh primerjav so ocenjeni eksperimentalno ter so ustrezno komentirani. Prav tako so predstavljena nova spoznanja, ki izhajajo iz merilnih rezultatov.

1 INTRODUCTION

The basis for extending the lifespan of mechanical devices is diagnostics and maintenance. Hydroelectric power stations have some of the longest operation times of any machines. The diagnostics of the origins of vibrations and displacement of the turbine shaft are very important in predicting certain works on individual assemblies of turbine equipment. With certain criteria (defined in [14]), we can foresee possible larger tensions of mechanical devices in a timely manner, because (in the majority of cases) the changes of the mentioned parameters are a sign of the worsening the condition of the machine. We can determine the origins with a frequency analysis of the vibrations. A prerequisite for finding the condition of individual machine is the time monitoring of the enlargement of amplitudes (of vibrations, and displacements). With good understanding of the occurrence between the operations of individual aggregates, this can help find solutions for some other problems that occur because of indirect impacts of displacements and vibrations.

1.1 Shaft displacement

The equipment of larger hydroelectric power stations is very large in both dimensions and mass. During operation of the turbine with the generator (greater than 100t), large persistent circumstances can occur because of the mass of the rotating parts. During operation, there are different forces that affect the aggregate (turbine + generator) and which cause displacement (eccentricity of rotating mass, magnetic forces of generator, of direction the stream of water on driving spades). The largest magnetic force or the moving direction of mechanical centre is dependent on uniform air distance between the rotor and dormant stator (geometric shape of rotor and stator). With sensors, the relative motion of the centre shaft in the x and y planes (rectangular considering axle of shaft) are measured. The phase move between swinging in this plane can either be $+\pi/2$ or $-\pi/2$. From there, it is visible that the centre of beds moves completely around the orbit. The direction of the motion of the centre is in the direction of rotation of shaft in the majority of cases. The shape of movement is in the *xy* direction and is highly dependent on the load. Amplitude displacement alongside the shaft in a stationary condition equals the sum of all amplitudes, which are stimulated by the oscillating stimulating force. For the impact of the individual harmonic, the direction of the stimulating force and the size of choking of individual resonant swinging is also important.

The allowed value of the maximum displacement shaft can be chosen from references of Standard VDI 2059, Part 5 for turbine bearings [14, 18, 20, 22], where it depends on the relative distance (in our case x 0.6 - value is recommended). The geometry of bearings for the designation of maximum displacement must be considered: to give support, rotation speed, viscosity of oil, and to consider the suitability of the oil film as for radically force generator or of turbine.

References are used for the choosing of displacement (Standard VDI 2059). It is necessary to place the cantilever arms for measuring displacement in two different positions of the plane. With measuring, we can set the value of displacement in both rectangular sides as well as the

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direction of the movement of the orbit. In the picture below, the orbit at rotation of shaft is shown.

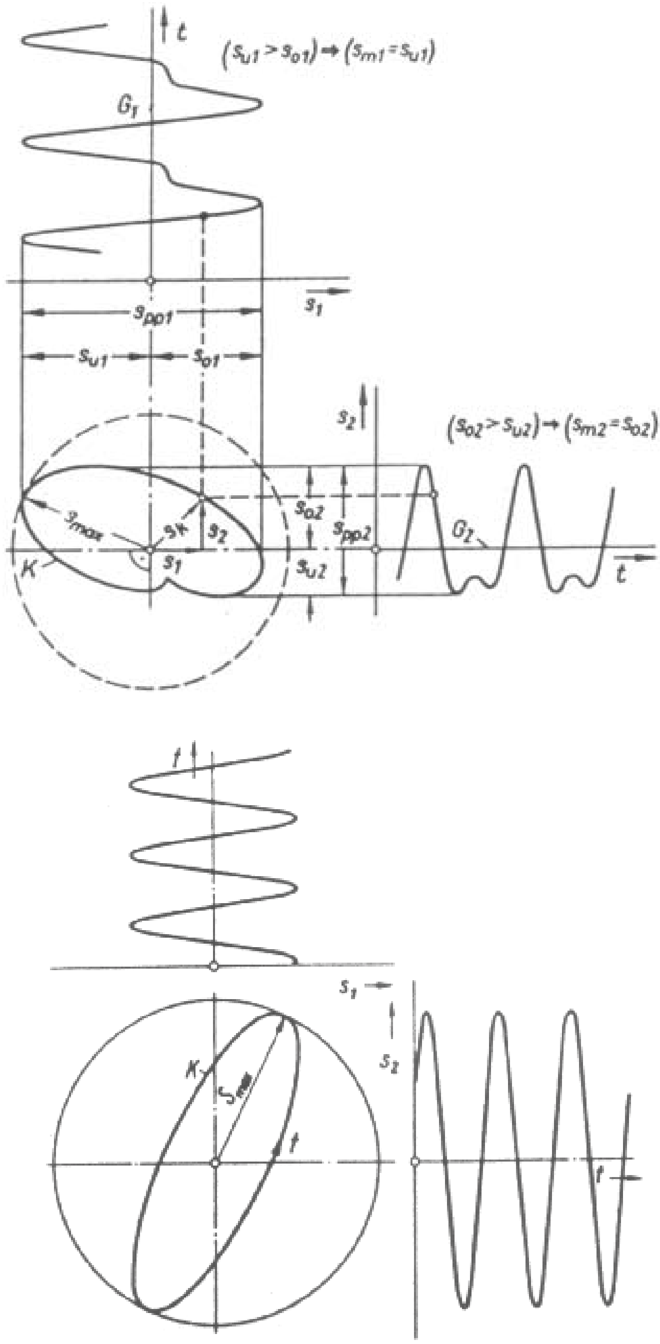


***Figure 1**: Designation of parameters displacement shaft*

1.1.1 Governing equations

The following equations are used for the calculation of measured values:
Designation of equivalent largest value in dependence from the interval of time:

$$s_{equ} = \frac{\pi}{2} \frac{1}{t_1 - t_2} \int_{t_1}^{t_2} |s(t)|\, dt \tag{1.1}$$

The maximum values in the plane of installed measuring sensors of displacement are shown with this equation:

$$s_m = \max.\,((s_0, s_u)^2) \tag{1.2}$$

The designation of largest swings of turbine shaft is shown with this equation:

$$s_k(t) = \sqrt{s_1^2(t) + s_2^2(t)} \tag{1.3}$$

$$s_{\max} = \max.\,(s_k(t)) \tag{1.4}$$

1.2 Casing vibrations of turbine shaft bearings

The amplitudes of affective speed are the basic quantities that dictate the quality of the machine with regards to vibrations. For frequencies, the vibration speed amplitudes can be measured and the origins can be established. With mechanical elements, the harmonic vibrations are more frequent where each harmonic is a consequence of a certain machine assembly. Most important for larger vehicles at low speeds are the swinging and vibrations in the lower part of frequency spectrum, where the impact of basic sources of vibrations (100 Hz) can be established. Amplitudes at higher frequencies are a consequence of higher harmonics and of vibrations of some machine parts (e.g. of the fundamental frequency of bearings, of sheet metals etc.) [12, 19].

1.2.1 Governing equations of vibrations

Mathematically, the path in dependence from the move can be defined:

$$x = X_{peak} \sin(2\pi \frac{t}{T}) = X_{peak} \sin(2\pi f t) = X_{peak} \sin(\omega t) \tag{2.1}$$

The speed of vibrations in dependence from time and motion with the equation is as follows:

$$v = \frac{dv}{dt} = \omega X_{peak} \cos(\omega t) = V_{peak} \cos(\omega t) = V_{peak} \sin(\omega t + \frac{\pi}{2}) \tag{2.2}$$

The definition of acceleration of vibrations is defined as the dependence of speed and time.

With equations (5, 6, 7) we can describe the basis of the vibration occurring while measuring them. There are other ways of acquiring vibration parameters used for measuring (e.g. analysis of the cylinder, analysis of time and frequency).

With frequency analysis, we can ascertain conditions of individual elements when transforming signal from time domain to frequency domain [20]. We can also establish more dominant vibrations in the frequency span. A prerequisite for choosing amplitudes is to be skilled in some basic frequencies of machine parts, as well as in suitable sampling (Hz, kHz etc.).

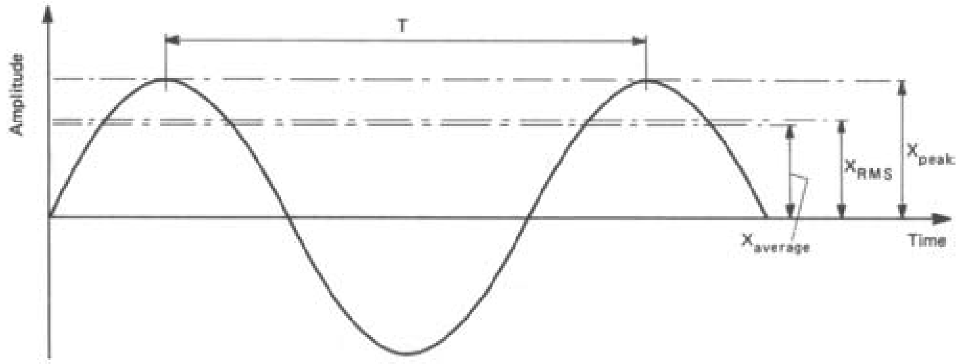


***Figure 2**: An example of harmonious signal of vibrations with RMS display and of absolute average values*

The middle value of amplitude is defined with following equation:

$$X_{Average} = \frac{1}{T}\int_0^T |x| dt \tag{2.3}$$

For vibration measuring, a distance RMS (root mean square) value can be used, which we can set with the association between amplitude values caused with vibrations:

$$X_{RMS} = \frac{\pi X_{Average}}{2\sqrt{2}} = \frac{X_{peak}}{\sqrt{2}} \tag{2.4}$$

2 EXPERIMENTAL PART – MEASUREMENTS ON PROTOTYPES

In this part, the results of measurement of the power of renewed aggregates of hydroelectric power stations are used [5, 7, 12]. After fitting the entire power station with new equipment, tests with the new turbine equipment are done (driver, guiding blade, generator etc.). The results of measurements on three different hydroelectric power stations that have different high-altitude corners and nominal strength are treated in the contribution. In the case of the VH hydroelectric power station and the OT hydroelectric power station, the maximum fluxes after turbines are equal. In both, four-bladed runners are used. Moreover, both hydroelectric power stations have similar structures (bearings, runners); they are only different in dimensions. The basic data are shown in the Table 1.

Table 1: Basic parameters of individual power plant

	Nominal strength of turbine (MW)	Type of turbine	Nominal flow (m^3/s)	Nominal net fall (m)	Speed of rotation (min^{-1})
Hydroelectric power station - (HEDR)	8.52	Kaplan	135	7.35	100
Hydroelectric power station - (HEOT)	20.49	Kaplan	183	12.50	125
Hydroelectric power station - (HEVH)	24.73	Kaplan	183	15.19	125

By comparing individual measured results, we obtain insight into the different energy potentials of power plants. An equal measuring principle is used for measuring individual sizes; they are also comparable. Measurements capture only one aggregate at each individual hydroelectric power station (power plants have three aggregates-turbines).

Picture 3 shows the acquisition of displacement, vibrations and axial force signals. The distance between both management bearings is different (from 4.5 to 6.7 m) considering the parameters in Table 1. Through carrying bearing, which is between both management bearings, the entire weight of rotation parts is transmitted (generator and turbine). Sensors are installed in equal positions in all cases of measuring, as shown in Picture 3. The direction of rotation of the turbine shaft is to the right in two cases, but in one case (HE DR) the direction of rotation is to the left.

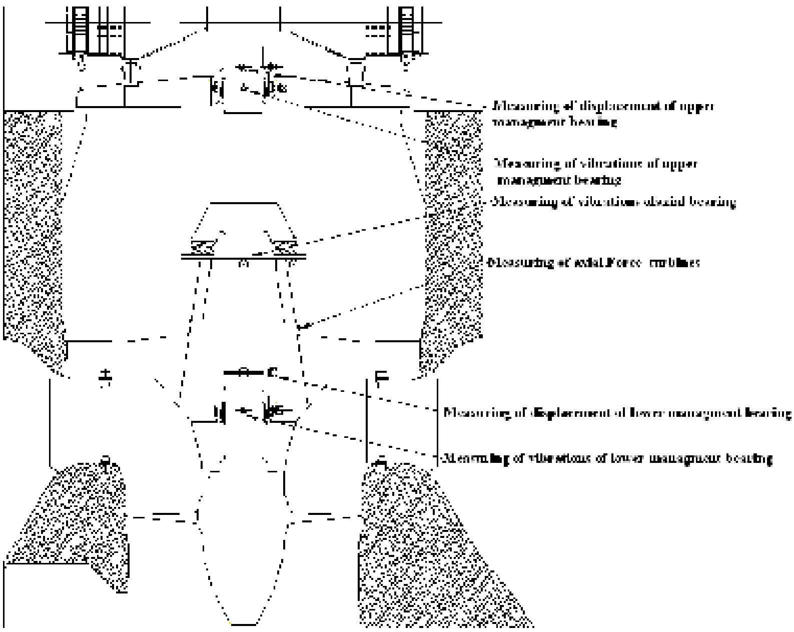


Figure 3: *An example of installed transmitters on both management bearings and carrying bearing*

2.1 Measurements

2.1.1 Turbine shaft displacements measurement

Measurement of displacement of the turbine shaft was acquired with sensors, which were attached to parts of the management bearing, causing the displacement shaft can be perceived during reduction or enlargement of the distance between the unchangeably installed distance and rotation turbine shaft. Sensors were installed in direction of the water holster, and at 90° with regards to the direction of the holster. The vector of movement of the centre of shaft was obtained in the measured plane in this case. Measurements of displacement were done on different loads of aggregate (free running, induced conditions, 25 %, 50 %, 75 %, 100 %).

2.1.2 Casing vibration measurements

Measurements were made on the casing of carrying bearing and both management bearings. Vibrations were measured in the direction of the water holster and 90°, with regards to the direction of holster. Vibrations were measured on management bearings in the radial direction, at carrying bearing in axial direction. Measurements of vibrations went on at different loads of aggregate (free running, induced conditions 25 %, 50 %, 75 %, 100 %).

2.1.3 Axial force measurements

Measurements of axial force were made on carrying construction of carrying bearing (IEC 545). Measurements of axial force were made on at different loads of aggregate (free running, induced conditions 25 %, 50 %, 75 %, 100 %).

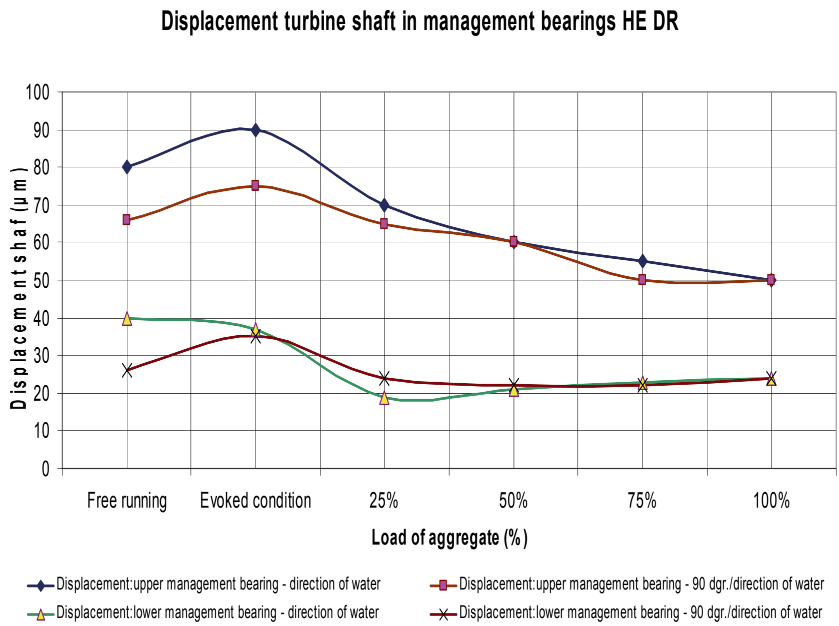
2.2 Measurement results

2.2.1 Turbine shaft displacements measurement

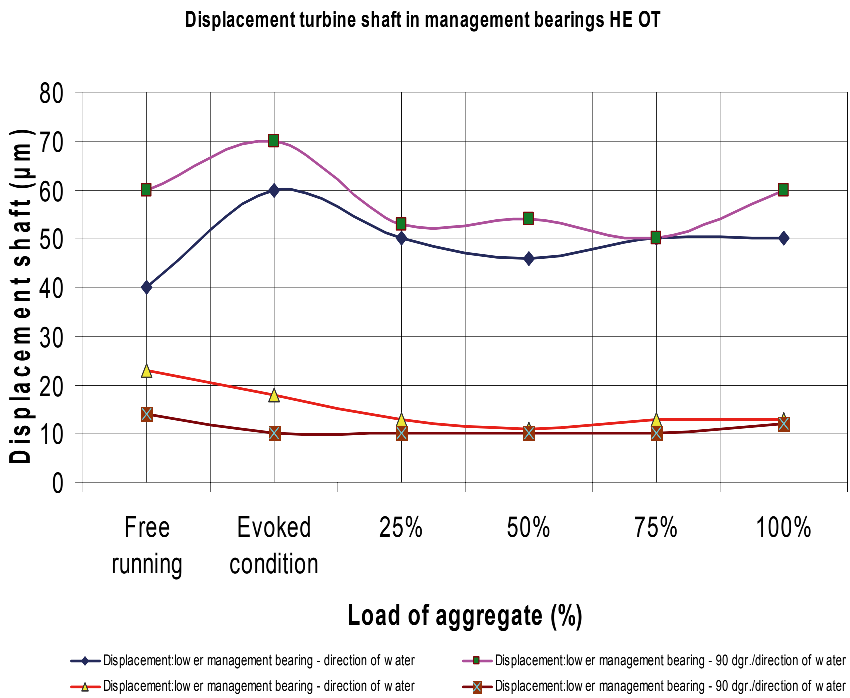
The greatest increase of displacement was noticed in the range of induced running, with regard to the working condition of aggregate. In this case, the enlargement of the displacement is approximately 12% on the upper management bearing, considering the condition of the stagnation aggregate. Increased phenomenon (shaft displacement) is observed in direction of water flow. The activity of electric forces between the rotor and stator has a bigger influence on displacement. The displacement reduces with the increasing of load below value in constant free running. The displacement of lower leading bearing is smaller: approximately two to three times in the entire working range with regards to upper leading bearing.

In Picture 4, it can be seen that values of displacement are much below the admissible frontier (196 µm) recommended in Standard VDI 2059, [14].

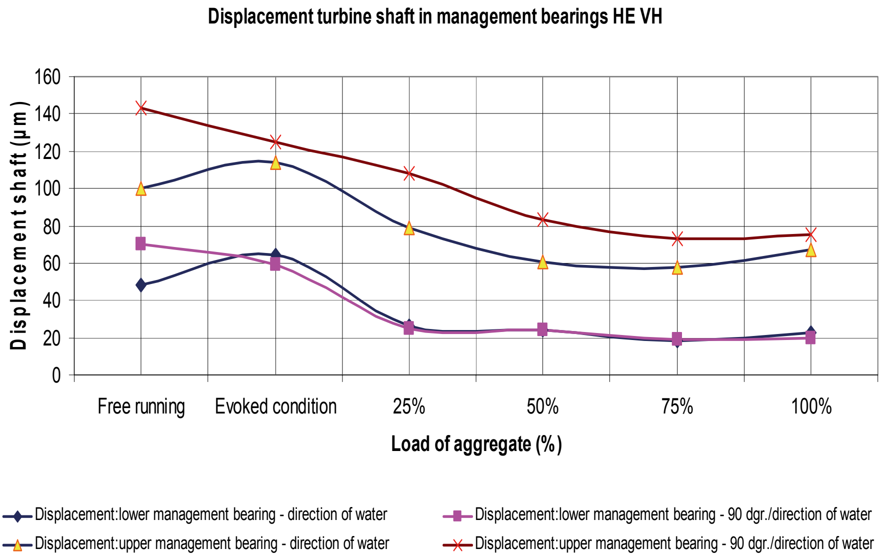
In Picture 5, the centres of orbit of the turbine shaft at different loads are shown. With analysis of the data of displacement, it is observed that the centre of orbit of shaft at operation in the upper leading bearing places itself in the fourth quadrant with regards to the direction of water. The points show the movement of the centre of the orbit (maximum distance y/2, and x/2), on which the turbine shaft travels, with regards to the centre of the orbit.


Displacement turbine shaft in management bearings HE DR
Displacement shaf (μm)
100
90
80
70
60
50
40
30
20
10
0
Free running
Evoked condition
25%
50%
75%
100%
Load of aggregate (%)
Displacement:upper management bearing - direction of water
Displacement:upper management bearing - 90 dgr./direction of water
Displacement:lower management bearing - direction of water
Displacement:lower management bearing - 90 dgr./direction of water

A)

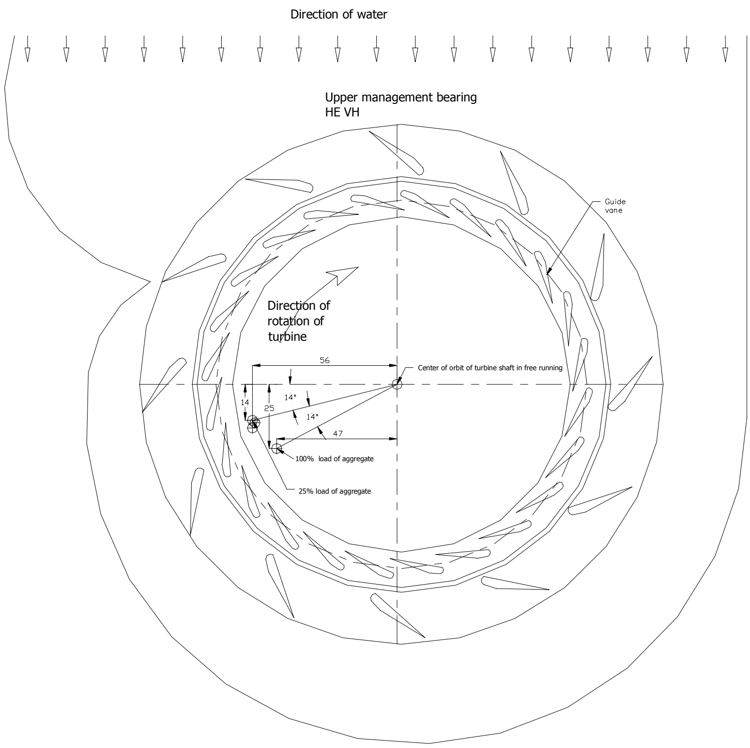

Displacement turbine shaft in management bearings HE OT
Displacement shaft (μm)
80
70
60
50
40
30
20
10
0
Free running
Evoked condition
25%
50%
75%
100%
Load of aggregate (%)
Displacement:low er management bearing - direction of w ater
Displacement:low er management bearing - 90 dgr./direction of w ater
Displacement:low er management bearing - direction of w ater
Displacement:low er management bearing - 90 dgr./direction of w ater

B)



C)

***Figure 4**: Displacement turbine shaft of three different aggregates, with regards to the load*



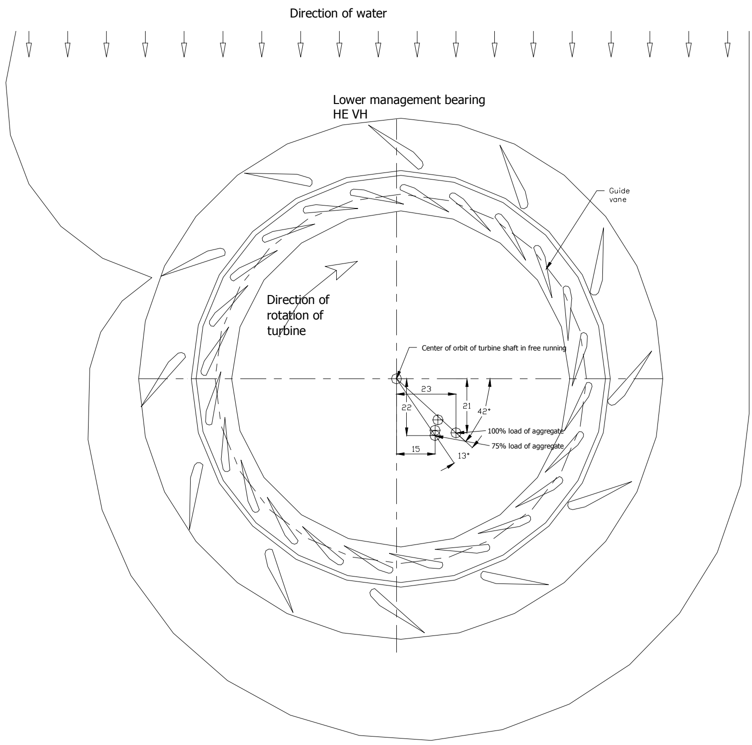


***Figure** 5: The dependence of the centre of the orbit of the turbine shaft with regards to the load in upper and lower leading bearing (the value of deviation of centre of orbit from mechanical centre is in μm)*

The centre of the orbit moves the direction of water with increases of load (opposite direction of rotation of shaft). All centres of orbits are in range of span of 15° corner at different loads. The centres of orbits are measured relatively with regards to the change of the centre of the free running turbine. In the case of the orbit centres in lower leading bearing, the centres of orbits at different loads are in the third quadrant with regards to direction of water (see Picture 5). The centres of orbits move with increasing of load in the opposite direction of the rotation of the turbine. It can be predicted that the impact on occurring moves of centre of orbit is in opening of driving spades, and the activity of electric force in the generator. From measurements, it can be ascertained that the shaft tilts approximately 0.008° at the 100% load.

2.2.2 Casing vibration measurements

The values of prominent increases in the speed of vibrations (RMS[2]) on individual bearing (lower management, upper management, carrying bearing) occur in all cases at relatively equal

[2] Root main square

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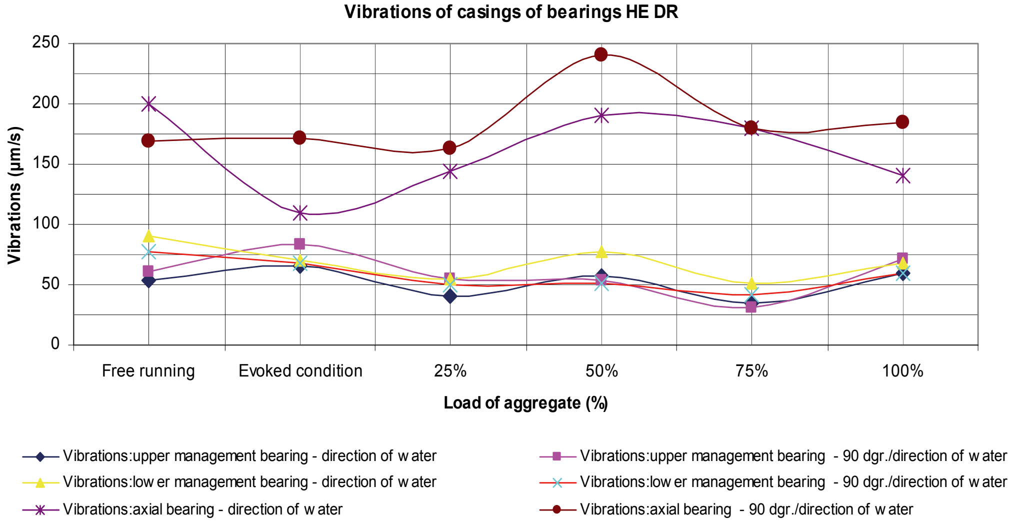
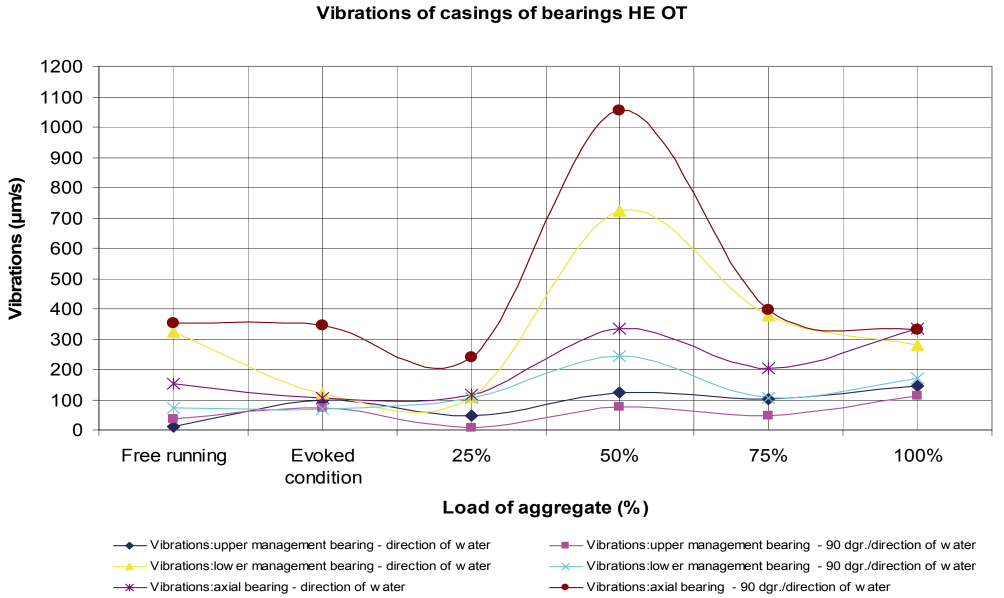
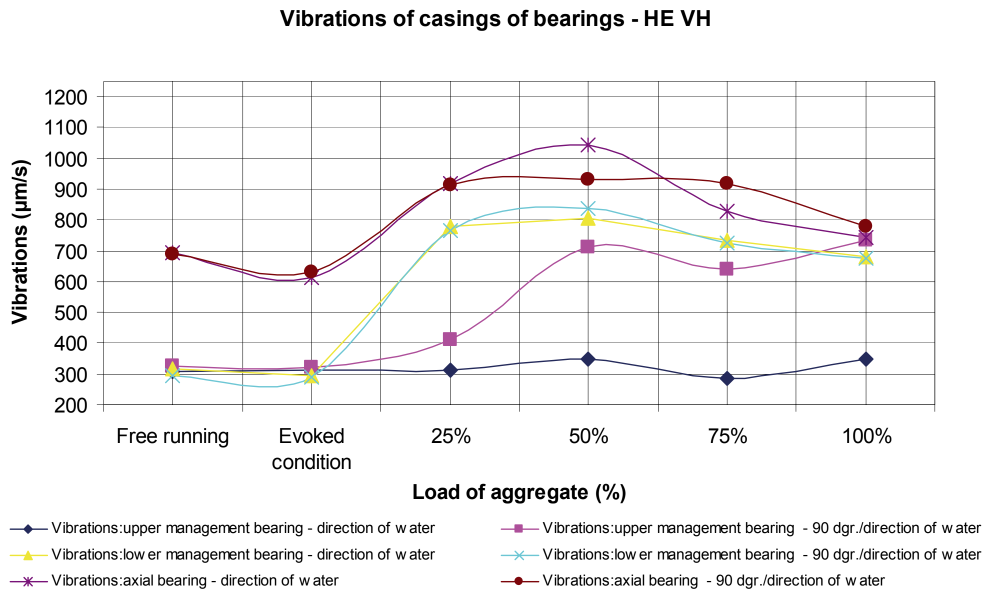
frequencies. The trend of increase of vibrations is very similar at three different aggregates (see Picture 6). The highest speeds of vibrations perform to load at 50%in all cases. Prominent vibrations occur on carrying bearing in the axial direction (rectangular considering direction of the direction of water).



A)



B)



C)

***Figure** 6: Dependence of speed of vibrations on bearings from load of aggregates*

At the carrying, bearing vibrations are 2.0 to 3.5 times larger than vibrations at the management bearings. They also have a different trend of amplitude increase when the vibration frequencies are considered. The increase of the value of speed of vibrations in equable free running can also be found. In this field, the driving spades are completely closed and the direction of the direction of water at partly opened guidance; it works in a larger degree on the pressure surface of the driving spades. The negative axial force on driver increases the most in the range of large speeds of vibrations. In this case, the driver is opened ca. 15° with regards to the optimal association (guidance-driver) and the carrying bearing is the most charged.

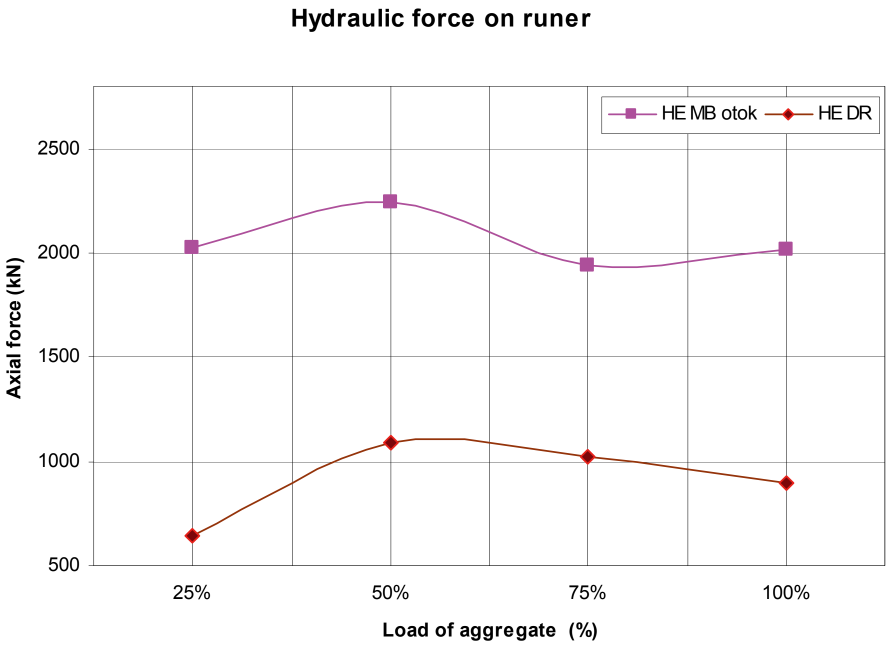
2.2.3 Axial force measurements

From data of the axial forces on driver being measured, it is clear that the maximum of axial force occurs in this field where larger vibrations are performed (50 % load).

Considering that the maximum on the driver in Field 1 is nominal, when comparing the three different hydroelectric power stations (of different nominal can and geometries), the empirical dependence of maximum axial force of driver can be passed with regards to the output of the strength aggregate:

$$F_{aks.g} = P_{50\%} \cdot 265{,}4 - 219{,}04 . \tag{2.5}$$

The equation is valid only for partial estimate of axial force and is issued from measured values on three analogous prototypes of chaplain turbines.



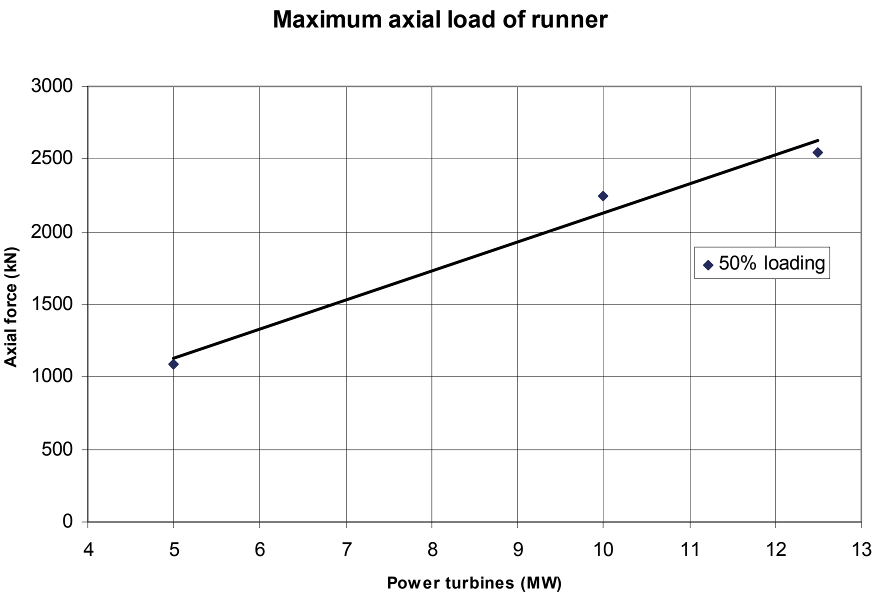


Figure 7: *Dependence of axial force on load of aggregate*

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3 CONCLUSIONS

We can summaries the following findings on treating the displacement of vibrations and axial force on chaplain turbines. The largest displacement of the turbine shaft occurs in the field of the induced aggregate. We can foresee that the cause for enlargement of the displacement (25-30 %) is the electric generator, in comparison to displacement at maximum load. The displacements are reduced with increasing of the load of aggregate. HE DR is not a modified trend of displacement, because of the opposite direction of the rotation on HE and its fitting the trends of HE of OT and HE VH. Considering the results, we can foresee that the axial driver has an impact on reducing displacement turbine shaft. The centre of orbit moves above the turbine wing into the upper leading bearing in direction of water (fourth quadrant). At all loads, the centres of orbits are inside the corner 15° relative to the mechanical centre shaft (the mechanical centre of shaft is valued as a centre at free running and is not bound to the geometry of bearings' centres). The centres of orbits of lower management bearing are turned at all loads of aggregate in the direction of the water of the turbine type (left quadrant). The distance from the centre in idle is approximately half considering the upper leading bearing. The turbine shaft is tilted ca. 0.008° in all cases of load relative the centre on to the right side (viewed from the point of the direction of water after turbine wing). Vibrations on casings of bearings perform operations from half the nominal strength of aggregate. The largest values are measured in the axial direction of the carrying bearing. We can foresee that it is the cause for enlargement in the largest axial force on the driver, and the stream circumstances of flowing off of driving spades. To explain: it is important to process the impact of working regimes on the axial force of driver in a more detailed manner and also to treat in detail the cause of setting up the position of the shaft (center of orbits) in all working points.

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Nomenclature

Symbols	(Symbol meaning)
$A_{average}$	Average (central-9 amplitude values
$F_{axs,g}$	Axial hydraulic force on turbine runner
f	frequency
G_1, G_2	sensor position
K	Shaft orbit
$P_{50\%}$	50 % of nominal turbine loading
s_{max}	Maximum shaft displacement
s_k	Instantaneous shaft displacements
s_1, s_2	instantaneous values
s_{01}, s_{02}	greatest values
s_{u1}, s_{n2}	least values

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s_{m1}, s_{m2}	maximum values
t	time
T	vibration period
X_{peak}	maximum displacements of the reference position
ε	Relative bearing distance
ω	Angular frequency

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ECONOMIC ACTIVITY AND NATURAL GAS AS A POTENTIAL DESTABILIZER OF THE SLOVENIAN ECONOMY

EKONOMSKA AKTIVNOST IN ZEMELJSKI PLIN KOT POTENCIALNI DESTABILIZATOR SLOVENSKE EKONOMIJE

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Keywords: natural gas prices, production by industries, energy supply, aggregate domestic consumption;

Abstract

This article empirically investigates whether natural gas has the potential of destabilizing the Slovenian economy. The results confirmed the indirect relation, that the increase of gas prices decelerates the dynamics of aggregate domestic consumption, which further decelerates activities in individual industries. An empirical analysis has proven that the natural gas does have the potential of forecasting production trends in individual industries within the Slovenian economy. By using the dynamics of natural gas price movements (and other explanatory variables), we can forecast the dynamics of movements in the production of textiles, leather, fur and clothes, rubber- and plastic-based products, metals, furniture, as well as in the processing industry, recycling, electricity, natural gas, steam and hot water supplies in Slovenia.

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Povzetek

V članku je empirično preiskovano ali zemeljski plin ima potencial destabilzacije Slovenskega gospodarstva. Rezultati so potrdili indirektno zvezo, da povišanje cene plina vpliva na dinamiko celotne domače porabe, ki zavira nadaljnje aktivnosti v posamezni industriji. Z empirično analizo se je izkazalo, da ima naravni plin potencial za napovedovanje trendov v posameznih proizvodnih panogah v Slovenskem gospodarstvu. Z dinamiko gibanja cen zemeljskega plina (in druge pojasnjevalne spremenljivke), bomo lahko napovedali dinamiko gibanja v proizvodnji tekstila, usnja, krzna in oblačil, gumenih in plastičnih izdelkov, osnovnih kovin, pohištva, kot tudi v predelovalni industriji, recikliranju, električni energiji, zemeljskega plina, pare in tople vode v Sloveniji.

1 INTRODUCTION

Despite numerous efforts towards a more efficient use of energy, energy needs are soaring. Economic growth in developing countries, especially in China and India, constitute an additional energy price pressure. Price trends do not exclude any energy source, because they are dictated – in addition to increasing needs – by the relatively expensive existing and new alternative technological solutions. Thus, further price increases in energy can be expected in world markets. Energy prices are important for production, business cycle, cost structure, financial markets, export revenues and real exchange rate dynamics. Hayo and Kutan (2005) found that the oil price has a positive impact on stock returns.[4] Meanwhile, Kutan and Wyzan (2005) found that natural reserves are expected to yield significant export revenues and real exchange rate dynamics.

The fastest growing source of primary energy is natural gas. It has been estimated that by 2025 the consumption of natural gas will increase by 67%. For a number of years, the prices have been higher than in the 90s, and will continue to increase in the upcoming years (Energy security 2008).

One MMBtu (MMBtu – one million BTUs, British thermal unit; 1000 cubic feet of natural gas is comparable to 1MBtu, which is occasionally expressed as MMBtu, which is approximately equivalent to 1 GJ) of natural gas gives us six times less thermal energy than a barrel of oil. The price of both energy resources are related in the long-run, because in the past the ratio between the price of crude oil and natural gas was around 10:1 (Hartley et all. 2007). The movement in prices of natural gas in comparison with crude oil and liquefied gas on important world markets during the last twenty years is shown in Picture 1.

[4] Fernandez (2007) confirmed the effect of political conflicts in the Middle East on stock markets worldwide.

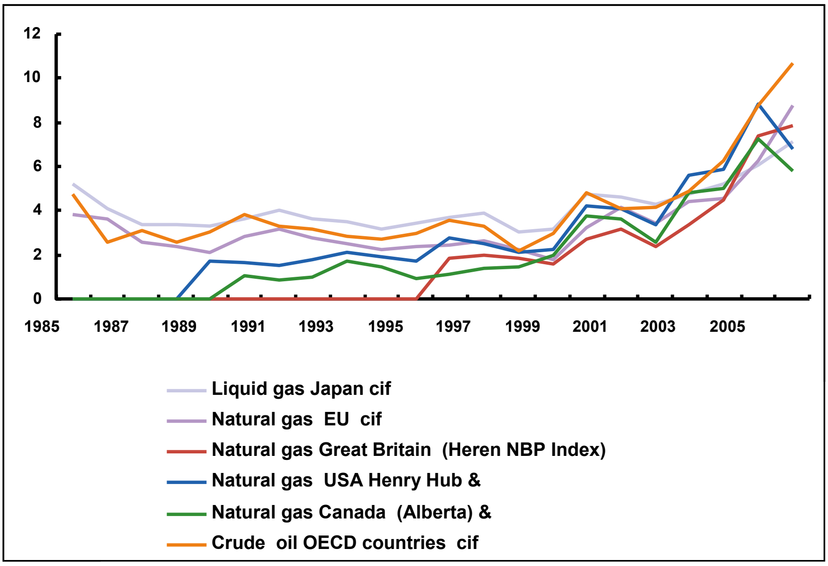

Figure 1: Movement of natural gas prices on important world markets during the last 20 years (CIF = cost insurance freight) Source: Statistical Review of World Energy (2008)

An increase in a global crude oil price will ultimately result in a higher residual fuel oil price and, hence, a higher natural gas price (Hartley et all. 2007). The import prices of natural gas in some European countries during the period between 1996 and 2006 are given in Picture 2. The prices of natural gas in the EU have increased more than two-fold within the last twenty years, and amounted to, on average, 8.77 US dollars in 2006 per 1 GJ. Between 2004 and 2006, the imported price was the highest in Spain and France, and lowest in the United Kingdom and Italy, where the import prices for 1 MMBtu of natural gas were, on average, almost 1.7 US dollars lower than in Spain. In 2007, the cheapest natural gas was found in of Lithuania, Latvia, Estonia and Bulgaria; the most expensive natural gas was in Germany, the United Kingdom and in Hungary (Statistical Review of World Energy 2008).

This article is divided into four parts: part one as introduction, part two discusses the EU's guidelines and the role of the common European natural gas market; part three discusses gas consumption in Slovenia. In part four, we empirically examine the intensity of the impact of natural gas on the Slovenian economy and individual industries, as well as examine the cause/effect relationships between the price and quantity of natural gas, different industries, aggregate domestic consumption, production, employment and inflation. In this way we will answer the question of whether natural gas is an energy product that has significant potential for destabilizing the Slovenian economy. We tested two hypotheses, a direct effect of natural gas on production by industries and an indirect effect through aggregate domestic consumption on industry production.

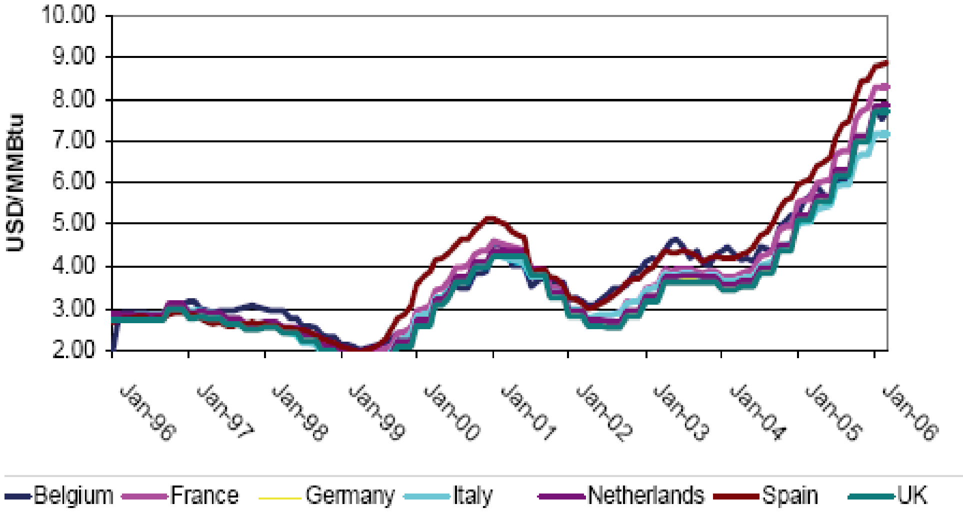

Figure 2: Average import prices of natural gas in European countries between 1996 and 2008, Source: Reinaud (2007).

2 THE ROLE OF THE COMMON EUROPEAN NATURAL GAS MARKET

The development of a common European energy market will ensure the security of supply and lower prices, which subsequently demands the development of connections, improved network infrastructure and the consistent implementation of the Community Competition Law (Brečevič 2003, Serletis and Shahmoradi 2005). It is not possible to establish a competitive and common European market without additional physical capacities, which would involve greater energy »participation« among economies and improved interconnections in the European natural gas network together with a decreased need for spare capacity and eventually also lower costs (Mulder and Zwart 2006).[5]

The European gas market is undergoing substantial changes due to increasing imports from countries outside of the EU and, in part, because of the liberalization process as well. Completion of the internal gas market and changes in the market structure are expected to generate an outcome that will meet fundamental energy policy requirements with regard to: prices, security of supply and protection of the environment. The formation of partnerships among the Caspian and Mediterranean countries, as well as among countries in North Africa and the Middle East, has improved the supply of natural gas in Europe. The new strategy set up by Europe and Africa includes the interconnection of energy systems, which could – when

[5] Natural gas network capacity should enable the transmission of natural gas for thermo-energy objects, for industrial customers and households, as well as facilitate spare capacity for natural gas transmission.

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taking into account a suitable natural gas transmission network - diversify natural gas supplies in Europe (Sagen et all. 2006).

European gas consumption has been increasing considerably over the last years and the share of natural gas in the total EU energy consumption is rising as well. The reasons behind this are related to the environmental attractiveness of gas compared with alternatives like coal, nuclear energy and the low construction costs of gas-fired power plants. With regard to increased gas consumption in households, in the energy sector and in the industry as a whole, and also due to the required formation of a common natural gas market, the following positive effects, arising from investments in natural gas infrastructure, can be expected in the national economy:

- lowering expenses for the transmission of natural gas,
- improved efficiency of the internal natural gas market, price reductions, higher standards of service and increased competitiveness,
- reduction of losses during the transmission and distribution of natural gas,
- increased involvement of the national economy in the energy infrastructure of EU member countries,
- increased storage capacities and reduced dependence on natural gas exporters,
- increased income from network charges.

The adoption of the European Directive concerning common rules for the internal market in natural gas (2003/55/ES), the Directive concerning measures to safeguard the security of the natural gas supply (2004/67/ES), the Directive concerning the production and distribution of energy (2001/77/EC in 2003/54/EC) determine the guidelines for the development of a natural gas network in New EU Member and Associated States.

The Energy Agency of the Republic of Slovenia determines the general conditions for natural gas supplies from the network. Beginning in July 2004, regulations setting rules for access conditions to natural gas networks came into force in the EU states (1228/2003), which is aimed at available network capacities and requires the use of market methods in granting free cross-border transfer capacities. The Council of the European Union in its Council Regulation No. 1223/2004 granted provisions to Slovenia for the transitional period regarding free cross-border capacity, which made it possible for Slovenia to use non-market methods in allocating free capacity until July 2007 (insofar as such capacity did not exceed half of the total available interconnection capacity). The EU Regulation of 2005, which sets rules for the access to natural gas networks, is aimed at ensuring non-discriminatory network access conditions for gas transmission networks taking into account the differences between national and regional markets (Morgan 2006).

The EU Member States should assign national regulators, to determine at the EU level, the tools for the cross-border flow of natural gas, including non-discriminatory network access, tariffs, capacity allocation together with a certain schedule for the market supply. Compliance with the directives should ensure the economical and efficient use of natural gas, investments aimed at improving natural gas storage, the solidarity scheme in cases of interruption of natural gas power supply, improve natural gas infrastructure, and should encourage investments in energy infrastructure with due regard to environmental protections (Jaffe and Victor 2005). Investments in energy infrastructure are also necessary because of the European guidelines, which necessitate the creation of stocks (e.g. a 90-day stock of petroleum and petroleum products, natural gas and liquefied petroleum gas).

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3 NATURAL GAS CONSUMPTION IN SLOVENIA

When considering the fact that half of the energy demand in EU countries is satisfied through imports, and that natural gas consumed in the EU comes mainly from three countries (Russia, Algeria and Norway), import dependence on natural gas gives this energy product the potential to influence the movement of macroeconomic variables and production by industries. If present trends persist, dependence on imports will rise to as high as 80%. It can safely be expected that the price and availability of natural gas is likely to have a growing influence on the national economy in the future. The liberalization of the gas market is expected to ensure the security of gas supply (Festić, Križanič and Repina 2008).

The price of petrol, natural gas and electricity has almost doubled in the last couple of years. At the same time, the price of natural gas is below the European average in Slovenia, where gas prices for industrial customers are approximately 13% below the European average and lower than the gas prices for households.

With regard to increasing demand for fossil fuels, congestion of supply chains and increased import dependency it can be expected that the price of natural gas is unlikely to fall. This fact can also encourage energy innovativeness and efficiency, increase efforts aimed at the competitiveness of renewable energy sources, and the importance of renewable energy sources and their potential for influencing natural gas and oil processes (Wiser et. al 2005).

The indicators in Table 1 show the dynamics of natural gas consumption growth in individual industries with regard to the dynamics of final natural gas consumption movements. Cumulatively, the dynamics of natural gas consumption growth in the energy sector exceeded the dynamics of final natural gas consumption growth by 32% in the period between 1997 and 2000. After 2000, the growth of final natural gas consumption exceeded the growth of natural gas consumption in the energy sector, namely by 17.5% in 2001, by 24% in 2003, by 1.6% in 2004 and by 22.2% in 2005. The dynamics of natural gas consumption growth in manufacturing and civil engineering lagged behind the dynamics of final consumption until 2002 by between 2.5% and 10.2%. The dynamics of natural gas consumption in households exceeded the dynamics of final consumption by 1.6% to 14.9% in the period between 2000 and 2005, whereas the cumulative dynamics of movements for the period between 1997 and 2000 showed a 19.6% higher growth of natural gas consumption in households with regard to final natural gas consumption growth. The dynamics of non-energy consumption lagged by 6.5% to 11% behind the dynamics of final consumption, or accelerated by 10% to 14%.

The key question of this analysis is the question of whether available natural gas prices and available quantities have the potential of influencing the production in different industries in Slovenia and if changes in the growth of production in the Slovenian economy can be influenced by natural gas prices and quantity fluctuations (Kliesen 2006). The theoretical basis for this analysis is that smaller quantities of available energy products and higher prices lower the dynamism of production, increase the general price level, reduce employment and have a negative influence on net exports. Since oil is more often used as an energy product, the influence of its price and available quantities on the stated dependent variables has been empirically confirmed (Hamilton 1983, Jones, Leiby and Paik 2004, Guo and Klisen 2005). Empirical studies on the influence of natural gas on the stated dependent variables are rather

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rare, due to the fact that natural gas as an energy product has not been so widely used. Some studies confirmed the influence of natural gas prices on regional economic activities (Leone 1982, Considine and Mount 1983), on the redistribution of income between households and natural gas suppliers (Stockfisch 1982) and on inflation (Ott and Tatom 1982). Conclusions derived from the above studies regarding the influence of higher natural gas prices on inflation, on the reduction of real income in households and the reduction of (regional) economic activity are not significant. Studies confirmed that a 20% natural gas price growth had approximately the same effect as a 10% petrol price growth on the growth of real GDP (Kliesen 2006). On the other hand, the growth of natural gas prices only lowered the consumption of lower budget households if it was unanticipated (Cullen et al. 2005).

Table 1: Natural gas consumption indicators in Slovenia

(mio Sm3)	1997/2000	2000/01	2001/02	2002/03	2003/04	2004/05
Import/consumption	1.0072	1.0011	0.9998	1.0015	0.9999	1.0010
Energy sector /final consumption	1.3258	0.8251	1.0376	0.7593	0.9842	0.7778
Manufacturing and civil engineering/final consumption	0.8979	0.8973	0.9749	1.0558	1.0083	1.0296
Households/final consumption	1.1962	1.0161	1.1468	1.1497	1.0399	1.0505
Other consumers/final consumption	0.2054	4.1016	1.1858	0.4799	1.1343	0.4433
Non-energy consumption/final consumption	-	0.9359	0.8893	1.1465	0.8864	1.1082

* Quotient of year-on-year indexes of growth rates for selected indicators.

* Sm3: standard cubic meter at 15 °C and 1.01325 bar.

* Manufacturing and civil engineering include manufacturing activities without the production of coke, petroleum products, nuclear fuel and civil engineering according to the standard classification of activities.

* Final energy consumption is energy consumption, which is consumed in transportation, industrial, commercial, agriculture, public and household sectors; with the exception of deliveries to the energy conversion sector and to the energy industry itself.

* Other consumers refer to sectors, which are not explicitly stated in the indicators.

Source: Own calculations on the basis of SURS, Energy balance (2007).

In the following chapter we test two hypotheses: a direct effect of natural gas on production by industries and an indirect effect through aggregate domestic consumption on industry production.

4 THE INFLUENCE OF PRICE AND AVAILABLE NATURAL GAS QUANTITIES IN THE SLOVENIAN ECONOMY

Data. By collecting the necessary data we relied on the internal data base of the EIPF (2007) and OECD (2007).[6] The model has been assessed on the basis of quarterly data within the stated period from the third quarter of 1992 to the first quarter of 2007. The models include key segments of the entire Slovenian economy, as well as production in individual industries. Movements in total (industrial) production, production in different industries, price movements (the consumer price index, the producer price index of durables and the producer price index of whole industrial products), movements in employment and exports (of goods and services), the Tolar-Euro exchange rate, the aggregate domestic consumption (as total domestic consumption of households, investment and national consumption), domestic consumption (of households), gross wages in the tradable sector, stocks of goods, the prices of metal, the petroleum product prices corrected by excise duties, the price of oil,[7] the price of natural gas[8] and natural gas consumption (as gross natural gas consumption in Slovenia) were utilized.

Moffatt and Salies (2003) demonstrated that logarithmic approximation is accurate if the rates of change among variables are reasonably small. The time series are transformed into differences in logarithms as an approximation for growth rates measured in percentage changes in the original time series. The difference in logarithms (dlog) is practically equivalent to percentage change. After deriving the transformed time series, the stationarity of all the selected time series' has been obtained at a 1% significance level (Dickey and Fuller 1979), although the unit root test revealed that at least one time series for each country seems to already be a candidate for stationarity in original form.

Because the analysis including the dummies did not significantly change the results, we decided to employ only annual growth rates as quarterly data - year-on-year basis for the time series of total industrial production, production by industries, real export of goods and services, standardized unemployment rates, stocks of goods, the aggregate domestic consumption, consumption of households and the prices of consumer and industrial products.

Methodology. In order to assess the effects of potential natural gas prices and quantity dynamics on the Slovenian economy, the method of least squares and impulse response methodology was employed. The equations were assessed by the difference of logarithms for chosen variables by taking into account the optimal time delay and best Akaike criterion. The ARMA technique incorporates residuals from previous observations into the regression model for current observation. If the correlogram shows that a serial correlation dies off after a small number of lags/increasing number of lags, the series will obey a low-order moving average process/autoregressive process (MA/AR) (Ruey and Tiao 1984). After achieving good results in the Breusch-Godfrey/ARCH test, the hypothesis H_0 about the non-existence of serial autocorrelation of residuals was accepted. According to the Chow forecast test and Ramsey-

[6] The Economic Institute of the Law School, Ljubljana.

[7] Brent, in $ per barrel. The prices of oil were converted in Euros.

[8] The price of imported natural gas through gas pipelines (in EUR/MBTu), wholesale price, weighted average for EU-25.

Reset test, which were used for proving the stability of the estimated functions, we have accepted the hypothesis regarding structural stability (Thursby 1982).

The VAR models include a considerable number of variables and it is necessary to test each of them for exogeneity. Testing for exogeneity follows the methodology proposed by Greene (2003). Greene (2003, 582) made clear that tests for exogeneity can be based on the concept of Granger causality applied to individual equations and examined by the Wald test in order to test the significance of a particular explanatory variable. The reaction of a variable to an impulse generated by another variable is assumed to reveal the causal relationship between them (Engle and Granger 1978) and the relative importance of each random innovation in affecting the variables in the models (Jones et al 2003).

How macroeconomic shocks - in the sense of natural gas prices dynamics – affect industry production was analyzed by impulse responses (Sims and Zha 1999). Analyzing the residuals' covariance matrix facilitates the assessment of the robustness of the impulse analysis towards the re-ordering of variables. Since there are correlations between some residuals, it is necessary to examine the sensitivity of the responses to the re-ordering of the variables. Therefore, recursive identification is used, which separates the residuals into orthogonal shocks using the Cholesky factorization of the covariance matrix of residuals (Canova 2003). Recursive identification subsequently attributes all the contemporaneous correlations of the residuals and all of the effects of any common components on the variable that is ordered first in the VAR system. Each impulse or shock equals one standard deviation of the time series for the respective variable and causes other time series to respond (Pesaran and Shin 1998).

We analyzed the potential influence of natural gas price and quantities of individual sectors, as well as on the entire Slovenian economy. Regression activities in individual industries shown in Table 2 were analyzed on the basis of the model as seen from the following equation:[9]

$$Dlog(X_t\text{-}sector)= {}_{t=1}^{i}\sum [b_1\cdot Dlog(P\_gas_t)]+ {}_{t=1}^{i}\sum [b_2\cdot Dlog(Q\_gas_t)]+ {}_{t=1}^{i}\sum [b_3\cdot Dlog(X_{t-i}\text{-}sector)]+ {}_{t=1}^{i}\sum [b_4\cdot Dlog(sp1_t)]+ {}_{t=1}^{i}\sum [b_5\cdot Dlog(efob\_eu_t)]+ {}_{t=1}^{i}\sum [b_6\cdot Dlog(zal_{t-i}/qb1_t)]+ \varepsilon_t \qquad (1)$$

Price movements were explained by the price movements of petroleum products corrected by excise duties, natural gas prices, metals, gross wages in the tradable sector, the movements of relationships between stocks and industrial production, and the movements of relationships between stocks and aggregate domestic consumption (equation 3). In order to assess the

[9] Where: *Dlog* represents difference in logarithm as an approximation for growth rate; b_m is the coefficients of regression equations; X_t is the output of the chosen sector; P_is the gas_t prices of gas imported through gas pipelines; Q_gas_t is the amount of natural gas used in Slovenia; X_{t-n} is the output for the chosen sector during past quarters; $sp1_t$ is the aggregate domestic consumption; $efob\_eu_t$ is the export of goods; zal_t is the stocks of goods and $qb1_t$ equals total industrial production. The maximum time shift is 10 quarters.

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influence on the whole economy (industrial production, inflation, employment, export of goods, aggregate domestic consumption) the following equations were used:[10]

$$Dlog(qb1_t)= \sum_{t=1}^{i} [b_1 \cdot Dlog(P\_gas_t)] + \sum_{t=1}^{i} [b_2 Dlog(Q\_gas_t)] + \sum_{t=1}^{i} [b_3 \cdot Dlog(sp1_{t-i})] + \sum_{t=1}^{i} [b_4 \cdot Dlog(efob\_eu_{t-i})] + \sum_{t=1}^{i} [b_5 \cdot Dlog(es\_eu_{t-i})] + \varepsilon \quad (2)$$

$$Dlog(price\_stst_t)= \sum_{t=1}^{i} [b_1 \cdot Dlog(P\_gas_t)] + \sum_{t=1}^{i} [b_2 \cdot Dlog(bpl\_t_t)] + \sum_{t=1}^{i} [b_3 \cdot Dlog(zal_{t-i}/sp1_{t-i}/)] + \sum_{t=1}^{i} [b_4 \cdot Dlog(sp1_{t-i}/qb1_{t-i})] + \sum_{t=1}^{i} [b_5 \cdot Dlog(tgor_t)] + \sum_{t=1}^{i} [b_6 \cdot Dlog(metals_t)] + \sum_{i=1}^{n} [b_7 \cdot Dlog(pc\_spt_t)] + \varepsilon \quad (3)$$

$$Dlog(zap_t)= \sum_{t=1}^{i} [b_1 \cdot Dlog(P\_gas_t)] + \sum_{t=1}^{i} [b_2 \cdot Dlog(Q\_gas_t)] + \sum_{t=1}^{i} [b_3 \cdot Dlog(sp1_{t-i}/zal_{t-i})] + \sum_{t=1}^{i} [b_4 \cdot Dlog(sp1_{t-i}/qb1_{t-i})] + \sum_{t=1}^{i} [b_5 \cdot Dlog(efob\_eu_{t-i})] + \varepsilon \quad (4)$$

$$Dlog(efob\_eu_t)= \sum_{t=1}^{i} [b_1 \cdot Dlog(P\_gas_t)] + \sum_{t=1}^{i} [b_2 \cdot Dlog(Q\_gas_t)] + \sum_{t=1}^{i} [b_3 \cdot Dlog(sp1_{t-i}/zal_{t-i})] + \sum_{t=1}^{i} [b_4 \cdot Dlog(sp1_{t-i}/qb1_{t-i})] + \sum_{t=1}^{i} [b_5 \cdot Dlog(eur_t)] + \sum_{t=1}^{i} [b_6 \cdot Dlog(cbs1_{t-i})] + \varepsilon \quad (5)$$

$$Dlog(sp1_t)= \sum_{t=1}^{i} [b_1 \cdot Dlog(P\_gas_t)] + \sum_{t=1}^{i} [b_2 \cdot Dlog(efob\_eu_{t-i})] + \sum_{t=1}^{i} [b_3 \cdot Dlog(sp1_{t-i}/zal_{t-i})] + \sum_{t=1}^{i} [b_4 \cdot Dlog(zal_t/qb1_{t-i})] + \sum_{t=1}^{i} [b_5 \cdot Dlog(pcs_t)] + \varepsilon \quad (6)$$

Results. The results confirm cyclical movements (Serletis and Kemp 1998) and the influence of the price and quantity of natural gas on some activities in Slovenia. The importance of natural gas for economic activity is increasing (see, Krichene, 2002, Michot 2004). With regard to the results given in Table 2, it can be said that a larger amount of natural gas has a positive effect on: the production of textiles, leather, fur and clothes (with a low coefficient of 0.5), on the processing industry (with a higher elasticity coefficient 1.9), on the production of metals (elasticity 4.3), on the processing of wood (7.5), on electrical machinery (2.9), and on the manufacture of furniture and other processing activities (total coefficients 8.8). Higher natural gas consumption triggers elasticity in the dynamics of the electricity supply, the natural gas supply, the steam supply and the hot water supply (elasticity coefficient 2.4), as well as on the whole of industrial production (with elasticity 0.06).

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[10] Where *Dlog* represents difference in logarithm; b_m is the coefficient of regression equations; $qb1_t$ is industrial production; $sp1_t$ is aggregate domestic consumption; $cbs1_t$ is the domestic consumption of households; zap_t is employment; $sp1_{t-n}/zal_{t-n}$ is the relation between aggregate domestic consumption and stocks of goods; $sp1_{t-n}/qb1_{t-n}$ is the relation between aggregate domestic consumption and industrial production; $zal_{t-n}/sp1_{t-n}$ is the relation between stocks and aggregate domestic consumption; $efob\_eu_t$ is the export of goods; es_eu_t is the export of services; eur_t is the Tolar-Euro exchange rate; $tgor_t$ is the price of petroleum products corrected with excise duties;, $metals_t$ is the price of metals; bpl_t_t is gross wages in the tradable sector; $price\_stst_t$ is the consumer price index; pc_spt_t is the producer's price index of durables and pcs_t is the producer's price index of all industrial products. Maximum time shift is 11 quarters.

The results show that the potential influence of natural gas prices on production in certain industries, namely, the price of natural gas, has a potential influence on the dynamics of the movement of the whole industrial production at a 5% significance level with an elasticity of coefficient -0.11 and at a time shift of two quarters (see, Kliesen 2006); as well as on the dynamics of aggregate domestic consumption at a 5% significance level with an elasticity coefficient of -0.99 and at a time shift of four quarters, with the response of exports being statistically insignificant. Long-term higher natural gas prices have an immediate and long-term impact on consumer spending on energy goods and services (Henry and Stokes 2006). The price of natural gas could be used for forecasting movements in the production of textile, leather, fur and clothes (with an elasticity coefficient of -3.2), the production of paper and cardboard (-1.3), intermediate consumption products (-0.09), leather and footwear (-1.2) and for the production of products from rubber and plastics (total coefficient -0.9). The dynamics of movements in recycling could be forecasted by means of natural gas price movements, because the total coefficient is negative (-2.7) at a 5% significance level. With the dynamics of natural gas price movements, the dynamics of movements in the production of metals could be forecasted, with the total coefficient at -0.15. Electricity, natural gas, steam and hot water supply negatively elastically respond (coefficient -5.7) to a 1% increase in natural gas prices (Table 2).

The collected results also show an influence of natural gas prices on inflation.[11] From the equation in Table 2, it can be seen that an increase in the price of natural gas by one percentage point contributes to an increase in living costs by 0.021 percentage points, whereas the growth of oil prices and petroleum products (without excise duties) is higher and amounts to 0.04 percentage points in Slovenia. Natural gas prices can ignite inflation and cause recession (Krichene and Askari 2007). An increase in natural gas prices decelerates aggregate domestic consumption in Slovenia (with the coefficient -0.99), which then further decelerates total industrial production (with the coefficient 0.37) and the production by industries (with a coefficient of 0.14 in recycling and the chemical industry, a coefficient of 0.53 in the furniture industry, a coefficient of 0.08 among electrical machinery equipment, a coefficient of 0.04 in the metal industry, a coefficient of 0.03 in the textile industry, a coefficient of 0.09 in the processing industry, a coefficient of 0.15 for plastics and a coefficient of 0.02 in the production of paper, pulp and cardboard). The developing countries and transition economies take explicit account of the direct impact of higher (oil and) natural gas prices and the secondary impact on electricity prices, other than through the general rate of inflation. Higher gas prices would undoubtedly drive up the prices of other fuels, magnifying the overall macroeconomic impact. Rising gas use worldwide will increase this impact (IEA 2004).

Positive employment effects arise from an extension of the available quantities of natural gas in Slovenia (for other countries see, KPMG 2005).[12] Higher natural gas prices are contributing to stubbornly high levels of unemployment and exacerbating budget-deficit problems in many OECD and other energy-importing countries (IEA 2004). The results of the study by Baclajanschi et al. (2007) suggest that natural gas prices changes could dampen economic growth while

[11] Bole and Rebec (2007) proved that the increase of natural gas prices contribute to an increase of industrial product prices with a coefficient of 0.031 in the time period of four quarters.

[12] If labour supply or tradable sector productivity increases in emerging Asian economies, which are an important factor driving energy price increases, then industrial countries receive some positive terms-of-trade effects coming through non-energy tradable goods that offset some of the negative implications of permanently higher real energy prices (Babee and Hunt 2007).

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putting additional strains on the current account deficit. But the significant impact of natural gas on exports was not proven for the case of Slovenia.

We confirmed (Table 2) that by using the dynamics of natural gas price movements (and other explanatory variables) we could forecast the dynamics of movement in the production of textiles, leather, fur and clothes, products from rubber and plastic materials, metals, furniture and goods from the processing industry, recycling, electricity, natural gas, steam and hot water supplies. The model indicates that for industries that have a large cost share of natural gas, natural gas price shocks mainly reduce supply (see, Lee and Ni 2002). It can be seen from the pictures given in the Appendix that the assessed equations are a relatively good indicator, on the basis of which we could reach conclusions about the influence of natural gas prices and quantities on the dynamics of production in different industries in Slovenia (Appendix, Pictures 1-13). It can also be concluded from the results in Table 2 that there is an indirect impact of natural gas prices through the dynamics of aggregate domestic consumption on production by industries. The consequent influence of the dynamics of aggregate domestic consumption impacts on the activities in individual industries (with coefficients on an interval from 0.004 to 0.044).

Furthermore, we performed the VAR model as an impulse-response analysis (Table 3) confirming the indirect impact of gas prices on individual industries through aggregate domestic consumption in Slovenia (see, Kilian 2007).[13]

Table 2: "The impact of gas" price and quantity on economic activities in Slovenia

	coefficient (time-lag)	t-stat. (P-value)	Coeff. (time-lag)	t-stat. (P-value)	Coeff. (time-lag)	t-stat. (P-value)	Coeff. (time-lag)	t-stat. (P-value)	coefficient (time-lag)	t-stat. (P-value)	Coeff. (time-lag)	t-stat. (P-value)
	P_GAS		Q_GAS		DB		EFOB_EU					
The production of textile, leather, fur and clothes (db)	-3.222940 (0)***	-6.013011 (0.0000)	0.500217 (9)**	2.511891 (0.0198)	0.026451 (9)	18.53186 (0.0000)	6.870247 (2)	8.131022 (0.0000)				
2000:2 2006:4, N = 27, R^2 = 0.907384, DW = 1.872980 Breusch-Godfrey LM test $_{(2)}$ = 0.068815 (0.933720), Chow Forecast test (2003:1 to 2006:4) = 0.563794 (0.831819)												
	X21		SP1		EFOB_EU		Q_GAS		P_GAS			
The production of pulp, paper and cardboard and products from paper and cardboard (x21)	-0.262142 (7)	-15.18943 (0.0000)	0.018392 (8)***	3.343124 (0.0031)	-1.890301 (8)	-2.348919 (0.0287)	0.353623 (10)*	1.370856 (0.0849)	-1.315647 (10)**	-2.490019 (0.0212)		

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[13] The price of natural gas influences the dynamics of aggregate consumption growth, with the Granger tests being causally significant for a time lag of 2-6 quarters. The dynamics of aggregate domestic consumption further influences activities in different industries.

2000:3 2006:4, N = 26, R^2 = 0.920949, DW = 1.527709

$ARCH_{(2)}$ = 0.057321 (0.812902), Chow forecast test (2002:3 to 2006:4) = 0.858094 (0.649628)

	P_GAS		Q_GAS		DH		SP1		ZAL/QB1			
The production of products from rubber and plastics (dh)	-0.933668 (10)**	-2.672800 (0.0139)	-4.408707 (10)	-0.805432 (0.4292)	1.055818 (4)	74.16612 (0.0000)	0.150098 (1)**	2.621724 (0.0163)	-0.153468 (5)	-0.658465 (0.0186)		

2000:4 2006:4, N = 25, R^2 = 0.931744, DW = 2.086851

$ARCH_{(2)}$ = 0.256314 (0.617483), Chow forecast test (2005:1 to 2006:4) = 0.903952 (0.548859)

	QA		SP1		EFOB_EU		Q_GAS		P_GAS			
Intermediate consumption products (qa)	0.335438 (4)	3.089778 (0.0044)	-0.000921 (9)	-2.215407 (0.0647)	0.485258 (0)	7.238334 (0.0000)	0.016487 (2)	0.814567 (0.4220)	-0.093476 (2)**	-2.474396 (0.0194)		

1998:3 2006:4, N = 34, R^2 = 0.765827, DW = 2.333918

$ARCH_{(2)}$ = 0.220694 (0.641800), Ramsey Reset $test_{(2)}$ = 0.587059 (0.562900)

	QD		SP1		EFOB_EU		Q_GAS		P_GAS			
Processing industry (qd)	0.613779 (2)	4.862532 (0.0001)	0.087719 (3)***	4.515071 (0.0001)	5.466996 (6)	2.055970 (0.0504)	1.966584 (6)**	2.342812 (0.0274)	-2.053990 (9)	-1.170855 (0.2527)		

1999:3 2006:4, N = 30, R^2 = 0.716084, DW = 2.108046

Breusch-Godfrey LM $test_{(2)}$= 0.071165 (0.931513), Ramsey Reset $test_{(2)}$ = 0.033914 (0.855437)

	X17		SP1		EFOB_EU		Q_GAS		P_GAS			
The production of textiles (x17)	0.014785 (5)	0.366130 (0.7181)	0.028063 (4)**	2.326284 (0.0306)	2.102739 (1)	3.686714 (0.0015)	0.548276 (9)	1.172850 (0.2546)	-1.852497 (10)*	-1.865871 (0.0768)		

2000:2 2006:4, N = 27, R^2 = 0.752543, DW = 2.145073

Breusch-Godfrey LM $test_{(2)}$= 0.780193 (0.554270), Chow forecast test (2003:4 to 2006:4) = 0.403260 (0.925275)

	X19		SP1		EFOB_EU		Q_GAS		P_GAS		ZAL	
The production of textiles, leather, footwear and leather products, except clothes (x19)	0.610665 (1)	7.965045 (0.0000)	-0.128567 (2)	-3.513177 (0.0616)	21.51613 (4)	4.658029 (0.0001)	-1.088944 (2)	-0.780773 (0.4417)	-1.213019 (1)***	-4.848211 (0.0000)	-46.27567 (2)	-2.856997 (0.0081)

1998:3 2006:4, N = 34, R^2 = 0.625625, DW = 2.408312

Breusch-Godfrey LM $test_{(2)}$= 1.468346 (0.349496), Chow forecast test (2003:2 to 2006:4) = 0.709729 (0.738056)

	X20		SP1		EFOB_EU		Q_GAS		P_GAS			
Wood processing, the production of products from wood,	-0.435065 (2)	-2.827475 (0.0104)	-0.125378 (8)	-1.878986 (0.0949)	27.12919 (2)	2.445472 (0.0238)	7.514130 (9)***	2.938952 (0.0081)	-3.608324 (9)	-0.747163 (0.463		

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cork, straw and wicker, except furniture (x20)										7)		
2000:3 2006:4, N = 26, R^2 = 0.480256, DW = 2.030427 $ARCH_{(2)}$ = 1.250471 (0.427437), Chow forecast test (2005:4 to 2006:4) = 0.389456 (0.848370)												
	X24		SP1		EFOB_EU		Q_GAS		P_GAS		ZAL	
The production of chemicals, chemical products, artificial fibre (x24)	0.601273 (3)	3.778989 (0.0014)	0.142721 (5)***	3.765901 (0.0014)	11.51988 (8)	2.157684 (0.0447)	-0.537118 (10)	-0.369004 (0.7164)	-0.233803 (10)	-0.085718 (0.9326)	-28.54448 (2)	-2.331299 (0.0316)
2000:4 2006:4, N = 25, R^2 = 0.669352, DW = 1.949627 $ARCH_{(2)}$ = 0.689568 (0.513332), Chow forecast test (2003:1 to 2006:4) = 0.773409 (0.698366)												
	X27		Q_GAS		P_GAS		SP1		ZAL/QB1			
The production of metal (x27)	-0.380223 (2)	-2.955733 (0.0078)	4.346521 (10)***	2.993553 (0.0072)	-0.153468 (5)**	-4.658465 (0.0186)	0.046263 (2)*	2.221293 (0.0380)	0.186595 (7)	0.723895 (0.4784)		
2000:4 2006:4, N = 25, R^2 = 0.594917, DW = 1.768461 $ARCH_{(2)}$ = 0.100145 (0.754639), Chow forecast test (2003:4 to 2006:4) = 0.520083 (0.858286)												
	X31		SP1		EFOB_EU		Q_GAS		P_GAS			
The production of electrical machinery and equipment (x31)	-0.152948 (10)	-1.835889 (0.0821)	0.079716 (5)***	3.984689 (0.0008)	10.61524 (0)	2.808698 (0.0112)	2.896689 (3)***	4.246850 (0.0004)	2.923981 (1)	1.534620 (0.1414)		
2000:4 2006:4, N = 25, R^2 = 0.595954, DW = 1.975637 $ARCH_{(2)}$ = 0.372314 (0.547998), Chow forecast test (2003:4 to 2006:4) = 0.885863 (0.601415)												
	X36		SP1		EFOB_EU		Q_GAS		P_GAS		ZAL	
The production of furniture and other processing industry (x36)	-0.337243 (8)	-2.874316 (0.0097)	0.538904 (7)***	7.053525 (0.0000)	28.90391 (6)	2.817725 (0.0110)	8.881817 (9)***	3.515827 (0.0023)	-2.617817 (11)*	-1.949176 (0.0662)	-45.29781 (1)	-2.202014 (0.0402)
2000:3 2006:4, N = 26, R^2 = 0.852104, DW = 1.795646 $ARCH_{(2)}$ = 0.649188 (0.532640), Chow forecast test (2003:4 to 2006:4) = 1.056942 (0.504015)												
	X37		SP1		EFOB_EU		Q_GAS		P_GAS			
Recycling (x37)	0.027433 (10)	0.288174 (0.7763)	0.142751 (2)***	6.965770 (0.0000)	15.99326 (0)	10.96167 (0.0000)	0.693842 (0)	1.427468 (0.1697)	-2.702904 (0)**	-2.232865 (0.0378)		
2000:3 2006:3, N = 25, R^2 = 0.728472, DW = 1.408091 Breusch-Godfrey LM $test_{(2)}$= 0.715051 (0.503304), Chow forecast test (2006:1 to 2006:3) = 0.999896 (0.418282)												

	X40		SP1		EFOB_EU		Q_GAS		P_GAS		QB1	
Electricity, natural gas, steam and hot water supply (x40)	0.396796 (4)	8.000022 (0.0000)	0.054496 (4)*	1.862187 (0.0766)	7.915669 (4)	2.416728 (0.0248)	2.438719 (8)**	2.245681 (0.0356)	-5.747702 (10)***	-6.717252 (0.0000)	0.147352 (4)	4.211986 (0.0004)

2000:1 2006:4, N = 28 R^2 = 0.850935, DW = 2.047823

Breusch-Godfrey LM test$_{(2)}$= 0.337827 (0.717517), Chow forecast test (2003:3 to 2006:4) = 1.038522 (0.506983)

	SP1		EFOB_EU		Q_GAS		P_GAS		ES_EU			
Industrial production, stocks and productivity (QB1)	0.373996 (4)***	4.747693 (0.0001)	0.276523 (4)	2.437814 (0.0219)	0.067417 (1)**	2.668476 (0.0129)	-0.108988 (2)**	-2.359337 (0.0261)	0.098514 (2)	3.319647 (0.0027)		

1998:3 2006:1, N = 31, R^2 = 0.814192, DW = 2.125026

ARCH test$_{(2)}$= 0.000607 (0.980526), Chow forecast test (2000:4 to 2006:1) = 0.322882 (0.963538)

	BPL_T		P_GAS		TGOR		METALS		ZAL/SP1		SP1/QB1		PC_SPT	
Consumer prices index - inflation (PRICES_STST)	-0.056551 (3)	-6.251809 (0.0000)	0.021948 (14)**	2.722150 (0.0151)	0.039637 (0)	3.695588 (0.0020)	0.005695 (11)	2.095563 (0.0524)	-0.026861 (0/11)	-4.240594 (0.0006)	-0.005438 (0/7)	-1.003694 (0.3305)	-0.059577 (11)	-2.846147 (0.0117)

2001:1 2006:4, N = 24, R^2 = 0.904033, DW = 2.913340

ARCH test$_{(2)}$= 0.457981 (0.506321), Chow forecast test (2004:1 to 2006:4) = 1.901214 (0.327287)

	P_GAS		Q_GAS		EFOB_EU		SPI1/ZAL		SP1/QB1			
Employment (zap)	-0.025518 (2)***	-7.151296 (0.0000)	0.012136 (6)***	5.065886 (0.0000)	0.039394 (8)	3.763953 (0.0011)	0.047100 (0/4)***	4.481398 (0.0002)	0.009656 (3/4)	1.602906 (0.1232)		

1999:4 2006:3, N = 28, R^2 = 0.759094, DW = 1.990993

Breusch-Godfrey LM test$_{(2)}$= 0.763465 (0.528475), Ramsey Reset test$_{(2)}$ = 0.371035 (0.774795)

	P_GAS		Q_GAS		SPI1/ZAL		SP1/QB1		EUR		CBS1	
Export of goods (efob_eu)	0.104661 (1)	1.673244 (0.1107)	-0.009447 (8)	-0.334794 (0.7414)	0.615145 (0/2)***	3.132783 (0.0055)	-1.479647 (0/0)	-6.237531 (0.0000)	0.926750 (7)	1.928675 (0.0688)	0.667617 (0)	2.352748 (0.0296)

2000:3 2006:4, N = 26, R^2 = 0.783541, DW = 1.660452

ARCH test$_{(2)}$= 0.041831 (0.839742), Ramsey Reset test$_{(1)}$ = 0.052013 (0.822167)

	P_GAS		EFOB_EU		SPI1/ZAL		ZAL/QB1		PCS			
Aggregate domestic consumption (sp1)	-0.994859 (4)	-1.971846 (0.0338)**	15.09266 (2)	1.031007 (0.3098)	0.009016 (7)***	11.19369 (0.0000)	-6.748507 (3)	-0.910699 (0.3689)	-1.061443 (3)	-3.995094 (0.0003)		

1997:1 2006:3, N = 39, R^2 = 0.815939, DW = 1.840738

ARCH test$_{(2)}$= 0.477947 (0.624158), Chow forecast test (2000:2 to 2006:3) = 0.477224 (0.926332)

*** 1% level of significance, ** 5% level of significance, * 10% level of significance.

Source: EIPF data base, OECD and own calculations (November 2007).

Table 3: Impulse response analysis (aggregate domestic consumption and output of individual industry, VAR)[14]

Response of DLOG(SP1):				
Period	DLOG(P_GAS)	DLOG(Q_GAS)	DLOG(SP1)	DLOG(X17)
4	-0.008689	0.006977	-0.008792	0.008732
5	-0.002389	0.002662	0.034324	-0.003249
Response of DLOG(X17):				
Period	DLOG(P_GAS)	DLOG(Q_GAS)	DLOG(SP1)	DLOG(X17)
1	-0.014387	-0.008431	-0.023146	0.056123
3	-0.007144	-0.003043	0.024202	0.009231
Response of DLOG(SP1):				
Period	DLOG(P_GAS)	DLOG(Q_GAS)	DLOG(SP1)	DLOG(X19)
2	-0.002681	-0.005871	-0.016462	-0.006936
4	-0.008076	0.010948	-0.008593	-0.009860
Response of DLOG(X19):				
Period	DLOG(P_GAS)	DLOG(Q_GAS)	DLOG(SP1)	DLOG(X19)
1	-0.024918	0.007336	-0.030517	0.087386
7	-0.003389	0.033734	0.017158	0.028184
Response of DLOG(SP1):				
Period	DLOG(P_GAS)	DLOG(Q_GAS)	DLOG(SP1)	DLOG(X21)
2	-0.003906	-0.005116	-0.018949	-0.007198
4	-0.007417	0.005735	0.001784	-0.007910
Response of DLOG(X21):				
Period	DLOG(P_GAS)	DLOG(Q_GAS)	DLOG(SP1)	DLOG(X21)
1	-0.001763	0.000152	-0.026045	0.033586
3	-0.019448	0.004099	-0.017941	0.013176
Response of DLOG(SP1):				
Period	DLOG(P_GAS)	DLOG(Q_GAS)	DLOG(SP1)	DLOG(X24)
2	-0.004675	-0.010640	-0.015650	-0.018028
4	-0.007830	0.012306	-0.004099	-0.012691

[14] We extracted only the relevant impulse-response relations from the whole system of equations.

Response of DLOG(X24):				
Period	DLOG(P_GAS)	DLOG(Q_GAS)	DLOG(SP1)	DLOG(X24)
2	0.000553	-0.009185	-0.034015	0.007654
3	-0.006139	0.013128	0.004166	0.033696
Response of DLOG(SP1):				
Period	DLOG(P_GAS)	DLOG(Q_GAS)	DLOG(SP1)	DLOG(X27)
2	-0.009283	-0.003054	-0.013593	0.017503
6	-0.005674	-0.000643	-0.008766	0.012989
Response of DLOG(X27):				
Period	DLOG(P_GAS)	DLOG(Q_GAS)	DLOG(SP1)	DLOG(X27)
1	0.011292	0.004527	0.022505	0.032469
2	0.007095	0.003848	-0.000620	0.003228
Response of DLOG(SP1):				
Period	DLOG(P_GAS)	DLOG(Q_GAS)	DLOG(SP1)	DLOG(X37)
2	-0.016663	0.011222	-0.010656	0.014976
6	-0.021495	0.013818	-0.002621	0.012528
Response of DLOG(X37):				
Period	DLOG(P_GAS)	DLOG(Q_GAS)	DLOG(SP1)	DLOG(X37)
2	-0.006831	0.009007	0.029030	0.000962
4	-0.018205	0.052442	0.014945	0.022650
Response of DLOG(SP1):				
Period	DLOG(P_GAS)	DLOG(Q_GAS)	DLOG(SP1)	DLOG(X31)
2	-0.014733	0.016211	-4.07E-05	0.006309
5	-0.016985	0.014573	0.035198	-0.008827
Response of DLOG(X31):				
Period	DLOG(P_GAS)	DLOG(Q_GAS)	DLOG(SP1)	DLOG(X31)
3	-0.001117	0.007645	-0.020006	0.003562
4	0.001269	0.018428	-0.034726	0.012784
Response of DLOG(SP1):				
Period	DLOG(P_GAS)	DLOG(Q_GAS)	DLOG(SP1)	DLOG(X40)

1	-0.001391	0.013143	0.053609	0.000000
5	-0.002544	-0.009412	0.043956	-0.007256
Response of DLOG(X40):				
Period	DLOG(P_GAS)	DLOG(Q_GAS)	DLOG(SP1)	DLOG(X40)
3	-0.016979	-0.008393	0.004827	-0.051879
4	-0.011365	0.010665	-0.071034	-0.020122
Response of DLOG(SP1):				
Period	DLOG(P_GAS)	DLOG(Q_GAS)	DLOG(SP1)	DLOG(X20)
2	-0.007515	-0.010974	-0.007583	-0.019759
8	-0.009876	0.014549	0.006797	-0.012090
Response of DLOG(X20):				
Period	DLOG(P_GAS)	DLOG(Q_GAS)	DLOG(SP1)	DLOG(X20)
3	0.010459	-0.011659	-0.018427	0.026175
5	0.009122	-0.003529	-0.011528	0.025565
Response of DLOG(SP1):				
Period	DLOG(P_GAS)	DLOG(Q_GAS)	DLOG(SP1)	DLOG(X36)
3	-0.004382	-0.014664	-0.009063	0.005294
5	-3.33E-05	0.011262	0.020010	0.002992
Response of DLOG(X36):				
Period	DLOG(P_GAS)	DLOG(Q_GAS)	DLOG(SP1)	DLOG(X36)
1	0.008553	0.011143	-0.006292	0.048553
3	0.003982	-0.005851	-0.014153	0.013612
Response of DLOG(SP1):				
Period	DLOG(P_GAS)	DLOG(Q_GAS)	DLOG(SP1)	DLOG(QA)
2	-0.004395	-0.000940	-0.001921	-0.015124
6	0.005970	0.009875	-0.002398	-0.010727
Response of DLOG(QA):				
Period	DLOG(P_GAS)	DLOG(Q_GAS)	DLOG(SP1)	DLOG(QA)
3	-0.003723	0.001062	-0.002526	0.013331
7	-0.001714	0.002079	-0.003372	0.013197
Response of DLOG(SP1):				

Period	DLOG(P_GAS)	DLOG(Q_GAS)	DLOG(SP1)	DLOG(QD)
3	-0.006382	-0.008004	-0.007782	0.001052
7	-0.004903	-0.011223	-0.003498	-0.002842
Response of DLOG(QD):				
Period	DLOG(P_GAS)	DLOG(Q_GAS)	DLOG(SP1)	DLOG(QD)
3	0.000897	0.000376	-0.001139	0.008226
6	0.008344	0.007483	-0.010084	-0.001083
Response of DLOG(SP1):				
Period	DLOG(P_GAS)	DLOG(Q_GAS)	DLOG(SP1)	DLOG(DB)
4	-0.006755	0.011396	0.003982	0.011434
10	-0.000176	0.006675	-0.010986	0.013609
Response of DLOG(DB):				
Period	DLOG(P_GAS)	DLOG(Q_GAS)	DLOG(SP1)	DLOG(DB)
2	0.008568	0.002074	0.024180	0.018820
7	0.006408	0.013340	0.011528	0.005353
Response of DLOG(SP1):				
Period	DLOG(P_GAS)	DLOG(Q_GAS)	DLOG(SP1)	DLOG(DH)
4	-0.012145	0.012468	0.003524	-0.018275
8	-0.012618	0.015558	0.001603	-0.014850
Response of DLOG(DH):				
Period	DLOG(P_GAS)	DLOG(Q_GAS)	DLOG(SP1)	DLOG(DH)
3	-0.006198	-0.001654	-0.012769	0.013633
7	0.007386	0.003302	-0.012861	0.014374
Stand. Errors: Analytic, Cholesky Order.: DLOG(P_GAS) DLOG(Q_GAS) DLOG(SP1) DLOG(Xxx)				

Source: EIPF data base, OECD and own calculations (November 2007).

The results in Table 3 show the influence of natural gas prices and quantity on aggregate domestic consumption in Slovenia and the influence of aggregate domestic consumption on the dynamics of individual industries, with the higher natural gas price decelerating the dynamics of aggregate domestic consumption (see, Cullen et al. 2005).[15] Changing energy prices may create

[15] We do not state the results of the whole response-impulse function. They present only the relevant impulse-response relation of the whole system of functions.

uncertainty about the future path of energy prices, causing consumers to postpone the purchasing of goods and increasing precautionary savings in response to higher energy prices (Kilian 2007). In the following activities in Slovenia, namely: the production of textiles, leather, fur and clothes, the production of pulp, paper and cardboard, recycling, electricity, natural gas, steam and hot water supplies and intermediary consumption products, the deceleration of economic activity in individual industries was confirmed if the price of natural gas was rising (deceleration was weak, with coefficients ranging between -0.003 and -0.021 and with a time lag between one and seven quarters). The production of textiles, leather and textile products decelerated if the dynamics of aggregate domestic consumption in Slovenia decelerated (in a time lag of one quarter), the production of pulp, paper and cardboard indirectly decelerated if aggregate domestic consumption decelerated and when the price of natural gas increased (with a time lag between one and three quarters). The production of chemicals, chemical products and artificial fibres decelerated if the dynamics of aggregate domestic consumption growth decelerated (with a time lag between two and three quarters), with the deceleration of metal production being weaker than the aforementioned activities (with a coefficient of -0.0006 in a time lag of two quarters). The intensity of deceleration in recycling is insubstantial (for a time lag between two and four quarters, and with a change of coefficient amounting to -0.015). As expected, electricity, natural gas, steam and hot water supplies decelerate in a time lag of four quarters if the dynamics of aggregate consumption decreased. With a reduction in purchasing power and an increased probability of being unemployed comes the postponement of large expenses, such as those for nonessential products or major purchases like furniture etc. (see, Kilian, 2007). The processing industry, the dynamics of production, intermediate consumption products, furniture, wood processing, rubber and plastic materials, the production of chemicals, chemical materials and artificial fibres also decelerate (with a time lag between one and seven quarters), with the weak deceleration found in the production intermediate consumption products (with the average coefficient value of -0.003) if the dynamics of aggregate consumption growth decelerated.[16]

The magnitude of the effect of natural gas price shock on production in individual industries indirectly through aggregate domestic consumption, derived from the impulse-response function of natural gas price shocks in the individual industries' production of a VAR, is between -0.0002 and -0.025 as an elasticity, spread over three to eight quarters. With regard to the coefficient values, it can be said that the intensity of reactions in individual industries to the impulses of natural gas price accelerations has been proved. This is also the case for the indirect intensity of responses in individual industries to the higher natural gas prices because of a deceleration of aggregate domestic consumption in the national economy.

5 CONCLUSION

The empirical analysis demonstrated the potential of natural gas price movements (and other explanatory variables) to forecast movements in production for some industries in the Slovenian economy. Natural gas price movements can help us forecast the movements in the production of electricity, natural gas, steam, hot water supplies, the production of metals,

[16] Al-Gudhea et al. (2007) distinguish between small and large shocks in this context. And show that asymmetry is more pronounced in small shocks, which may be due to consumer search costs.

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textiles, leather, footwear, leather and fur products, clothes, the production of pulp, paper, cardboard and products from paper and cardboard, the production of products from rubber and plastic materials, the processing industry and the production of furniture, the production of intermediary consumption products and recycling.

The indirect influence of the dynamics of natural gas price movements on individual economic activities through the decrease in the dynamics of aggregate domestic consumption, which decelerates the dynamics of production movements in individual industries, was proven. The dynamics of gas prices decelerates the dynamics of aggregate domestic consumption, which further decelerates the activities in individual industries with deceleration coefficient values ranging from -0.003 to -0.021 with a time lag between one and seven quarters.

The obtained results suggest that natural gas price shocks influence economic activity beyond that explained by direct input cost effects and via the indirect effect of possibly delaying purchasing of goods. From the results it can also be stated that natural gas has the potential to destabilize the Slovenian economy.

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LIST OF ABBREVIATIONS:

bpl_t: the gross wages in tradable sector

cbs1: the domestic consumption of households

db: the production of textile, leather, fur and clothes

dh: the production of products from rubber and plastics

efob_eu: the export of goods

es_eu: the export of services

eur: the Tolar-Euro exchange rate

metals: the price of metal

P_gas: the price of natural gas (=cene_plina in the pictures in the Appendix – impulse-response)

pc_spt: the producer price index of durables

pcs: the producer price index of all industrial products

price_stst: the consumer prices index

Q_gas: natural gas consumption in Slovenia (=poraba_plinslo in the pictures in the Appendix – impulse-response)

qa: the production of intermediate consumption products

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qb1: total industrial production

qd: the processing industry

sp1: the aggregate domestic consumption (as total domestic consumption of households, investment and national consumption)

sp1/qb1: the relationship between aggregate domestic consumption and total industrial production

sp1/zal: the relationship between aggregate domestic consumption and stocks of goods

tgor: the petroleum products prices corrected by excise duties

x17: the production of textiles

x19: the production of textiles, leather, footwear and leather products, except clothes

x20: the wood processing, the production of products from wood, cork, straw and wicker, except furniture

x21: the production of pulp, paper and cardboard and products from paper and cardboard

x24: the production of chemicals, chemical products, artificial fibers

x27: the production of metal

x31: the production of electrical machinery and equipment

x36: the production of furniture and other processing industry

x37: recycling

x40: the production of electricity, natural gas, steam and hot water supply

X_{t-n}: output of a chosen sector in past quarters

zal: the stocks of goods

zal/sp1: the relationship between stocks of goods and aggregate domestic consumption

zap: employment

APPENDIX: Estimated OLS and impulse response functions

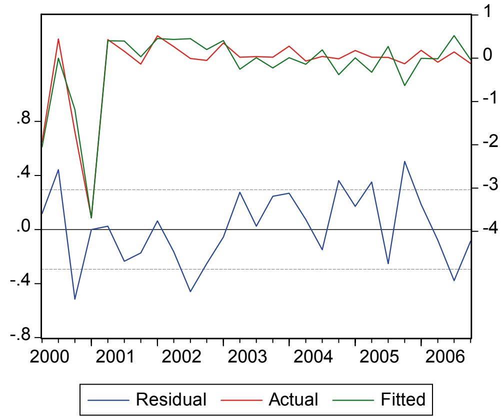


Figure 1: The production of textile, leather, fur and clothes (DB)

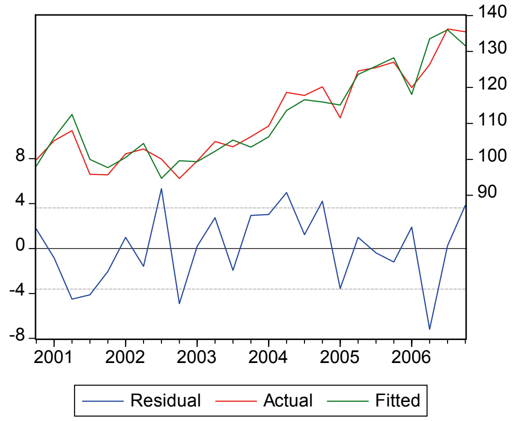


Figure 2: The production of products from rubber and plastics (DH)

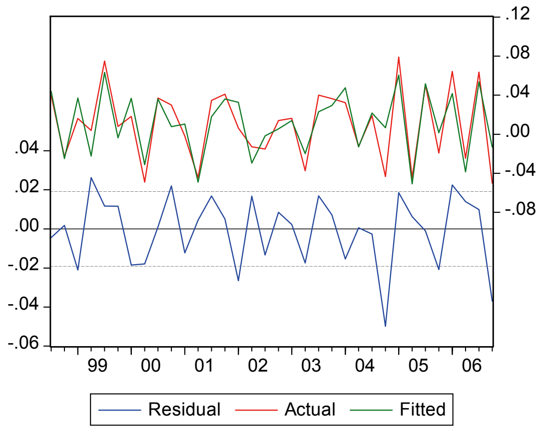


Figure 3: The intermediate consumption products (QA)

Figure 4: The processing industry (QD)

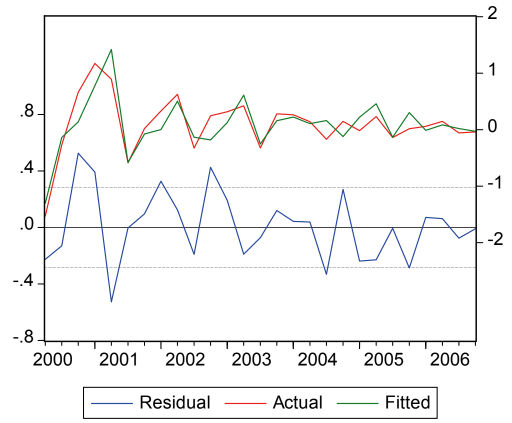


Figure 5: The production of textiles (X17)

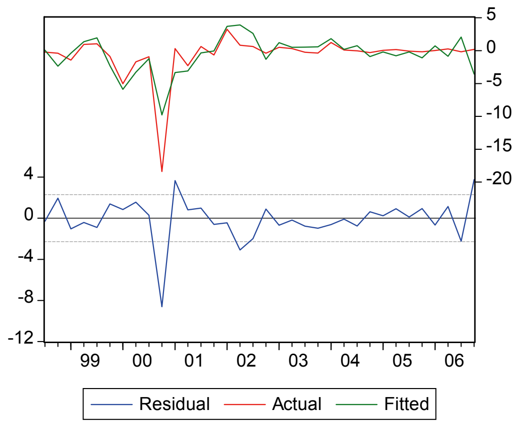


Figure 6: The production of textiles, leather, footwear and leather products, except clothes (x19)

Figure 7: The wood processing, the production of products from wood, cork, straw and wicker, except furniture (X20)

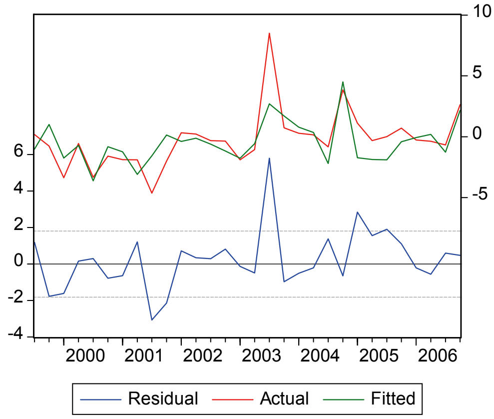


Figure 8: The production of pulp, paper and cardboard and products from paper and cardboard (X21)

Figure 9: The production of chemicals, chemical products, artificial fibre (X24)

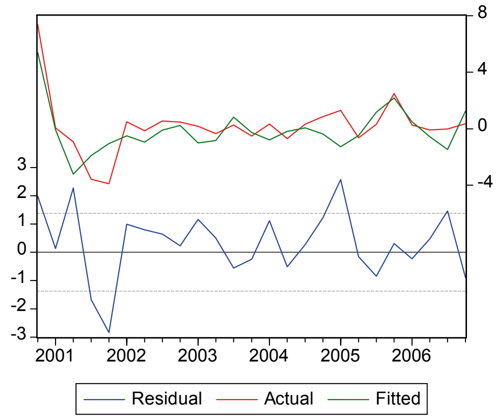


Figure 10: The production of metal (X27)

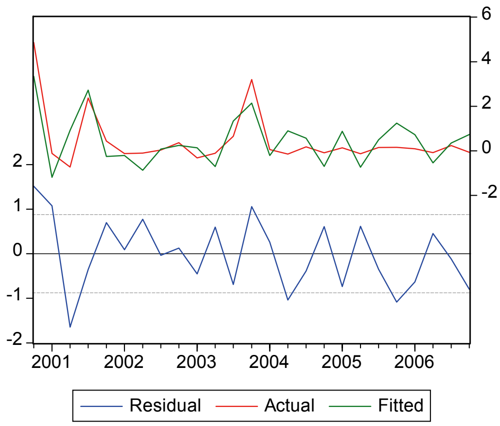


Figure 11: The production of electrical machinery and equipment (X31)

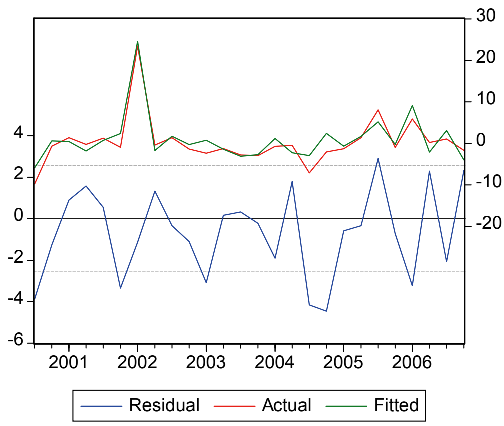


Figure 12: The production of furniture and other processing industry (X36)

Figure 13: The recycling industry (X37)

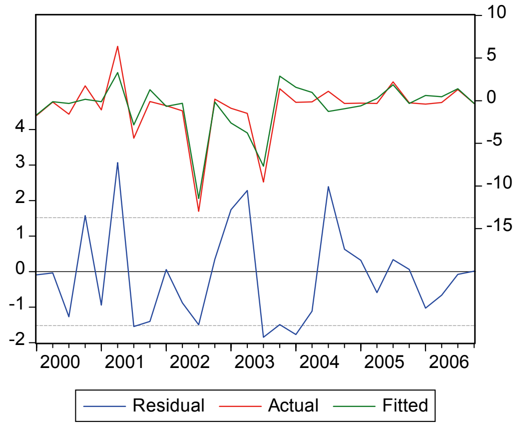


Figure 14: The electricity, natural gas, steam and hot water supply (X40)

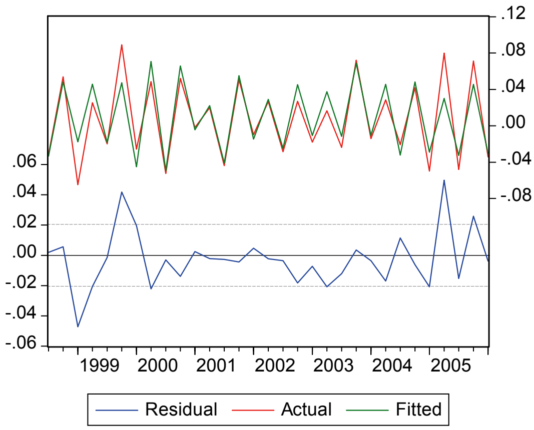


Figure 15: The total industrial production (QB1)

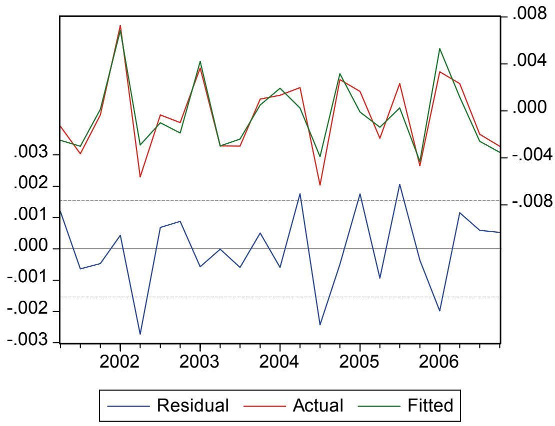


Figure 16: The consumer prices index (price_stst)

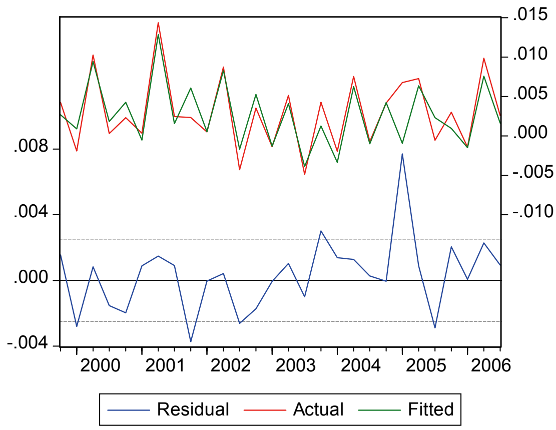


Figure 17: The employment (zap)

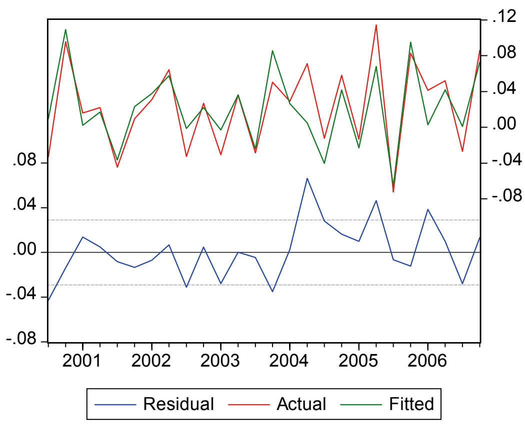


Figure 18: The export of goods (efob_eu)

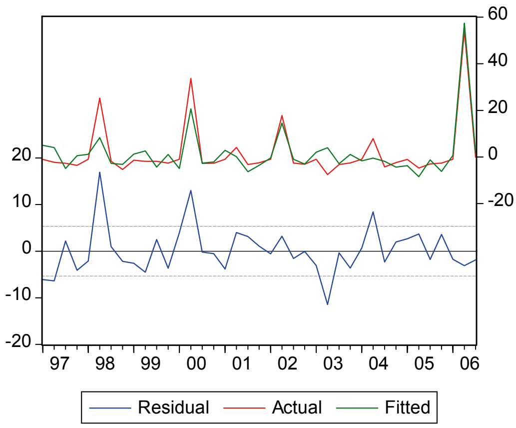
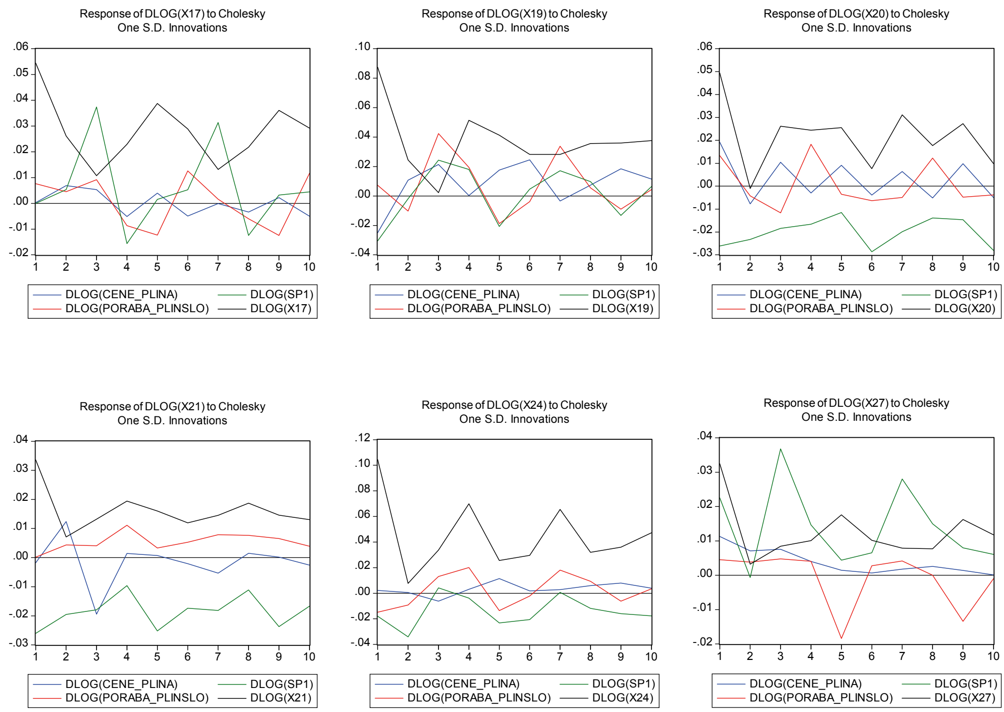
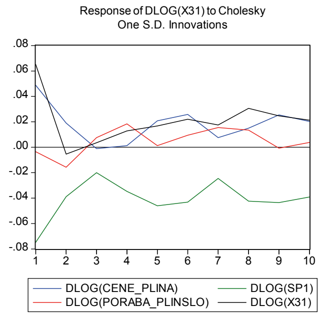
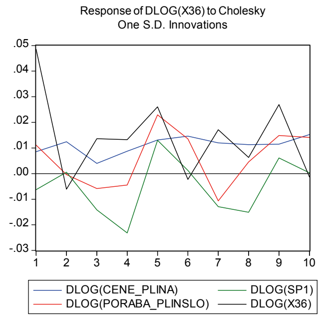


Figure 19: The aggregate domestic consumption (sp1)

APPENDIX 2




Response of DLOG(X31) to Cholesky
One S.D. Innovations
DLOG(CENE_PLINA)
DLOG(SP1)
DLOG(PORABA_PLINSLO)
DLOG(X31)


Response of DLOG(X36) to Cholesky
One S.D. Innovations
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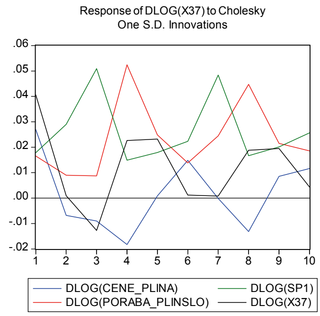
DLOG(SP1)
DLOG(PORABA_PLINSLO)
DLOG(X36)


Response of DLOG(X37) to Cholesky
One S.D. Innovations
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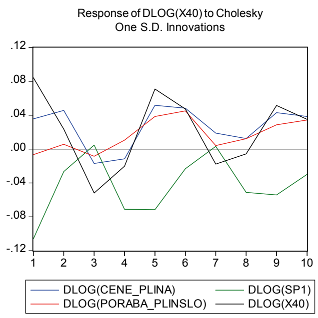
DLOG(SP1)
DLOG(PORABA_PLINSLO)
DLOG(X37)


Response of DLOG(X40) to Cholesky
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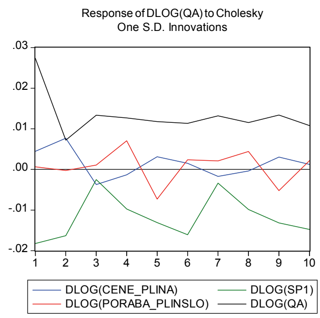
DLOG(PORABA_PLINSLO)
DLOG(X40)


Response of DLOG(QA) to Cholesky
One S.D. Innovations
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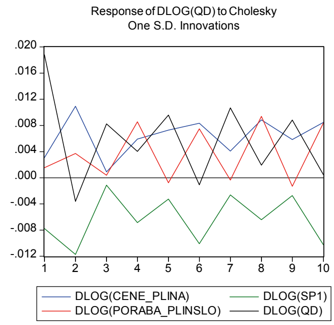
DLOG(SP1)
DLOG(PORABA_PLINSLO)
DLOG(QA)


Response of DLOG(QD) to Cholesky
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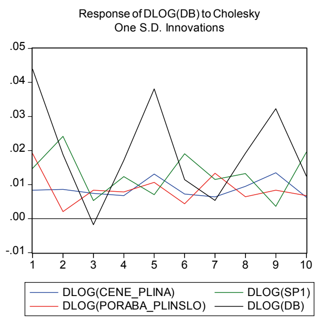
DLOG(SP1)
DLOG(PORABA_PLINSLO)
DLOG(QD)


Response of DLOG(DB) to Cholesky
One S.D. Innovations
DLOG(CENE_PLINA)
DLOG(SP1)
DLOG(PORABA_PLINSLO)
DLOG(DB)

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CONSUMPTION OF DRY GEOTHERMAL ENERGY

IZRABA SUHE GEOTERMALNE ENERGIJE

B. SALOBIR[ℜ]

Keywords: mining, geothermic resources, heating;

Abstract

Geothermal energy is a very high efficiency alternative resource of using the warming energy of the Earth. But in fact, only 0.1 % of today's world energy is made from the alternative resources.

Slovenia has a large potential for the exploitation of low-enthalpy geothermal resources. Low-enthalpy geothermal resources are exploited for direct use (balneology, agriculture, aquaculture, industrial use and space heating). Potential investors are encouraged to consider geothermal energy use owing to the oscillation of fossil fuel prices and also due to the creation of extra value with non-energetic water use.

Geological research provides basic information needed for the estimation of exploitable energy resources preserved in the Earth's interior. This information must answer the questions related to the conditions of geothermal resources' appearance (existence, spatial extension, temperature) and to the conditions of intake and use of geothermal resources in connection with technological requirements (exploitability, capacity, ecological point of view, maintenance,...).

Since the mechanism and geometry of geothermal systems are mostly not completely solved, or are not solved at all, this applied research project intends to develop improved conceptual models of more interesting geothermal resources, using recent results of structural and regional geology. In this way the improved models will serve for the forecast of recharge and discharge mechanisms of thermal aquifer, long-term influence of exploitation of underground water and/or for the selection of locations with ***potential for geothermal resource existence***.

Povzetek

V zadnjem času se vse bolj nagibamo k uporabi alternativnih virov energije, h katerim spadajo tudi geotermični energetski viri. Te energije je na Zemlji v izobilju, se pa izjemno malo izkorišča. Večinoma izkoriščamo le geotermalne vodne vire iz globokih vrtin, same suhe zemeljske toplote

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pa zelo malo. V zadnjih letih se je razvila uporaba odjemnikov Zemljine toplote, ki delujejo na principu konvekcije toplote, ki jo sprošča Zemlja v globini, to pa prestrežemo s tako imenovano geosondo. Tu ne pride do stika medija (vode) z Zemljino notranjostjo, saj je ves sistem nepredušno zaprt in vodi toploto do toplotne črpalke, od tam pa naprej v toplotni krog ogrevanja ali hlajenja stavbe, saj je sistem reverzibilen.

Za izgradnjo sistema je potrebna vrtina, ki jo zgradimo z rudarskim delom na podlagi litološke in geotermične prognoze in obvladovanje vstavljanja odjemnika v vrtino ter njegova povezava z ogrevalnim sistemom stavbe. Ker je vrtina in njena uporaba le del celotnega sistema se rudarji posvečamo tudi izračunu toplotne izdatnosti vrtine, ocenjevanju geotermičnega gradienta, medsebojnim vplivom posameznih vrtin in nadaljnjim izračunom razvoda in ogrevanja ali hlajenja stavb. Tako smo že uresničili projekte, ki z eno ali več vrtinami ogrevajo pomembne objekte, do takih, ki za ogrevanje in hlajenje potrebujejo dvajset in več vrtin - odjemnikov. Vsekakor je izkoriščanje tega segmenta geotermične energije pomembna niša v rudarski dejavnosti, ki jo moramo naprej razvijati in je ne smemo zanemariti ali izpustiti iz rok. V času intenzivnega iskanja obnovljivih energetskih virov, ki bi vsaj delno zamenjali klasične vire, je le razvoj vsake od najdenih možnosti prava pot za nadaljevanje dela in naše rudarske stroke.

1 INTRODUCTION

Consumption of dry geothermal energy has been increasing lately as the kind of energy being accessible everywhere and abundant limitlessly, even in the courtyard. It provides high energy independence.

The kind of energy is put into profitable use by a borehole, into which a system of inflow and return pipes with water flow or any other means, capable of accepting Earth's heat and giving it off effectively into the heat pump on the surface, is placed and connected by a joint probe.

2 GEOTHERMAL ENERGY AS A SOURCE OF HEAT

Geothermal energy is the heat of the Earth's interior. It comes to the surface through small magmatic intrusions and by conduction through deep tectonic discordances as boreholes and volcanic inflow channels. Characteristic boreholes of geothermal energy develop at decomposition of radioactive elements in the Earth's crust and with other chemical processes going on in the crust. An important factor when an area is perspective is geothermal anomaly, which from the hydrologic and hydro chemical point of view gives a clear picture of possibilities and manners of using up the energy potential. According to its use and forms geothermal energy can be divided into

- **hydrothermal energy and**
- **petro-geo-thermal energy.**

The first is the geothermal energy of liquid and gaseous fluids and the second is the geothermal energy of rocks. Geothermal energy is composed of three elements:

- **energy flow through the Earth's crust in the form of material conduction (magma, water, steam, gas)**
- **heat flow due to conduction and**

- **stored energy in rocks and fluids in the Earth's crust.**

Low temperature sources are represented more often than those with high temperatures. Conventional consumption of geothermal energy is usually divided into:

- **high temperature sources with water temperature above 150°C used in electricity generation**
- **low temperature sources with water temperature below 150°C used mainly for heating.**

3 HEAT ORIGIN

Temperature variations inside the Earth cause heat flow from the interior to the Earth's surface. A part of the heat origins from so called ***original or primary heat*** stored during the Earth's development. The largest part of heat is developed by decomposition of radioactive elements in the lithosphere rocks (rock mantle of the Earth). Table 1 shows heat quantities which appear in various rocks and radioactivity concentrated in them.

Table 1: Table of radioactivity concentration in some rocks and heat development

ROCK	CONCENTRATION $g \cdot t^{-1}$			TOTAL HEAT DEVELOPED	
	URANIUM	CALIUM	TORIUM	$\frac{\mu cal}{g_{letno}}$	$\frac{mJ}{kg_{letno}}$
SEDIMENTS	3,00	20.000	5,0	3,73	15,62
GRANITS	4,75	37.900	18,5	8,18	34,24
INTRUSIVES	2,00	18.000	7,3	3,40	14,24
BAZALTS	0,60	8.400	2,7	1,21	5,07
EKLOGITES	0,25	2.600	0,45	0,34	1,42
HONDRODITES	0,012	845	0,04	0,04	0,17
PERIDOTITES	0,015	63	0,05	0,02	0,08
DUNITES	0,008	8	0,023	0,01	0,04

Heat development by radioactive decomposition is larger in acidulous rocks lying closer to the surface in comparison with the basic and ultra-basic rocks lying much deeper. Heat flow from the Earth's interior towards the surface is approximately $67{*}10^{-6}kWm^{-2}$.

Heat also develops due to some chemical reactions in the Earth's interior. A part of it is friction when the Earth's crust moves due to the tide and ebb and the friction at the edges of the moving tectonic plates making the Earth's crust.

Heat is conducted from the Earth's interior to the surface in three ways:

- **by conduction**
- **by convection and**
- **by heat radiation.**

The most important way of heat transfer inside the Earth is conduction. Homogenous isotropic media can be expressed by the formula:

$$q_t = -k \text{ grad } \Phi, \tag{1}$$

where ***k*** is specific heat conduction, ***grad Φ*** is gradient temperature. Supposing that heat flow from the Earth's interior towards the surface is positive and vertical, the formula can be as follows:

$$q_t = k \frac{\partial \phi}{\partial z} \tag{2}$$

The heat conduction ***k*** can be measured with adequate measurement instruments by rock sampling or determining rocks on the grounds of certain heat phenomena in the boreholes. The value of ***k*** can be gained from a certain table, where heat conductivity of ***k*** [$Wm^{-1}K^{-1}$] is schematically shown for various materials. The highest heat conductivity has quartzite, dolomite, sandstone, conglomerate, granite and basalts.

Temperature gets higher towards the Earth's centre with a geothermal level of 1K every 33 m of depth. Geothermal level shows the depth for which descends should be done towards the Earth's interior to get the temperature to rise for 1 unit (1 Kelvin). Temperature rise can often be expressed by geothermal gradient which marks the temperature according to the depth unit. Geothermal level is changed from 1.5 to 180 m/K. Geothermal level in the area varies from the Southwest of Pannonia, the Alps and the Dinarides in the South. The geothermal level in the area of SW Pannonia is 25 m/K, the Dinarides area reach as much as 169 m/K, but the Alpine area 90m/K. The temperature-depth ratio diagram is shown in the figure below:

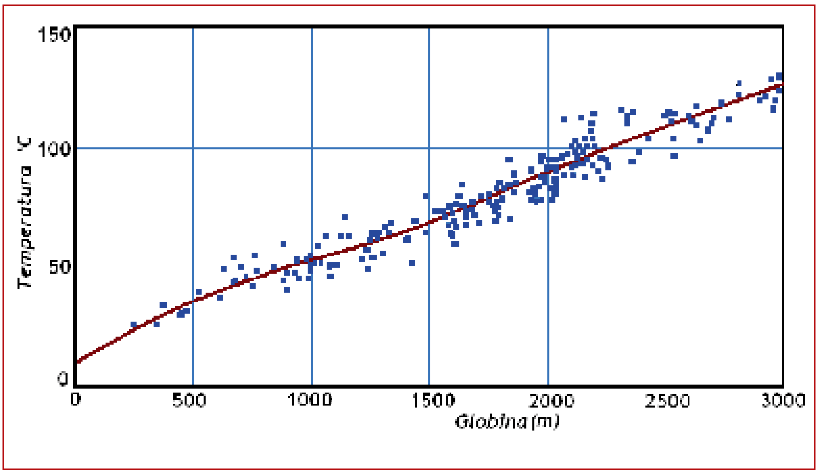

Figure 1: *Temperature-depth ratio diagram*

The temperature gets higher towards the Earth's centre by changeable gradients. It should be 3300 K in the Earth's centre. Shallow surface is exposed to climatic influence in the areas and equals average annual air temperatures. Daily ground temperatures under the influence of Sun rays can be changed up to the depth of 1m, while they can vary up to the depth of 20 m annually, considering micro thermal ground characteristics and the amount of temperature changes. Average annual ground temperature in the continental part of Slovenia is 11-12 ^{o}C, but at the Adriatic coast and on the islands it comes to 13-16 ^{o}C.

4 GEOTHERMAL PARTS OF SLOVENIA

Geothermally most perspective are the regions in the Pannonia depression, the Rogatec-Celje-Šoštanj region, the Planina-Laško-Zagorje region, the Krško-Brežice region and the Ljubljana basin. All those areas are geothermal different and still mostly unrehearsed. The diversity is conditioned by rocks a geothermal borehole is drilled into.

According to the available information, low-enthalpy sources of geothermal energy have been used in Slovenia so far. Perspective carriers of geothermal energy are geologically newer structures. Tectonic depressions are a part of them filled with tertiary and partially quarterly sediments. They have developed by sinking on the faults in more recent geological period. The tertiary layers are poor thermal conductors; therefore, their geothermal gradient becomes higher.

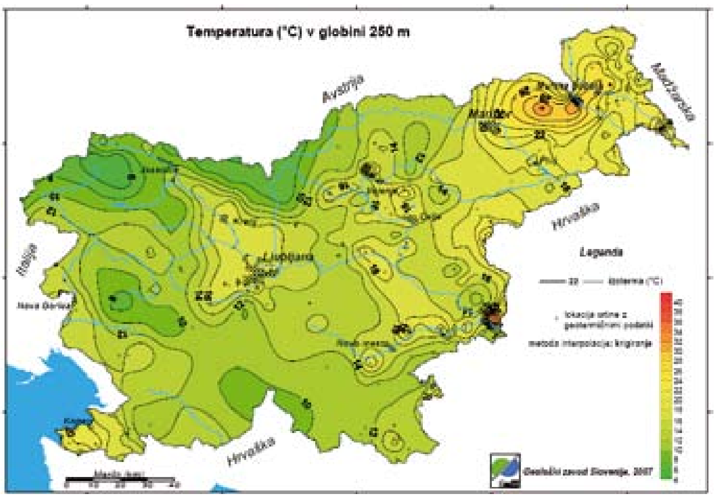

***Figure 2**: Geothermal map of Slovenia*

Rock temperature rises with the depth faster than elsewhere. Tertiary base in the depressions consists mostly of borehole-conductive rocks (dolomites, limestone, metamorphic rocks) containing hot water. The edges of the depressions usually come out to the surface where they are filled with precipitations entering the underground through highly crapped zones and heat up making a convection circulation upwards where the tertiary layers are joined. The rocks are

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much more heated due to the convection water circulation than they would be in a normal geothermal gradient.

5 TERMS

Geo-probe is a device for the Earth's interior thermal outlet according to the Construction Act. Any other name is irrelevant. To avoid arguments, terms such as ***geo-collector***, ***geo-outlet***, ***geo-consumer*** and the like are used. For further use, it is the best to take over the name regulated by the Act to avoid several names for one and the same thing.

Renewable and non-renewable resources

According to the physical law on energy maintenance, geothermal energy is a non-renewable source of energy. As it appears in such amounts it is considered to be limitless. Limitlessness means to maintain a balanced condition. Long-term exploitation does not allow more energy leaving the system than entering it. Limitless use is possible only with renewable resources. Renewable resources are always linked to some durable energy processes in nature. Such processes have to be created not to affect natural energy circulation. Renewability can be simply described as the energy taken from the reservoir which can always be substituted by additional energy amount. Besides, it is requested that the energy taken is substituted in approximately the same period as taken.

6 DESIGNING A HEATING SYSTEM WITH EARTH ENERGY

Geo-probe system must be designed during the construction plan. As to the realization and borehole drilling deeper than 30 m, mining legislation is used and a mining project prepared. The project plans drilling a borehole, its preparation to in-build a geo-probe and its connection to the object and heating pump. Mining engineers usually do not make plans from the heating pump to the piping around the building; the job is left to mechanical engineers. However, mutual cooperation seems to be important as there are some questions, like borehole number and their depth, raster set-up, location in the building, piping length, heating power needed and cooling requirements for the building.

6.1 BOREHOLE CONSTRUCTION AND ELABORATION

A borehole is a mining operation at the depth from 50 to 150 m, mostly around 100 m considering the geothermal level of the area. To make a borehole, a primary column is drilled and piped if necessary, which depends on the borehole conditions. The borehole is made by a mobile drill machine, model Mustang Atlas Copco, which is an impact hammer equipped with the DTH cap. All muck and drainage are collected in the bin. If the hanging wall is solid, there are no problems drilling the borehole, but if it is soft, then special drilling procedures and placing piping along the whole borehole or partially is performed. When the borehole is finished, which lasts one day on average, the system of four pipes with a geo-probe is placed at the end and a weigh added to push the pipes to the end of the borehole. After pipe placement, pressure test is made and then the borehole is cemented. The segment of drilling into the Earth interior is finished. The Construction of a geo-probe is shown in figure 3.

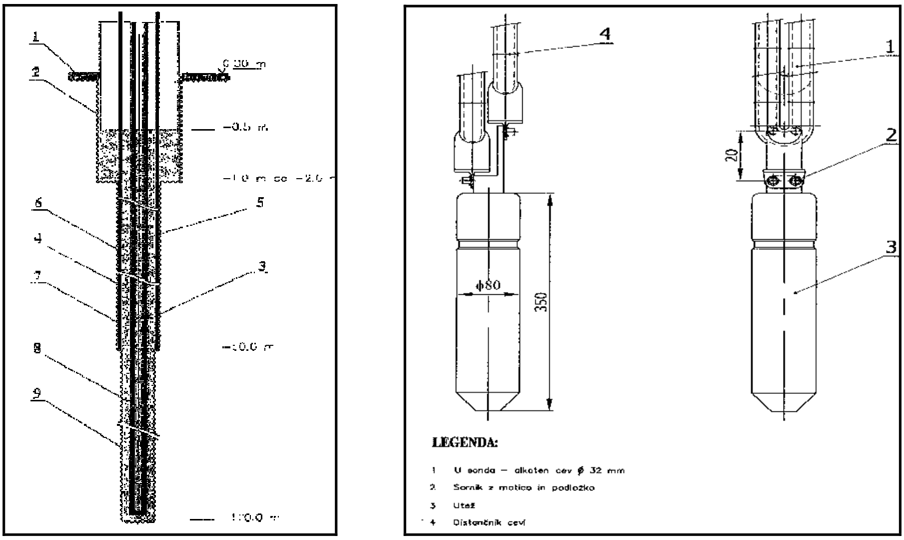

Figure 3*: Left: Borehole construction, right: Construction of geo-probe*

6.2 BOREHOLE NUMBER AND DEPTH

Considering an insulated new building with floor heating, one borehole should be made for heating or cooling for every 150 m² of surface on average. In reconstruction of an older building, where the geothermal system takes over the heating completely, twice more boreholes are to be made, which depends on the heat level at a certain location. Thermal power of the borehole is determined by the formula:

$$\frac{L_1 q_1 + L_2 q_{21} + ... + L_n q_{n1}}{\sum (L_1 ... L_n)} = Q[kW] \tag{3}$$

$$Q\lambda = Q_{vrt}[kW] \tag{4}$$

where:

$L_1...L_n$:................is the length of individual borehole sections in a certain rock (m),

$q_1...q_n$:..................is the .heat level of individual borehole sections (W/m),

λ: .... is the borehole efficiency (about 80 %),

Q_{vrt}:.......................is the borehole heat power (kW).

The number of boreholes is determined by the formula:

$$N_{vrtin} = \frac{P_{\min}}{Q_{vrt}\vartheta} \tag{5}$$

in

$$N_{moz} = \frac{S_{prost}}{S_{vrt}} \tag{6}$$

where:

N_{vrtin}:..................is the number of boreholes needed,

P_{min}: ....is the minimal heating power needed in the building (kW),

Q_{vrt}:....................is the borehole heating power (kW),

ϑ :........................is the system efficiency (about 75 %),

$\boldsymbol{N_{max}}$:..................is the largest possible number of boreholes in an area,

$\boldsymbol{S_{prost}}$:.................is the available area surface,

$\boldsymbol{S_{vrt}}$:....................the surface one borehole takes (about 50 m^2).

6.3 HEATING OF RESIDENTIAL AREAS AND LARGER BUILDINGS

There have been some examples of heating the whole residential area with one deep borehole as deep as 1400 m all over the world and especially in Switzerland, which supplies the central heating station and then heats and cools the apartments in the residential complex. The same is planned for the pilot residential area of Ljubečna near Celje.

7 INCREASING TREND OF GEOTHERMAL ENERGY CONSUMPTION

Simple performance and use have increased the consumers’ interest in the system application in family houses and larger business objects. For family house mostly two boreholes are drilled from 80 to 120 m deep, larger consumers need 4 to 6 boreholes, while business buildings have 20 and over. For example, the new business building of Primorje Ajdovščina has 20 boreholes under the underground garage and the Hotel Jama at Postojna has 25 boreholes under the hotel parking place. The boreholes can be well hidden under an object, parking place or backyard. They can not been seen on the surface and do not affect the environment. Such a solution has been realized in Germany to heat and cool one of their biggest banks. The government can also offer a substantial refund for the cost of geo-probe due to promotion of renewable energy resources.

8 CONCLUSIONS

In Slovenia we have over than 200 boreholes for consummating geothermal energy and over than 150 family and other houses and public objects under partial or complete dry geothermal warming system, energy from the surface of the Earth, but this process increases.

Geothermal energy is clean, cheap, and easy and equal accessible in all places accessible, inexhaustible, long duration resource, and environmental safe. Future with dry geothermal warming technology is more and more users of this type warming, application in new modern

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buildings, with good insulation system, pilot settlements with only one, over than 1000 m deep borehole, superstructure of classic radiator warming technique with geothermal system, combination of classical and alternative warming resources.

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OPTIMAL ENERGY CAPACITIES AND TECHNOLOGIES FOR PERMANENT AND RELIABLE ELECTRICITY SUPPLY, CONSIDERING RISK CONTROL

OPTIMALNE ENERGIJSKE ZMOGLJIVOSTI IN TEHNOLOGIJE ZA TRAJNO IN ZANESLJIVO OSKRBO Z ELEKTRIČNO ENERGIJO, Z OBVLADOVANJEM TVEGANJ

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Keywords: Energy sources, optimal electricity production, risk control;

Abstract

In this paper optimal energy source structures for electricity production, through the needs of the system transmission operator (TSO) who is responsible for secure and reliable supply within its own regulating area, as well as over disposable energy fuels, are discussed. Long term reliable electricity energy supplies, system suitability, suitability of production capability, suitability of electricity grid, market suitability and short term secure and reliable supply are considered. Cost risks calculations are given, considering different technologies and sources, using a model of reference price of electric energy. The optimal structure of energy producing resources is treated from the point of view of the transmission system operator (TSO), primary frequency control, secondary frequency control and tertiary minute control.

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Povzetek

V tem prispevku so obravnavane optimalne strukture virov energije za proizvodnjo električne energije, glede na potrebe operaterja prenosnega sistema (TSO), ki je odgovoren za varno in zanesljivo oskrbo elektro sistema, kot tudi glede razpoložljivega vira energije. Upoštevana je dolgoročna zanesljivost dobave električne energije, sistemska ustreznost, primernost proizvodnih zmogljivosti, primernost za električno omrežje, trg in primernost kratkoročnih varne in zanesljive dobave. Podani so izračuni, ki upoštevajo stroške in tveganja, glede na različne tehnologije in vire, z uporabo modela referenčne cene električne energije. Določana je optimalna struktura virov za proizvodnjo energije, obravnavana z vidika upravljavca prenosnih omrežij (TSO), primarna frekvenca nadzora, pogostost nadzora sekundarna in terciarni minutni nadzor.

1 INTRODUCTION AND BASIC NOTATIONS

Optimal energy source structures for electricity production could be treated through the needs of the transmission system operator (TSO) who is responsible for secure and reliable supply within its own regulating area, as well as over disposable energy fuels. At the same time, the system regulator could choose the reliable technology that assures technically reliable operating in the long term as well as the functioning the competitive market. We will define limitations and risk parameters of the individual technology and calculate costs competitiveness of each technology using the model of the reference price of electricity energy.

Long term reliable electricity energy supply: appropriate approaches to energy fuels, productions facilities, electricity networks and markets. It is related with long term availability of energy fuels, generators for production, electricity network and markets, but not on current supply.

Access to primary fuels means that the producer of the electricity energy is allowed to freely choose when selecting the primary energy source based on reasonable prices. At the same time, it is not pushed into a selection based on political or geopolitical reasons.

The wide availability of primary sources of energy fuels that investors could select based on reasonable prices, is important for both EU citizens, and EU member states. The fact is that the domestic sources are preferable, from security and reliability of supply points of view, but this does not mean that such security and reliability of supply cannot be obtained with primary fuels from abroad, especially when such imports are dispersed and from politically and economically stable regions.

System suitability: the electricity energy system possibility of transferring primary fuels into electricity and transferring it to the end consumers in a sustainable way. This is determined suitability of production efficiency and suitability of the electricity grid.

Suitability of production capability: the presence of sufficient production capability to satisfy electricity market inquiries in times of base as well as peak consumption, when considering the amount of electricity imports. From the aspect of secure and reliable electricity supply, it is very important that more primary energy sources and technologies are on disposal for electricity production. That is the reason the EU as well as the individual members of the EU must allow all possibilities to the investors for free choices about energy sources and uses of technology. One important perspective is the suitability of production capabilities with regards to public acceptability about different energy technologies and sources. This can have major influence on electricity production.

Suitability of electricity grid (as well as transmission, distribution and cross-border interconnections): grid availability (infrastructure) to satisfy the requirements of electric energy. The issue appears when decisions must be made about which infrastructure is necessary and what efficiency level is satisfactory. Reduction or blocking of capacities of cross-border transmission is major barrier for greater trading assurance with electrical energy. That why it is expected from the EU that clears procedures will be determined for all EU member states in which exact priorities for new member states will be defined. However, the important fact is that the harmonisation on this field of interest will not have significant influence if the competence of planning and develop of transmission and distribution lines for electricity will stay in the competence of the individual member states of the EU. Beside the clear economic incentives for the new transmission lines, the fact that the public acceptability about the new transmission lines is very low must be considered, especially at cross-border connections. This fact has halted many new electricity network connections in the last decade. It can be established that the public acceptability as well as the protests of different associations is the main reason for the obstruction of faster electricity network development.

Market suitability: the market's ability, for an acceleration of the connection between the electrical energy producer and consumer. The market makes opportunities for efficient and competitive electricity producers for to survive under the market conditions and offers the consumers the free choice of supplier selection. Network tariff gives system operators sufficient income to cover capital expenses and operating expenses for services offered to producers as well as to costumers. It is necessary that the market is transparent and non-discriminatory.

Short term secure and reliable supply: operational system reliability as a unique system including capability to cover short time deviations of some system parts. Short time or operative reliability requires sufficiently technical reserve with other ancillary systems services and suitable market frames, which ensure the system operator arrangements with fast controls between demand and supply. The system operator must have on disposal enough system ancillary services, such as secondary frequency control of power and voltage, tertiary reserves, capable aggregates for black starts, cold reserves, etc.

The responsibility to ensure enough technical system reserve is on the system operator, who must collaborate with neighborhood system operators and define the level of reserves. The regulator function is to supervise and ascertain whether the system operator is qualified, especially with regard to technical and other system ancillary services.

2 OPTIMAL STRUCTURE OF ENERGY PRODUCING RESOURCES FROM THE POINT OF VIEW OF TSO

A pre-condition for the electricity market is to ensure that the network system gives opportunity to all participants, producers and customers to transmit energy. A frequency of 50

Hz must be ensured, which is reachable at an equilibrium of power, meaning when production and consumption of power in the network is equal. While the coincidental events that destroy power equilibrium, such as shutdown of the production unit, or unexpected change of consumption due to weather changes, cannot be avoided, the additional working power in the network system must be ensured to protect the equilibrium of power in such events.

System ancillary services for frequency control (primary, secondary and tertiary minute control) must be ensured in advance; increases or decreases of production are made between operations as a measure at unexpected events such as unexpected consumption increases caused by unexpected hot weather, changes in public lighting or at cutoff the production source/ electricity power plant shutdown.

The system operator must ensure system frequency control with regards to technical criteria and minimal expense when buying on domestic or foreign markets, as well as with its own system power plants.

The activity of system operators of transmission networks is based on Directive 2003/54/EC– Instructions of system operating of transmission network (Official Gazette RS no. 46/02), based on the UCTE (2005) agreement and other regulations. These documents also prescribe the use of different regulations on electricity markets:

Primary frequency control: a mechanism that ensures the (solidarity) help between synchronous interconnected state-owned network systems. Primary reserve of power for regulation works with fast response time, locally, at aggregates up to 30 seconds. The turbine control regulator performs primary control and supervises frequency in the network. When the frequency is higher than normal (50 Hz), generator output power is decreased. Conversely, when frequency is lower than normal, the generator power output is increased. Primary control plays the important part of frequency control at synchronous operating as well as at extraordinary operating conditions as well as when crossing into island operations. Extra operating conditions, such as island operations can be calculated only with sources that are located inside the island territory. Therefore, it is important that the primary energy reserve sources are located inside the state's electric energy system, possibly dispersed as well as possible. In Slovenia, we reach this goal with obligatory collaboration of all producing units in primary frequency control. This service of producing units is given free of charge.

Secondary frequency control: a mechanism that cares for autonomy of state electro energy systems that are interconnected. This is achieved with the elimination of deviation in the system that caused non-equilibrium between production and consumption. With this measure, the deviation is repaired at the system borders where the primary control influences the neighborhood electricity systems when help is provided. The secondary power reserve for the frequency system control must act with response times up to 15 minutes. The automatic controlling must be feasible without any operator help. Secondary frequency control requires strong support between the republic control centre (RCV) and the individual generators. RCV issues a controlling command every few seconds in order to mobilize power.

The inclusion of the production unit to the physical connection to a foreign grid in the system of secondary frequency control would require the instantaneous measurements of charging against its response to the current balance of the domestic system, and the deduction of the balance of the foreign system. The current balance is of paramount importance for the control system. The manner of measurement of response in the calculation of the balance would be, in both of the systems, increase the likelihood of invalid values of balance, which can result from loss of any measurement of power in the secondary response to regulation, crossing the controlling area. The problem was particularly critical with regards to the growing number of such units. Therefore, the UCTE association currently is not in favour of the involvement of foreign elements in the secondary system of regulation and, in practice, such performance is not currently used between the members of associations. Therefore, the system operator for the lease of the secondary regulation is limited to domestic sources.

The main task of the **tertiary minute control is** that, in case of failure of the biggest production blocks in the system, of helping secondary frequency control to eliminate the resulting imbalance of power. The response time of the tertiary minute control is the same as for the secondary frequency control (15 minutes), but its usage permits manual intervention of operators; for example: manual start up of the gas turbines, manual start up of coal mills, aggregates in hydro power plants, change schedules at the borders, etc.

Tertiary minute control may include unloading of large customers. System operators may prescribe a minimum size of reserves from any source; because of manual intervention (by phone), he is interested in intervening as little as necessary and activating as much reserve power as possible.

In technological terms, therefore, the tertiary control is less simple and less difficult than the secondary frequency control regulation. This applies to the leasing of tertiary reserve at home and abroad.

When a TSO leases reserve capacity from abroad, it must pay attention to the availability of cross-border transmission capacity, which must always be available for the supply of reserves. The increased load of transmission grid, either because of internal load or because the transit flows, therefore, should not compromise the delivery of system reserve from abroad.

The **volume of the reserve** means the amount, measured in MW of each type of reserve. The total volume of individual services provided by the system operator in accordance with the rules of the UCTE and the grid code in 2005, leased to domestic and foreign providers, as follows (ELES, 2005):

- Primary control: all the production units
- Secondary control: 80 MW
- Tertiary regulation - minute reserve: 200 MW lease at home and 135 MW abroad.

The cost of secondary and tertiary regulation is compensated by the network tariff for ancillary services, but primary regulation (production units in Slovenia) is provided free of charge actual cost.

3 RISKS

Risks such as unplanned changes in the value of the assets or liabilities (Jorion, 2000), include business risks (based on the product market in which the firm is acting), non-risks (resulting

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from changes in the environment) and financial risks (due to the uncertainty of financial markets). The latter require the integration of management strategies, investments and "hedging" an integral part of risk management in society (Crouhy, Gala, Dan and Mark, 2000).

The process of deregulation and liberalization of the energy market has greatly increased risks to energy companies. With the entry of energy companies onto a competitive, open market, risk management has become one of the most important business functions. The risks to which energy companies are exposed can be divided according to different criteria. In the HSE, we identified potential sources of risk in the areas of law, marketing, investment, trade, financial management and planning (Figure 1).

Energy companies are particularly exposed to the following types of risk.

Economic-market risk:

- control law: a stable regulatory framework is necessary for the operation of energy companies, but that over the life of the plant vary, modify the environmental legislation, access to the system, taxes, restrictions on prices, etc.;
- the price of electricity on the market: the price on the open market is very volatile, and in the long term cannot be accurately predicted;
- increases in the price of primary fuels (coal, gas, oil ...): the price of individual fuels on the market is moving very differently, there may be price conflicts between incoming fuel and the cost of electricity. Prices can be secured (hedging), but not for the whole lifetime of the plant; therefore, it is necessary to draw up a suitable portfolio of power plants using different energy fuels;
- competition on the market: competition on the market leads to increased pressure on prices and reduces the profitability of power plants;
- acquisitions: these are a very common form of the open energy market. With large acquisitions, they move to competition on the market, but also alter the behaviour of other market participants, which may lead to crowding out smaller producers of electricity from the market.

Production risk:

- technological factors: banks usually finance verified technology, but the most recent technology has reduced costs in kWh produced, increasing the competitiveness of power plants, as well as availability and reliability;
- construction: the construction can be stopped or extended because of opposition from local communities, opponents of the project, environmental impact, etc;
- operating and maintenance costs: this is difficult to predict, especially in conditions when the operating mode changes. More halt and boot turbines result in higher maintenance costs, reduced availability and reliability and reduced lifetime of certain components (eg, steam generator);
- availability and reliability of power: this depends on the selected technology and experience of operating and maintenance crews. Major energy companies can improve the availability of power plants that buy the same number of turbines and have more experienced operating

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and maintenance crews in identical turbines as well as increasing the provision of spare parts for several identical turbines; it has been proven that having more identical units enables preventive action to a greater degree;

Financial risk:

- the price of capital: during construction or operation; interest rates may change, which can make a project more or less expensive. It may have been secured with a fixed interest rate or in other ways, but the price of capital rising can also lead to other increased costs;
- conditions of funding: you can modify the conditions of financing credit insurance, their participation in the project;
- the liquidity of the capital market etc.; investments in the energy companies are usually large capital investments, so good market liquidity and financial institutions is essential.

Energy companies must prepare a risk management register of the risks, recorded in a systematic manner in order to identify controlled risks. These can be: marketing, production, financing, staffing, investment, legal, etc. Below is shown an attempt to set the most important risks to an energy company. For each step, we need for each type of risk to determine whether there is a large, medium or low risk, which is for each company-specific.

Figure 1 shows this, as defined by a specific energy company; it is clear that there is a very wide range of risks and associated risk management problems that are crucial to decisions on new investments.

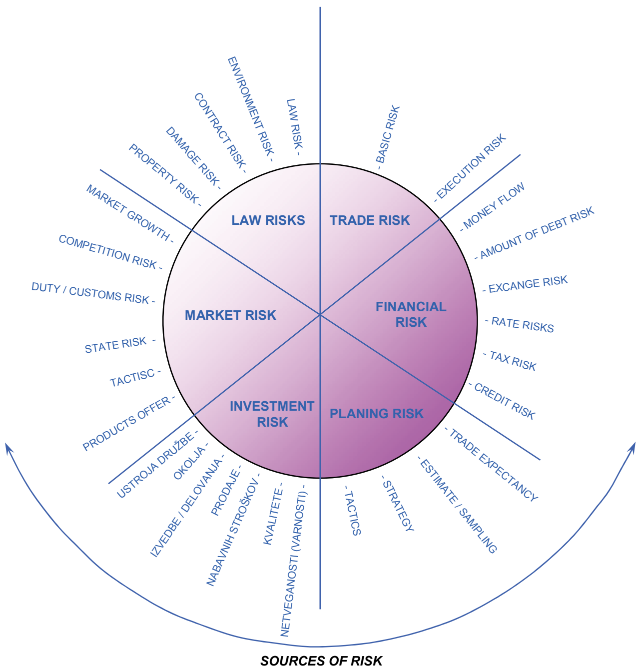

Figure 1: Potential sources of risk

Source: HSE - Holding Slovenske Elektrarne 2005, internal analysis.

When planning new investments, it is important that we have an adequate portfolio of production aggregates that can produce the energy required for the sales chart. Since electricity can not be stored, output must be equal to consumption at any time, which means the need for units operating in the band (24 hours per day) units, which may operate in a trapeze (usually from 6 to 20 hours), and units that operate only in peak periods. According to the source, it is important that we have the result of an appropriate risk management portfolio of hydro production, production based on coal, gas, nuclear fuel as well as other alternative energy sources. An appropriate portfolio of production resources is necessary to manage the technological as well as price risks. In such a case there is less likely to have shortage of more resources simultaneously as well as that more fuel prices be increased at the same time. Table 1 shows us the risks with respect to the technology in a variety of criteria, such as unit size, capital, fuel costs, operating costs etc. Typically, technologies that use low-value fuel are expensive (nuclear, hydro), and have long periods of operation; technologies using expensive fuel (gas, coal), are cheaper, short construction times.

Table 1: Risk in relation to technology

TECHNOLOGY / LINES	*UNIT SIZE*	*CAPITAL kWh*	*FUEL COSTS*	*OPERATIN G COSTS*	*COSTS CO_2*	*OPERATIN G TIME*	*CONTROLLIN G RISK*
CCGT	MEDIUM	LOW	HIGH	LOW	MEDIUM	SHORT	LOW
COAL	BIG	HIGH	MEDIUM	MEDIUM	HIGH	LONG	HIGH
NUCLEAR	VERY BIG	HIGH	LOW	MEDIUM	ZERO	LONG	HIGH
HYDR	SMALL	HIGH	ZERO	VERY LOW	ZERO	LONG	MEDIUM

* CCGT: Combined Cycle Gas Turbine – gas-steam turbine

Source: Directorate-General for Energy and Transport, DG TREN.

It should be noted that the energy company should have the proper balance of technology if it is to manage the risks.

4 COST RISK CALCULATIONS of DIFFERENT TECHNOLOGIES AND SOURCES USING A MODEL OF REFERENCE PRICE OF ELECTRIC ENERGY

An electric energy calculating model considers facts that the reference energy price is influenced by typical main technologies that are today available on the market (gas, nuclear, coal, hydro…). In the model, normal technical risk (reliability and turbine disposability) is also considered, which is present the current and foreseen market structure that is expected because of climate change, technological development or other interests for the next period. In

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this way, we get a price that presents reference costs, considered costs, as well as current and future structures of European sources for electric energy production.

As mentioned before, the equation of reference price of electric energy can be formed. The price must be ensured over institutional regulators such as controllers, agencies for energy or new European agencies. The price is market with symbol *c.* Variables are defined as:

- $c_{t,v}$ **source price "v" in time point "t"**: represents the average value of typical energy source (produced from coal, gas, nuclear fuel, water, wind…). In the time point, we must considered typical technology that is expected based on current research and development.
- $u_{t,v}$ **source weight "v" in time point "t"**: represents part of individual source in whole structure of all sources for electric energy production. For the future, we must consider the goal structure.
- w_t **weight of time point "t"**: represents the weight respected on time point. We suppose that presently the time point will have large value but less in the future. It is important that the time interval for the future is enough long, because of change rigidity of producing structure.
- d_t **discount grade** for bank interests from time point "t" for currency in which we calculate, as example: EURIBOR for €. The values are in relative form (if they are in percentages (%), they must be divided with 100 %).
- l_t **time distance** for time point "t" in years.

Because the equation is in a general form, we do not prescribe the limitations of different sources for electric energy production as well as time horizons. We defined crowd of sources in time point in the future as:

- Ψ **source crowd , $v \in \Psi$ in $\upsilon \in \Psi$.** In principle, the controller has at his disposal many different types of energy sources, such as nuclear power plants, gas plants, coal thermal plants, hydo-plants, etc.
- Γ **crowd of time points, $t \in \Gamma$ in $\tau \in \Gamma$.** The controller is not limited with number of time points, or with the time period. It is recommended that the time period is at the beginning more condensed (monthly interval) and in the future less condensed (years, decades).

The official discount grade, for correct estimation of production costs of individual sources in the future, must be considered when the price is calculated. The sum of individual weights must be equal to the unit, that's why we must divided individual weights with the sum of weights in the corresponding category in the equation. With such a determined basis and on the above-mentioned idea of the minimal price *c,* the following equation can be written:

$$c = \sum_{t}^{t \in \Gamma} \frac{w_t}{\sum_{\tau}^{\tau \in \Gamma} w_\tau} (1 + d_t)^{l_t} \sum_{v}^{v \in \Psi} \frac{u_{t,v}}{\sum_{\upsilon}^{\upsilon \in \Psi} u_{t,\upsilon}} c_{t,v} \tag{1}$$

From Equation (1) it follows that the price *c* depends on prices of the individual sources, from the structure of sources, the discount grade and from time points. A hypothetical reference price calculation: because of the limited research resources and of model limits that demand defined adjustment proposals, we try to consider the prices in the hypothetical calculation as possibly equal to real prices at the market. This is presently adopted at a low level structure of sources of states members of the OECD (considered at four main production sources), prediction of source development from the IEA (International Energy Association), and production costs of the new power plant, as it is in the annual report of one of the leading European company (Vattenfal, 2007).

Calculating example for reference price of electric energy (Example 1):

The controller calculated with three time points: first it is next year, second is for the next three years, and third is for next ten years. The following matrix could be written:

$$\mathbf{L} = \begin{bmatrix} 1 \\ 3 \\ 10 \end{bmatrix} years\ . \tag{2}$$

Bank interest could be taken as fixed for all three time points, i.e. 4 % at year level. For this data, the following matrix could be written:

$$\mathbf{D} = \begin{bmatrix} 4 \\ 4 \\ 4 \end{bmatrix} \%\ . \tag{3}$$

Considered are four types of electric power plants that predominate in the production structure: nuclear power plants, coal power plants, gas power plants and hydro-power plants. What are the possibilities the controller (electricity net operator) has and could have with the future development of the individual sources?

Nuclear power plants: New capacities are projected or planned to be build in several European states, i.e. Bulgaria, Finland, France, Poland, Romania and United Kingdom. The Slovenian government supports nuclear plants for the future, with plans to build a second operating plant in Krško (Government RS, 2006). Documentation that will persuade public is in the preparation. However, it is hard to expect the final solution before the problem of the radioactive waste storage from the first nuclear plant is suitably solved. Great expectations are directed to the new technologies of third and fourth generations of reactor that are expected to safe and economical. The great advantage of nuclear power plants is fact that there are no carbon dioxide (CO_2) emissions, as well as flexibility in nuclear fuel assurance (more suppliers). The weaknesses are in following fact: very long building period, high building expenses and, with this, connected higher capital risks, safety and storage of radioactive waste that in many states is still not satisfactory solved. Otherwise, an individual power plant could achieve exit power up to 1600 MW, representing the production of 12 TWh (approximately all Slovenian consumption), represents €700 million/year income at current market prices. Estimated fix

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costs (mainly the capital costs) are between €32 and €39 /MWh and variable costs (fuel, work, waste storage etc) are up to €5/MWh. On this basis, we estimated a common price between €37 and €4 /MWh. For our case we estimated that presently operating plants operate more cheaply (amortization) but not significantly, because the plants must be disassembled, which is reflected in the price of €35/MWh. We predict that this price will be increased up 40 €/MWh in third time point, when we expected that new plants will operate, with prices up to €50/MWh.

Thermo-power plants: Coal is mostly used fuel for electricity production and will be also in the future. It is relatively cheap and in many states represents competitive energy source. Major pressure on decreasing carbon dioxide (CO_2) emissions leads to developing new technologies that will operate in future without any emissions of carbon dioxide (CO_2). The advantage of the coal is in the fact that there are reserves for up to 250 years, and in fact that the deposits are in relatively stable states. The weaknesses are in relatively long period of construction and that they have a major effect on their surroundings.

A thermo-power plant with installed power up to 700 MW could produces up to 4.2 TWH of electricity energy. Estimated fixed costs (with operating and with maintenance) are between €19 and €26/MWh, and variable costs are between €29 and €33/MWh. Common costs are estimated between €49 and €55/MWh. For our case, we take the beginning price for year €45/MWh, reflecting amortization of the plants. In the future time periods, when the new plants that will be more effective, we estimated that the common price will be higher because of expensive new technologies and increased environment state taxes. We also estimated, because of greater interest and price increases of alternative fuels (oil), that the price of coal will increase. This is reflecting in the price in the second time point of €50/MWh and for the third time point €70/MWh.

Gas-power plants: Gas is, in principle, a much cleaner energy source in comparison to oil or coal. Gas technology represents the fastest growing technology among power plant technologies. Carbon dioxide (CO_2) emissions are much lower than those of coal technology; therefore, many states try to exchange coal plants for gas plants. Major gas deposits in nature are in Russia and in Middle East. The advantages are, beside low carbon dioxide (CO_2) emissions, the fast construction, relatively small capital expenses, high efficiency and great flexibility of gas turbines. Disadvantages are in unsure supply, deposits are at unstable areas (states), high changeability of prices, and in carbon dioxide (CO_2) emissions. A gas plant in a combined process with installed power of 400 MW and with electric energy production of 2.4 TWh. The fix costs are between €11 and 13 €/MWh, and vary (especially gas price) between €45 and €52/MWh. The common price is between €56 and €65/MWh. In our case, we considered the initial price in this year (€60/MWh), and later higher prices that are a consequence of oil increase prices on the world market. In second time period, we get price of €65/MWh, and in the third €85/WMh.

Hydro-power plants represent the largest source of renewable energy and, in some states, a major part of the production structure (Sweden, Norway, Canada, Brazil, China …). Very first plants are over 100 years old. The advantages are in efficiency, no CO_2emissions, possibilities of

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water storage, and the flexibility of power plants. Disadvantages are in the high dependency of water availability, influence on environment (land changes), and high investment costs. Hydro-power plants can be smaller than 1 MW of as large as 400 MW or even more. Estimated costs are between €44 and €66/MWh, but these are typically only fixed costs, while the variable costs almost do not exist. In our case, we get price over the time periods €35, €40 and €60/MWh. We consider fact that the existing hydro-power plants produce electric energy at low prices when compared with new ones and do not expected existing structural changes in other time points, while the building time is long. In the third time period, we expect that there will be structural change, because the new plants will start to operate; that will be more expensive. The price increase can also be expected on the basis of environment tax increases and because of indemnification payments for land damage.

From the above-mentioned facts, the following matrix could be written:

$$\mathbf{C} = \begin{bmatrix} 35 & 45 & 60 & 35 \\ 40 & 50 & 65 & 40 \\ 50 & 70 & 85 & 60 \end{bmatrix} \text{€/MWh}\,. \tag{4}$$

Based on data from OECD states, we assume in the Matrix (4), that the ratio between sources 23%: 39%: 25%: 13% (nuclear power plants: thermal-power plants: gas-power plants: hydro-power plants, respectively). The operator may have request to change these ratios, based perhaps on global climate changes, to reach the goal ratios of 15%: 36%: 38%:11%. That means that the ratio of nuclear energy will decreased from the initial 23% to 15%, the ratio of coal energy form today’s 39% to 36%, the ratio of gas energy will increase from 25% up to 38% and the ratio of hydro energy will decrease from 13% to 11%.

We logically considered the predictions of institutions, such as IEA and others of how the sources will develop in the future (more is written in Section 3). Based on previous predictions, the following matrix could be written:

$$\mathbf{U} = \begin{bmatrix} 0.23 & 0.39 & 0.25 & 0.13 \\ 0.20 & 0.38 & 0.30 & 0.12 \\ 0.15 & 0.36 & 0.38 & 0.11 \end{bmatrix} \tag{5}$$

The operators know that the sources structure is changed slowly, and therefore wish to increase the influence of nearest time points (first year with 50%), and decrease all later time points. f (30 %, 20%). On this basis the operator must give clear signal for the future.

Based on upper predictions, the follow matrix could be written:

$$\mathbf{W} = \begin{bmatrix} 0.5 \\ 0.3 \\ 0.2 \end{bmatrix} \tag{6}$$

In this way, based on the above predictions and calculation with Equation (1), we get a reference price of electric energy equal €45.06/MWh.

Example No. 3: The reference price of electric energy calculation with the technology structure change (with respect to Example 1)

Based on the model (Example 1), where we used the structure sources of OECD states, and the source developing as predicted by the IEA, and with the prices of Vattenfall, we changed the sources structure and the influence of sources that are valid on Slovenian market. We wish to know how the source structure influences, besides the technology reliability of supply, the reference price of the electric energy at Slovenian market.

We used the above-mentioned matrix:

- The matrix of time distance:

$$\mathbf{L} = \begin{bmatrix} 1 \\ 3 \\ 10 \end{bmatrix} \textit{years} \qquad (2)$$

- The matrix of discounts:

$$\mathbf{D} = \begin{bmatrix} 4{,}0 \\ 4{,}0 \\ 4{,}0 \end{bmatrix} \% \qquad (3)$$

- The price sources matrix:

$$\mathbf{C} = \begin{bmatrix} 35 & 45 & 60 & 35 \\ 40 & 50 & 65 & 40 \\ 50 & 70 & 85 & 60 \end{bmatrix} \text{€/MWh} \qquad (4)$$

- The matrix of ponders:

$$\mathbf{U} = \begin{bmatrix} 0.37 & 0.36 & 0.02 & 0.25 \\ 0.39 & 0.35 & 0.02 & 0.24 \\ 0.37 & 0.31 & 0.05 & 0.27 \end{bmatrix} \qquad (7)$$

- The matrix of time points:

$$\mathbf{W} = \begin{bmatrix} 0.5 \\ 0.3 \\ 0.2 \end{bmatrix} \qquad (6)$$

We calculate the reference price of €38.72/MWh, meaning that the source structure in Slovenia is up to 16% more suitable than the average at OECD states (€45.06/MWh). This means, beside the reliable supply which based on technical characteristics' of the individual technologies, is also from the competitive point of view, very important that regulator defines optimal production capacities. In this way is possible to prevent that the supply become unstable, because of the one energy source that is in the moment most concurrent. In the other hand it must be consider, that the optimal technologies are also limited by natural possibilities.

How important the right technology structure of electric energy production sources is shown with information from Scandinavian electricity market, which has hydro-energy producers as a major part of its structure. The prices of electric energy were between €25 and €30/MWh in the year 2005. In beginning of the year 2006, the price increased up €40 to €50/MWh; almost a 70% increase. The reason was bad hydrological conditions. Assumed are that the oil and gas high prices at the word markets increase the demand for usage of coal that caused increase of the CO_2 allowances up to 30 €/ton. This has influence on electric energy price increase produced in the thermo-power plants for 18 to 20 €/MWh (Vattenfall estimation). Consider the high dependence of the competitiveness of the technology and the natural energy resources for the competitive energy market is particularly important to remove blockage in the transport routes. Only then will investors be able to select a location and bring the competitive electricity supply to end users. Some consider that the capacity structure is a priority task of regulators, because of its influence on security of supply as well as on competitiveness which is much bigger that for example the market concentration against which it is driven more and more measures (Duerr, 2006).

5 CONCLUSION

Given the high dependence of the competitiveness of the technology and types of natural endowments for the operation of the market and the corresponding location of power, it is particularly important in order to remove blockage in the transport routes. Only then will investors be able to select a location and bring a competitive electricity supply to end users. Some consider the structure of technology a priority task for regulators, because the greatly reduced price of electricity as well as security of supply, such as the concentration of the market, against which it is driven an increasing number of measures (Duerr, 2006).

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AN APPLICATION OF STATISTICAL CHAIN THEORIES ON THERMODYNAMIC PROPERTIES OF BINARY AND TERNARY HYDROCARBON MIXTURES

UPORABA TEORIJE VERIG ZA IZRAČUN TERMODINAMIČNIH LASTNOSTI BINARNIH IN TERNARNIH OGLJIKOVODIKOVIH ZMESI

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Keywords: statistical thermomdynamics, thermomechanics, chain theory, refrigeration;

Abstract

This paper discusses a mathematical model for computing the thermodynamic properties for binary and ternary mixtures of propane, n-butane and isobutane in their fluid phase with the aid of statistical chain theory. The constants required computing the characteristic temperatures of rotation, electronic state etc., and the moments of inertia are analytically obtained by applying knowledge of the atomic structure of the molecule. The procedure for calculating essential thermodynamic properties such as pressure, speed of sound, the Joule-Thomson coefficient, compressibility, enthalpy and thermal expansion coefficient is presented in the paper. This paper will discuss, for the first time, the application of statistical chain theory and accuracy for binary and ternary mixtures among propane, nbutane and isobutane, in their

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entire fluid phases for all important thermodynamic properties. To calculate the thermodynamic properties of the Lennard-Jones chains,we have used the Liu-Li-Lu and Tang-Lu models. The thermodynamic properties of the Lennard-Jones mixtures are obtained using the one-fluid theory. In recent years, thermodynamic theories based on statistical thermodynamics have been rapidly developing; fluids with chain bonding and association have also received much attention. Interests for these fluids are prompted by the fact that they cover much wider range of real fluids than spherical ones. A good theory for these fluids will be very beneficial to chemical engineering applications by reducing the number of parameters and making them more physically meaningful and more predictable. In technical practice, energy processes are of vital importance. In order to design devices in this field, it is necessary to be familiar with the equilibrium and nonequilibrium properties of state in single- and two-phase environments for pure refrigerants and their mixtures. To calculate the thermodynamic properties of real fluid, the **Liu-Li-Lu (LLL)** (revised Cotterman) equation of state based on simple perturbation theory and the SAFT-VR equation of state for LJ chain fluid was applied. To compare the thermodynamic properties of real fluid obtained by the SAFT theory we used the **REFPROP** model.

Povzetek

Članek predstavlja postopek izračuna termodinamičnih lastnosti za binarne in ternarne zmesi ogljikovodikov. Konstante, ki so potrebne za izračun kot so na primer vztrajnostni momenti, karakteristične temperature in še mnoge druge so izračunane povsem analitično. Predstavljen model omogoča izračun vseh ravnotežnih termodinamičnih veličin s pomočjo statistične termodinamike in teorije verig. Za izračun termodinamičnih veličin stanja Lennard-Jonesovih verig smo uporabili Liu-Li-Lu-jev model in Tang-Lu-jev model. Analitični izračuni so primerjani z REFPROP programom in kažejio na zelo dobro ujemanje.

1 INTRODUCTION

For aeons, life on the Earth has been protected by the protective atmosphere layer. This layer consists of ozone, which protects the Earth from harmful ultraviolet radiation of the Sun. As far as we know, the Earth is the only planet with such a layer. If the ozone layer disappeared, the ultraviolet solar radiation would sterilise the Earth's surface, making the life of most of the Earth's creatures impossible. In the areas where there are holes in the ozone layer, an increase of the solar radiation has been observed. The data obtained so far has confirmed that even a minimum depletion of the ozone layer can cause an increase in the incidence of skin cancer and result in a higher number of eye injuries, while at the same time reducing the body's defensive ability. At the same time, the radiation depletes crops and damages forests and sea life.

The discovery that the depletion of the stratospheric ozone is a result of the activity of the organic substances containing bromine and chlorine led to the signing of an international agreement in 1987 on the reduction of the production and consumption of ozone-depleting substances: the Montreal Protocol on Substances that Deplete the Ozone Layer. The Montreal Protocol was signed by more than 130 countries and is regarded as one of the most efficient agreements. The amendments to the Montreal Protocol were signed in London (1990), Copenhagen (1992) and Vienna (1995). The signatories to the Protocol are obliged to reduce

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and gradually discontinue the production and consumption of ozone-depleting substances containing one or more elements of chlorine and bromine.

The temperature of the Earth is maintained through the balance between the solar radiation coming from the space and cooling, which occurs through the emission of the infrared radiation of the Earth's surface and the atmosphere back to the space. The Sun is the Earth's only external source of heat. When solar radiation in the form of visible light reaches the Earth, it is partly absorbed by the atmosphere and partly reflected from the clouds and the Earth. What remains is absorbed by the surface, which is heated, thus warming the atmosphere. The warm surface and atmosphere of the Earth emit invisible ultrared radiation. In practical terms, the atmosphere does not hamper the solar radiation, though ultrared radiation is absorbed in it, namely in gases, which are present in very small amounts. Even though these gases are present only in traces, they act as a blanket preventing the emission of infrared radiation into the space. By slowing down the radiation, which allows the cooling, the Earth's surface is heated. In a greenhouse, the glass permits sunlight to enter and partly prevents infrared radiation from exiting. The gases in the Earth`s atmosphere, which perform in a similar way, are called the greenhouse gases. Among these gases are water vapour, carbon dioxide, ozone, methane, nitrous oxide and halogenated hydrocarbons. The heating caused by greenhouse gases increases evaporation, resulting in a larger quantity of water vapour in the atmosphere, which in turn leads to excesive heating.

Fluid mechanics and thermodynamics are two fundamental sciences needed for the computation of liquid and gas flow properties.On the surface, it seems these are two completely different scientific disciplines, each of which making major progress using mathematics and experimental techniques. The impression is that thermodynamics helps compute the physical properties required in flow computation. Boltzmann, the founder of non-equilibrium mechanics, provided a new direction and idea for the development of hydromechanics. Using the famous Boltzmann equationm the boundaries between thermodynamics and fluid mechanics have become very indistinct. The intermolecular potential and the resulting attractive and repulsive forces between the molecules are used to compute the flow properties. Unfortunately, the Boltzmann equation has not provided any analytical solutions yet and in many cases the Navier-Stokes equation is still being used in engineering for the fluid flow computation purposes. However, the Navier-Stokes equation has a limited scope of application in fluid mechanics.

2 COMPUTATION OF THERMODYNAMIC PROPERTIES OF THE STATE

To calculate thermodynamic functions of state, we applied the canonical partition [1-6]. Utilising the semi-classical formulation for the purpose of the canonical ensemble for the N indistinguishable molecules, the partition function Z can be expressed as follows [5]:

$$Z = \frac{1}{N!h^{Nf}} \int .. \int \exp\left(-\frac{H}{kT}\right) \cdot d\vec{r}_1 d\vec{r}_2 .. d\vec{r}_N d\vec{p}_1 d\vec{p}_2 .. d\vec{p}_N \qquad (1)$$

where f stands for the number of degrees of freedom of individual molecule, H designates the Hamiltonian molecule system, vectors $\vec{r}_1, \vec{r}_2 .. \vec{r}_N$ .. describe the positions of N molecules and

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$\vec{p}_1, \vec{p}_2 ... \vec{p}_N$ momenta, k is Boltzmann`s constant and h is Planck`s constant. The canonical ensemble of partition function for the system of N molecules can be expressed like this:

$$Z = Z_0 Z_{trans} Z_{vib} Z_{rot} Z_{ir} Z_{el} Z_{nuc} Z_{conf} \tag{2}$$

Thus the partition function Z is a product of terms of the ground state (0), the translation (trans), the vibration (vib), the rotation (rot), the internal rotation (ir),the influence of electrons excitation (el), the influence of nuclei excitation (nuc) and the influence of the intermolecular potential energy (conf).

Utilising the canonical theory for computating, the thermodynamic functions of the state can be put as follows[5,6]:

$$\begin{aligned}
&\text{Pressure } p = kT\left(\frac{\partial \ln Z}{\partial V}\right)_T, \\
&\text{Internal energy } U = kT^2\left(\frac{\partial \ln Z}{\partial T}\right)_V, \\
&\text{Freeenergy } A = -kT \cdot \ln Z, \\
&\text{Entropy } S = k\left[\ln Z + T\left(\frac{\partial \ln Z}{\partial T}\right)_V\right], \\
&\text{Free enthalpy } G = -kT\left[\ln Z - V\left(\frac{\partial \ln Z}{\partial T}\right)_V\right], \\
&\text{Enthalpy } H = kT\left[T\left(\frac{\partial \ln Z}{\partial T}\right)_V + V\left(\frac{\partial \ln Z}{\partial V}\right)_T\right],
\end{aligned} \tag{3}$$

where T is temperature and V is volume of molecular system. The computation of the individual terms of the partition function and their derivatives, except the configurational integral ,is dealt with in the works of Lucas [4]; Gray and Gubbins [5] and McClelland [6].

The various derivatives and expressions of the fundamental equations (3) have an important physical significance. This paper presents expressions that are very important for planning the energy processes. The various derivatives also prove to be of physical interest:

The coefficient of thermal expansion:

$$\beta = \frac{1}{V}\left(\frac{\partial V}{\partial T}\right)_p. \tag{4}$$

The isothermal compressibility:

$$\chi = -\frac{1}{V}\left(\frac{\partial V}{\partial p}\right)_T. \tag{5}$$

The molar heat capacity at constant volume per mole:

$$C_v = \left(\frac{\partial U}{\partial T}\right)_V . \tag{6}$$

The molar heat capacity at constant pressure per mole:

$$C_p = \left(\frac{\partial H}{\partial T}\right)_p = C_v + \frac{TV\beta^2}{\chi} . \tag{7}$$

The speed of sound**:**

$$c_0 = \sqrt{-V^2 \frac{1}{M}\left(\frac{\partial p}{\partial V}\right)_s} = \sqrt{-V^2 \frac{\frac{C_p}{T}\left(\frac{\partial T}{\partial V}\right)_p \frac{1}{M}}{\left(\frac{\partial V}{\partial T}\right)_p - \frac{C_p}{T}\left(\frac{\partial T}{\partial p}\right)_v}} , \tag{8}$$

where M is mollar mass.

For the cooling systemsm it is also very important to calculate the Joule-Thomson's coefficient:

$$\mu_J = \frac{1}{C_p}\left(T\left(\frac{\partial V}{\partial T}\right)_{p,\psi} - V\right) \tag{9}$$

3 STATISTICAL ASSOCIATING FLUID THEORY (SAFT) [8-25]

Over the last fifty years, quite accurate models have been developed for predicting the thermodynamic properties for simple molecules on the basis of statistical thermodynamics. By "simple", we mean molecules for which the most important intermolecular forces are repulsion and dispersion with weak electrostatic forces due to dipoles, quadrupoles and higher multipole moments. Many hydrocarbons, natural constituents, simple organic and simple inorganic molecules fall within this cathegory. However, many other components, such as electrolytes, polar solvents, hydrogen-bonded fluids, polymers, liquid crystals, plasmas and particularly mixtures, do not belong to this group. The reason for this is that,for such fluids new intermolecular forces become important: Coloumbic forces, strong polar forces, complexing forces, the effects of association and chain formation.etc.

An important type of these complex fluids consists of those that associate to form relatively long-lived dimmers or higher n-mers. This sort of fluids includes hydrogen bonding, charge transfer other types can occur. The intermolecular forces involved are stronger than those due to dispersion or weak electrostatic interactions but still weaker than forces due to chemical bonds.

In recent years, thermodynamic theories based on statistical thermodynamics have been rapidly developed. Fluids with chain bonding and association have also received much attention. Interests for these fluids are prompted by the fact that they cover a much wider range of real fluids than spherical ones. A good theory for these fluids will be very beneficial to chemical engineering applications by reducing the number of parameters and making them more physically meaningful and more predictable. In technical practice, energy processes are of vital importance. To calculate the thermodynamic properties of the real Lennard-Jones (LJ) fluid **Liu-Li-Lu (LLL)** (revised Cotterman) equation of state based on simple perturbation theory and SAFT-VR equation of state for LJ chain fluid, was applied. The developed RDF has been applied to the development of a new SAFT model. The presented model has been used to calculate several typical properties of LJ chains and associating LJ chains. This paper discusses the accuracy of presented models in real engineering practice for the first time.

The original derivation of SAFT models can be understood wit the Wertheim papers [1,2]. They require a comprehensive knowledge of graph theory to be fully understood. With the help of SAFT theory, we can express the residual part of free energy as:

$$A^{res} = A^{seg} + A^{chain} + A^{assoc}$$

For the pure components we can express more detailed equation:

$$A^{res} = A^{seg}\left(m\rho, T, \sigma_s, \varepsilon\right) + A^{chain}\left(\rho, d, m\right) + A^{assoc}\left(\rho, T, d, \varepsilon^{AB}, \kappa^{AB}\right) \tag{10}$$

where ρ is the molar density of molecules, m is number of segments, ε^{AB} is association energy of interaction between two sites and κ^{AB} is volume interaction between two sites.

The residual Helmholtz energy consists of three terms representing contributions from different intermolecular forces. The first term A^{seg} represents segment-segment interactions. In the present paper. segment-segment interactions are represented through Lennard-Jones interaction potential. Each segment is characterized by its diameter σ_s, segment interaction parameter ε_s and each molecule is characterized with the number of segments, m.

The second term A^{chain} is the result of presence of covalent chain-forming bonds between the LJ segments.

The third term A^{assoc} is the result of site-site interactions between segments; hydrogen bonding for example, .For the hydrocarbons, the association term is of no importance and will be neglected in our equations.

<u>The Liu-Li-Lu model [12]</u>

The present model is developed on the basis of SAFT and perturbation theory around hard sphere with new coefficients by fitting reduced pressure and internal energy data from molecular simulation:

$$A^{seg} = A^{hs} + A^{pert} \tag{11}$$

The hard sphere term A^{hs} is calculated with the expression given by Mansoori et al. [27]:

$$\frac{A^{hs}}{R_m T} = \frac{6}{\pi\rho}\left[\frac{3\xi_1\xi_2}{1-\xi_3} + \frac{\xi_2^{\ 3}}{\xi_3^{\ 2}(1-\xi_3)^2} + \left(\frac{\xi_2^{\ 3}}{\xi_3^{\ 2}} - \xi_0\right)\ln(1-\xi_3)\right] \tag{12}$$

where the symbol ξ_i is expressed as:

$$\xi_i = \left(\frac{\pi}{6}\right)\rho\sum_i \psi_i m_i d_i^{\ i} \tag{13}$$

In equation (13), d_i represents the hard sphere diameter and is a temperature dependent function and ψ_I is a molar fraction of component i. In our case, we have used the equation developed by Cotterman et al. [26]:

$$d_i = \sigma_i \frac{1+0.2977T^*}{1+0.33163T^* + c_3 T^{*2}} \tag{14}$$

where T^* is reduced temperature:

$$c_3 = \left(0.0010477 + 0.025337\frac{m_i - 1}{m_i}\right)$$

In the case of pure fluid, Eq. (12) is reduced to the Carnahan-Starling equation [12]:

$$\frac{A^{hs}}{R_m T} = m\frac{4\eta - 3\eta^2}{(1-\eta)^2}, \tag{15}$$

For the dispersion term, we have used the Cotterman et al [26]. equation and the one-dimensional VDW theory for mixtures:

$$A^{pert} = m_x \frac{A^{(1)}}{T_x^{\ *}} + m_x \frac{A^{(2)}}{T_x^{\ *2}} \tag{16}$$

$$\frac{A^{(1)}}{R_m T} = \sum_{m=1}^{4} A_{1m}\left(\frac{\eta}{\tau}\right)^m, \quad \frac{A^{(2)}}{R_m T} = \sum_{m=1}^{4} A_{2m}\left(\frac{\eta}{\tau}\right)^m, \tag{17}$$

$$\tau = 0.7405, \qquad \eta = \frac{\pi\rho d_s^{\ 3}}{6} m_x, \tag{18}$$

The effective segment diameter d_s is determined on the basis of the Barker perurbation theory. We use a function developed in the work of Chapman et al. [20]:

$$d_s = \sigma_x \frac{1+0.2977T^*}{1+0.33163T^* + c_3 T^{*2}} \tag{19}$$

$$c_3 = 0.0010477 + 0.025337\frac{m_x - 1}{m_x} \tag{20}$$

$$T_x^* = \frac{kT}{\varepsilon_x} \tag{21}$$

For the mixtures, we have used VDW1 mixing rules:

$$\begin{aligned} m_x &= \sum_i \psi_i m_i \\ m_x^2 \sigma_x^3 &= \sum_i \sum_j \psi_i \psi_j m_i m_j \sigma_{ij} \\ m_x^2 \varepsilon_x \sigma_x^3 &= \sum_i \sum_j \psi_i \psi_j m_i m_j \varepsilon_{ij} \sigma_{ij} \end{aligned} \tag{22}$$

For the determination of mixing parameters we have used the Lorentz-Berthelot equation:

$$\varepsilon_{ij} = \sqrt{\varepsilon_i \varepsilon_j}, \quad \sigma_{ij} = \frac{\sigma_i + \sigma_j}{2} \tag{23}$$

According to Wertheim's first order thermodynamic perturbation theory, the contribution to free energy due to chain formation of the LJ system is expressed as:

$$\frac{A^{chain}}{NkT} = \sum_i \psi_i (1 - m_i) \ln g^{LJ}(\sigma) \tag{24}$$

Johnson et al. [36] gave a correlation result of the radial distribution function for LJ fluids dependent on reduced temperature and reduced density:

$$g^{LJ}(\sigma_s) = 1 + \sum_{i=1}^{5} \sum_{j=1}^{5} a_{ij} (\rho^*)^i (T^*)^{1-j} \tag{25}$$

4 RESULTS AND COMPARISON WITH EXPERIMENTAL DATA

The thermodynamic properties can be calculated either with classical thermodynamics [32-35] or with statistical thermodynamics. In the present paper, we have used statistical thermodynamics to calculate the thermodynamic properties of hydrocarbons.The constants necessary for the computation, such as the characteristic rotation, electronic temperatures etc.are obtained from data [27-29]. The vibration constants are obtained from the NIST Chemistry Web Book page. The inertia moments are obtained analytically by applying the knowledge of the atomic structure of the molecule. The constants for the Lennard-Jones potential are obtained from the literature of Hirschfelder, Curtiss and Bird [30]. We carried out calculations for binary and ternary mixtures between n-butane (C_4H_{10}), isobutane (C_4H_{10}) and propane (C_3H_8). The comparison between analytical results and models obtained by classical thermodynamics is presented in the works of Avsec et al. [31] The comparison of our calculations for binary HC mixtures with the REFPROP model is presented in Figures 1-4. They

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show the relative deviation of the results for mixtures between n-butane and propane in the real gas region between the analytical computation (Liu-Li-Lu model (LLL)), and the REFPROP model obtained by classical thermodynamics. The relative deviation is defined by the next expression:

$$\text{Relative deviation} = RD = (data_{ST} - data_{TRWW}) / data_{TRWW} \tag{26}$$

The results for all the models obtained by statistical thermodynamics show relatively good agreement. The computed vapour pressure, isothermal compressibility, molar isobaric heat capacity and speed of sound were confirmed well for all models obtained by statistical associating thermodynamics. Somewhat larger deviations can be found in the region near the critical point due to the large influence of fluctuation theory and the singular behaviour of some thermodynamic properties in the near-critical condition. The perturbation models yield surprisingly good results on the basis of SAFT theory (LLL). The models on the basis of SAFT theory give better results in comparison with models on the basis of classical statistical thermodynamics, especially in high temperature and high pressure regions.

Figures 1 and 2 show a comparison between the LLL and REFPROP models for speed of sound, isothermal compressibility and volumetric coefficient of expansion. The figures are elaborated for propane for the real gas phase at 5 MPa, 500 K and 0.1 MPa, 300 K as a function of the molar fraction of n-butane. The present analytical model yields very good results with much lower deviations in all other points.

Figure 3 shows a comparison between the LLL and REFPROP models for speed of sound, pressure, isobaric molar hea capacity and isochoric molar heat capacity for *n*-butane-propane mixture at 50% of molar fraction of butane at saturated gas conditions. The present analytical model yields very good results with much lower deviations in all other points. Figure 4 shows the comparison between our analytical model and the REFPROP model for a mixture between *n*-butane and isobutene at 50 mol% of *n*-butane at saturated gas conditions. Figures 5 to 7 show thermodynamic properties in the an equimolar ternary mixture between propane, isobutane and *n*-butane in comparison with the REFPROP model.

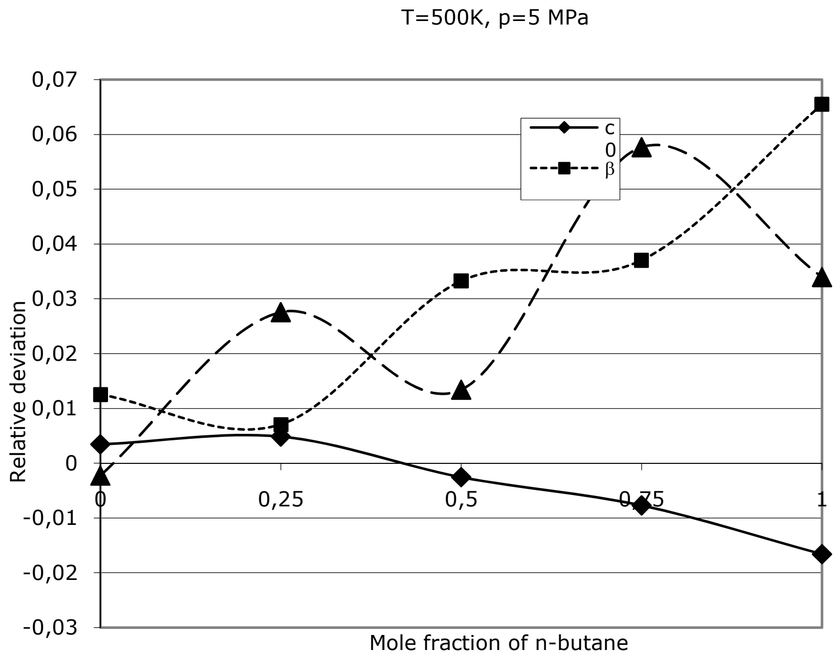

Figure 1: Relative deviation of thermodynamic properties at 5 MPa for propane-n-butane mixture

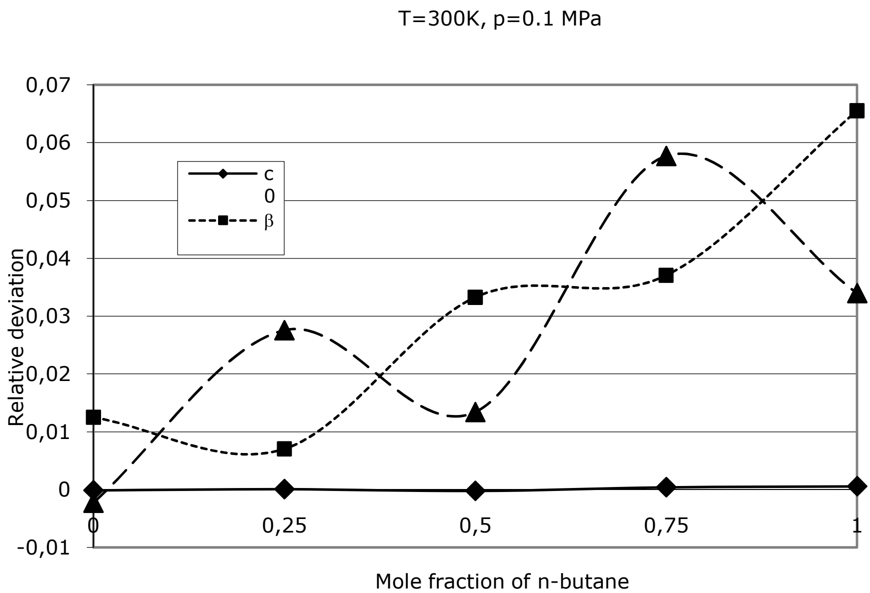

Figure 2: Relative deviation of thermodynamic properties at 500 K and 0.1 MPa for propane-n-butane mixture

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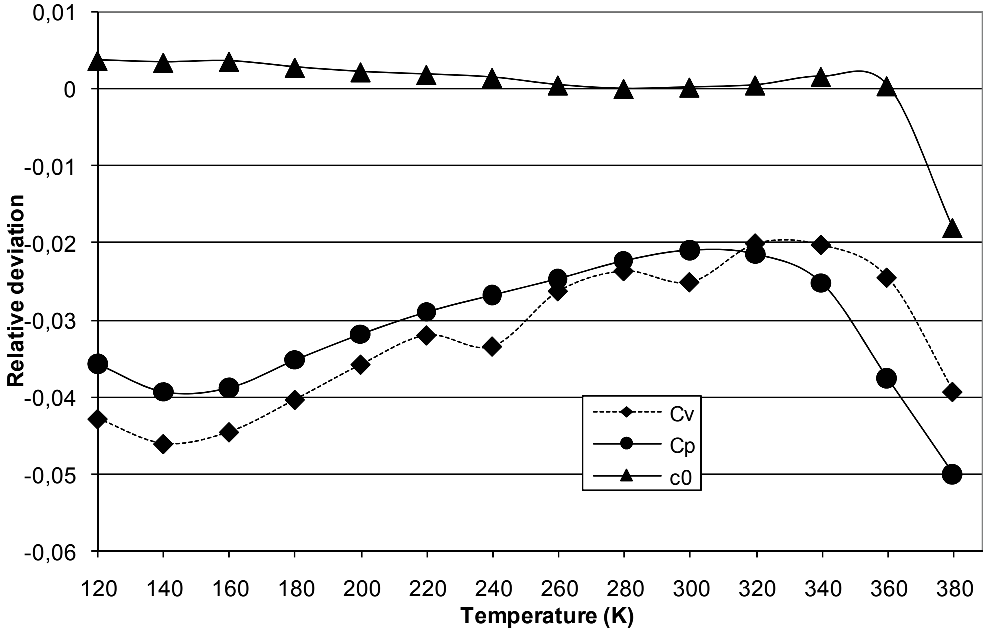

Figure 3: Relative deviation of thermodynamic properties at saturated conditions for n-butane-propane mixture

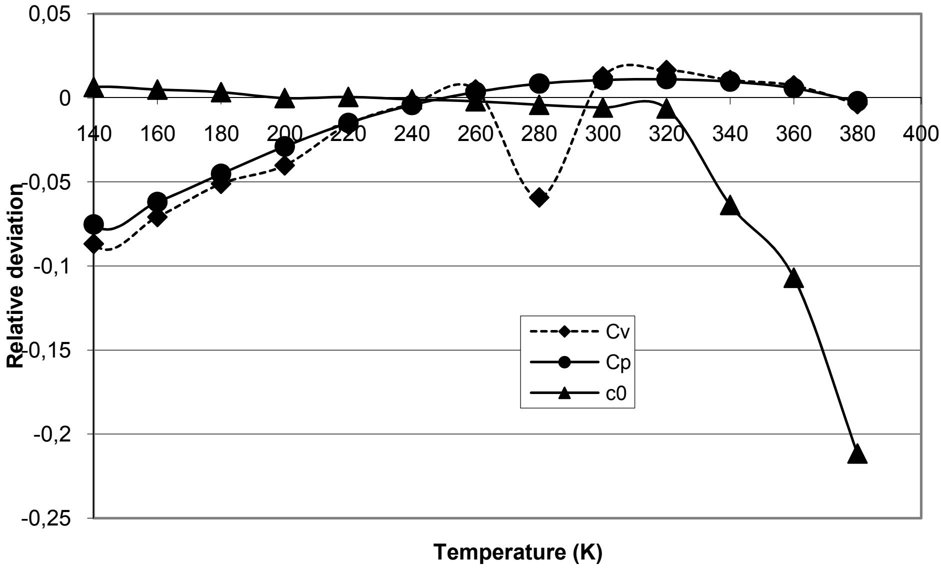

Figure 4: Relative deviation of thermodynamic properties at saturated conditions for n-butane-isobutane mixture

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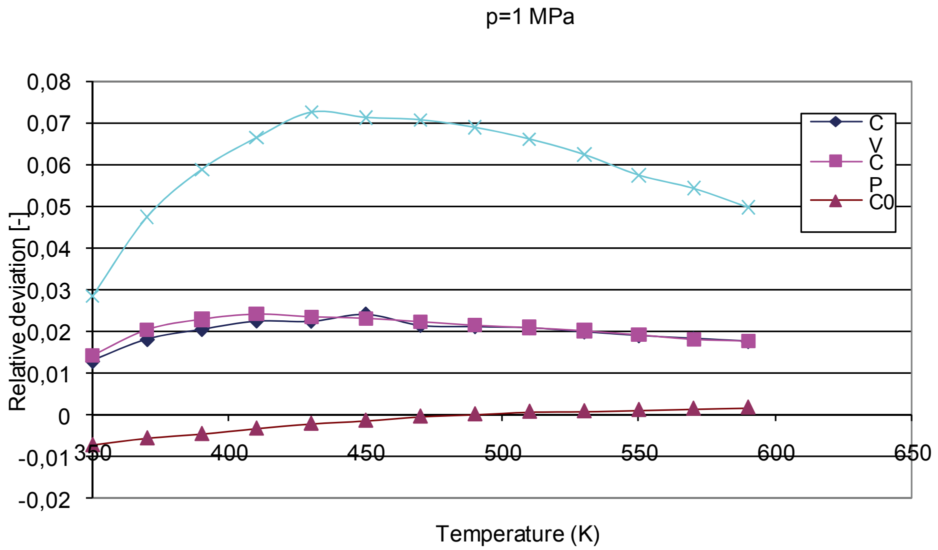

Figure 5: Thermodynamic properties for n-butane, propane and isobutane mixture

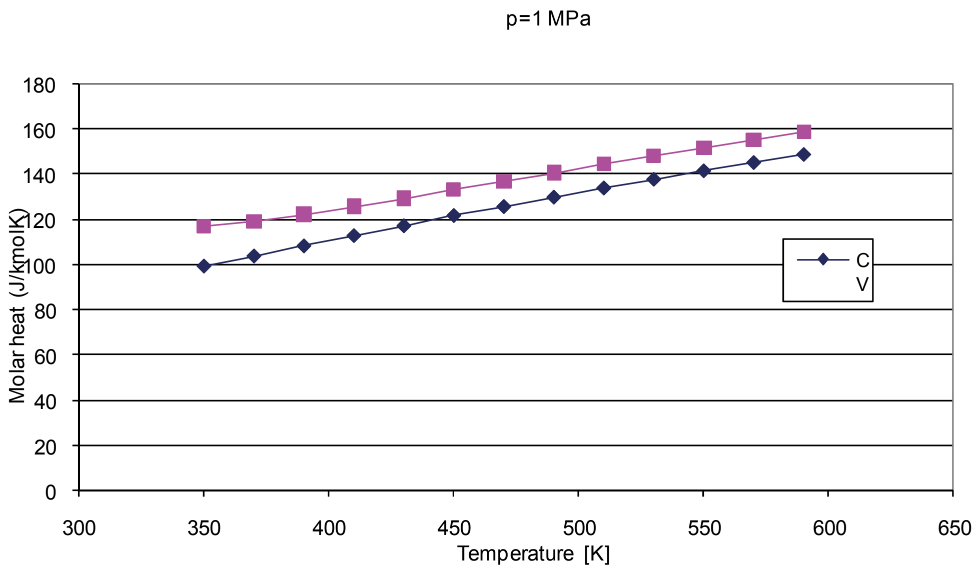

Figure 6: Thermodynamic properties for n-butane, propane and isobutane mixture

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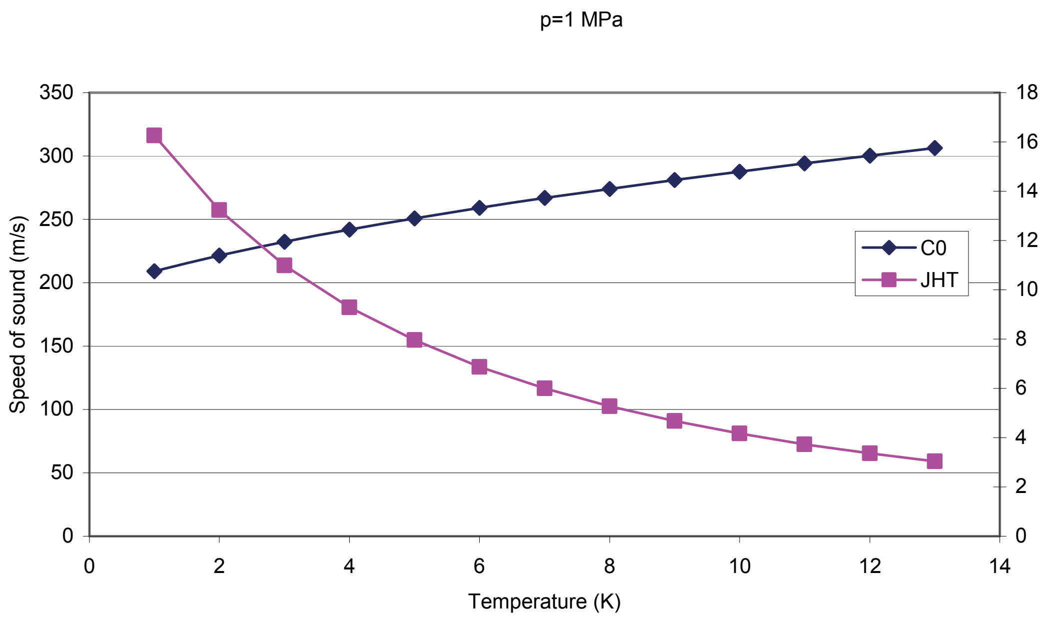

Figure 7: Speed of sound and Joule-Thompson coefficient for ternary mixture between n-butane, propane and isobutane mixture

The analysis shows that multi-pole effects must be taken into account for the areas of very low factors of reality to be able to expect full matching of results, even though the matching is even now very satisfactory. The present analysis provides a good basis for further upgrading of this model allowing the calculation of very accurate thermodynamic properties of state in liquid and gas ranges as well as in super- and sub-critical regions.

The results for all models obtained by statistical thermodynamics show relatively good agreement. The computed vapour pressure, isothermal compressibility, isobaric molar heat capacity and speed of sound conform well for all models, obtained by statistical thermodynamics. Somewhat larger deviations can be found in the region of critical conditions due to the large influence of fluctuation theory and singular behaviour of some thermodynamic properties in the near-critical condition. The perturbation models based on the SAFT theory (LLL) yield surprisingly good results. These models give better results in comparison with the models based on classical statistical thermodynamics, especially in high temperature regions.

5 CONCLUSIONS

The paper presents the mathematical model for computation of thermodynamic functions of the state for binary and ternary mixture of hydrocarbons in the fluid state on the basis of statistical chain theory. The same procedure can be applied for calculation of thermophysical properties for hydrofluorocarbons, of course with the knowledge of multipolar effects. The analytical results are compared with the REFPROP model and they show relatively good agreement.

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Nomenclature

A	free energy
A^*	reduced free energy
AAD	absolute average deviation
c_0	speed of sound

C_p	molar heat capacity at constant pressure
C_V	molar heat capacity at constant volume
D	hard sphere diameter
Exp	experiment
f	number of degrees of freedom
G	free enthalpy
g_0	hard sphere radial distribution function
H	enthalpy, Hamiltonian
HC	hydrocarbons
HFC	hydrofluorocarbons
k	Boltzmann constant
LJ	Lennard-Jones
LLL	Liu-Li-Lu
m	number of segments
M	molar mass
N	number of molecules in system
p	pressure, momentum
R_m	universal gas constant
S	entropy
SAFT	statistical associating fluid theory
T	temperature
T^*	reduced temperature
r	intermolecular distance
U	internal energy
v	specific volume
V	volume
Z	partition function
β	coefficient of thermal expansion
δ	inversed reduced volume
ε	Lennard-Jones parameter
ε^{AB}	association energy of interaction between two sites
ε_s	segment interaction parameter
η	packing factor
θ	characteristic temperature
ρ	density
ρ^*	reduced density
τ	inversed reduced temperature
κ^{AB}	volume interaction between two sites.
μ_J	Joule-Thomson coefficient
χ	isothermal compressibility
σ	Lennard-Jones parameter
σ_s	segment diameter
ψ_i	molar fraction of component i

Superscripts and subscripts

0	ground state
assoc	association
c	critical point
chain	chain
conf	configurational
el	influence of electron excitation
ir	internal rotation
nuc	influence of nuclear excitation
pot	potential energy
res	residual
rot	rotation
seg	segment
trans	translation
vib	vibration

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