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Ethics codes and ethics management in the oil and gas industry

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Abstract

Codes of ethics and in a broader meaning ethics management are essential instruments for integrating ethics principles and norms of ethics into everyday corporate practice. Ethics management is an overall concept which does not only mean a mechanical introduction of ethics institutions, but it also provides a reasoned and a complex approach to this issue. In the oil industry several efforts have been made to promote ethics. Its ethics institutional systems can be considered to be well developed. After giving a definition of ethics, business ethics and ethics management concepts, this article conducts a comparative analysis of ethics codes of selected companies, among them several high-profile firms, operating in this industry sector. Codes of ethics are ethics norms, principles and behavioural rules set in a written form which contribute to clarifying what is considered legitimate and highly responsible in conducting an everyday corporate business. The article analyses the contents and forms of appearance of selected ethics codes adopted in the oil industry and points out similarities and differences between their practices. The introduction of ethics institutions targeting the successful implementation of the codes of ethics highlights best practice, which contributes to the successful introduction of the ethics code and to promoting the development of ethics in corporate culture.

Összefoglalás

Etikai kódexek és etika menedzsment az olaj- és gáziparban

Az etikai kódexek és a tágabb értelemben vett etika menedzsment az etikai alapelvek és normák mindennapi vállalati gyakorlatba való integrálásának fontos eszközei. Az etika menedzsment olyan átfogó koncepciót jelent, amely nemcsak az etikai intézmények mechanikus bevezetését jelenti, hanem átgondolt, komplex megközelítést ad. Az olajiparban számos törekvéssel találkozunk ezen a téren, az etikai intézményrendszer fejlettnek tekinthető. A cikk az etika, az üzleti etika és az etika menedzsment fogalmának definiálása után összehasonlítja az iparág kiválasztott, köztük több meghatározó vállalatának etikai kódexét. Az etikai kódexek az etikai normák, alapelvek, magatartási szabályok írásba foglalását jelentik, hozzájárulnak annak tisztázásához, hogy a vállalat üzleti hétköznapjaiban mit tekintenek legitimnek és felelősségteljesnek. A cikk megvizsgálja a kiválasztott olajipari etikai kódexek tartalmát és formai megjelenését, kiemeli a vizsgált vállalatok gyakorlata közötti hasonlóságokat és a különbségeket. Az etikai kódexek sikeres bevezetését célzó etikai intézmények bemutatása rávilágít a legjobb gyakorlatokra, amelyek alkalmazása hozzájárulhat az etikai kódex sikeres bevezetéséhez, elősegítve ezzel az etikus vállalati kultúra fejlesztését.

Conceptual framework

In order to clarify concepts of ethics code and ethics management it would be practical to start with giving a definition of these terms used in a broader environment, with giving a definition of ethics and business ethics. Figure 1 illustrates the logical order of explaining the terms.

ETHICS

Ethics is a philosophical branch of science and its subject is people's behaviour and actions. It is a moral philosophy which studies right or wrong behavioural conduct. Its main topics are as follows: How can we distinguish right from wrong, or a good conduct from bad conduct? What are the conditions for equitable coexistence? When do we act morally? [1]. On the one hand, ethics examines the current habits and behavioural mores (norms, virtues, or values), so it is of descriptive character. On the other hand, not only does it reflect morality, but critically evaluates and formulates opportunities for moral correction as well, so it is a normative science, too [2]. Our behaviour is regulated by such ethical values as respect, honesty, responsibility and fairness and these values appear in ethical principles applied in different areas of life.

BUSINESS ETHICS

In business life grounds for considering ethical standpoints are sometimes questioned. One of the oldest sayings, "pecunia non olet", is attributed to Titus Flavius Vespasianus, the Roman Emperor, who said "Money does not smell" to a person who complained about the tax levied upon public restrooms. There is a close relationship between morality and economy. Economics became an independent science only in the 18th century. Until then it was a part of moral philosophy. On the basis of special regularities of economics it is generally believed that economics cannot contain value statements and normative theses. As a result of changes, two sciences merged: the "pure" economics characterised by economic rationalism, and ethics, characterised by irrational morality [3], which had an impact on business practices.

Fig. 1. Conceptual framework

Since the 1960s, due to the ecological problems coming to light, the social movements going on, the ever increasing number of scandals engulfing business life, numerous reports of bribery and huge sums of sweeteners, the interest in ethical issues in business life has been increasing and expectations for conducting business ethically have been growing. Business ethics, as an independent discipline, was established in the United States of America in the 1970s. This was the time when issues related to the moral status of corporations emerged. Its followers analysed whether companies have moral responsibilities, or whether it is only individuals who have to bear such responsibilities. Within the scope of business ethics topics such as the role of conflicts in economics, corporate offences and discrimination in business were examined [4]. The end of the 1990s brought about the internationalization of the business world and business ethics also became international. It integrated issues such as the ethical problems of globalization and ethical responsibilities of multinational companies. After the first steps, the scope of business ethics has been increasing considerably for the past few decades. It encompasses several topic areas and such fundamental ethical concepts applied in business life as morality and responsibility, a company's legitimacy and corporate governance [5].

The distinctive feature of business ethics lies in its approach to the issue of stakeholders. Under this approach a company must strive to provide optimal results to everybody concerned instead of being concerned with maximizing the profits of a single stakeholder group, namely the stockholders. Practice based on the stakeholder theory can be considered to be a new and more efficient methodology of strategic management. It is important to note that it is not only legal responsibility and social pressure that play a major role in considering the interests of actors concerned, since social legitimacy to operate a company is ensured only if companies take into consideration internal values held by the groups concerned. In this respect the stakeholder approach is not only an efficient instrument of strategic management, but rather a moral responsibility of corporate managers [6]. Although this theory exists, business ethics limits itself to complying with provisions of law. Experts urge the introduction of the „business ethics 2.0' approach, which goes behind this issue and is value oriented [7].

One of the challenges the evolution of business ethics has had to respond to in the past few years is how to apply the philosophical theory of ethics in practice, how to integrate ethical principles

into everyday business life and achieve real and favourable effects. An instrument called ethics institutionalization has emerged to promote this process. Applying this instrument, companies show their intentions to provide a proper framework for ethics development, establish different ethics institutions and, in addition, introduce them and operate them. Introduction of an institution often constitutes a part of an ethics programme. Experience show that implementing a programme is often not enough. Appropriate measures should also be introduced on a regular basis in order to promote corporate culture in a favourable direction. On the other hand, apart from concentrating on cultural, so-called soft elements, appropriate changes in organizational structures and processes should also be initiated, especially in the hiring practices of employees, selection of suppliers or in reward systems.

ETHICS MANAGEMENT

The need for a comprehensive approach is embodied in the concept of ethics management, which mean, not only the mechanical introduction of ethics institutions, but which also provides a well-reasoned and a complex approach. "Ethics management is about imbuing an organization with ethical responsibility as an indispensable element of the corporate existence" [8], this means the systematic and coherent development of actions and the introduction of measures in order to meet fundamental and reasonable expectations of the actors concerned and to bring into equilibrium stakeholders' expectations that are in conflict with each other. Ethics management encompasses establishing ethical diagnoses of the current situation of the corporation, setting future objectives and determining and applying methods and instruments that contribute to the ethical development of a corporation [8].

Institutional ethics systems still play an essential role in ethics management, which is a complex mix of formal politics, structures and activities [9], and consists of the following main elements (Figure 2).

• Code of Ethics

Codes of ethics are norms, principles and behavioural rules of ethics set in a written form that contribute to clarifying what is considered legitimate and highly responsible in an everyday corporate business. The first codes appeared in 1920s [10], and became more and more widespread. In 1990 only 14% of 200 global major corporations had a code of ethics, but in 2007 this figure amounted to 86% [11]. About 35% of 80 studies conducted on the efficiency of the code of ethics consider the code to be positive and effective. A further 16% believe there is a loose relationship between the existence of the code and the ethical behaviour of a corporation. According to 33% the relationship is insignificant, while 14% express mixed results. Only one study found that the code had quite an opposite effect [12].

• Ethics Council, ethics officer and ombudsman

The main functions of the Ethics Council in practice are as follows: to elaborate corporate ethics guidelines, to observe their enforcement and to provide support to help employees comply with the guidelines in particular cases [13]. An ethics officer acts as a coordinator and a monitor and his responsibility, among others, is to resolve any conflicts that arise. There is an international organization, the Ethics and Compliance Officer Association, which has 1,200 members in over 30 countries and has been operating for about 20 years. It provides valuable assistance to its members [14]. Ombudsmen can have the same functions as ethics officers, but the difference is that ombudspersons are independent.

• Ethics training courses and communication

The purpose of ethics training events and communication is to make ethics norms known and promoted, to discuss ethical dilemmas and to provide their solutions. According to researches conducted in this area, ethics training events play an essential role in building the ethics culture of organizations [15]. Over 80% of 200 high-profile companies have launched ethics e-learning courses and two-thirds of the employees in 56% of companies have taken part in oral ethics trainings in the past few years. There are several forms of ethics communication, starting from the information sent via e-mail on the intranet through articles published in the corporate newsletters to communicate corporate events. Choosing the most innovative form is worthwhile [11].

Fig. 2.Ethics institutions

• Hotline
Hotline services can be provided within the company or out of company and offer notification opportunities for the actors concerned. Under the US Federal Sentencing Guidelines internal reporting mechanisms have to allow employees anonymity or confidentiality without fear of retaliation [12]. Eighty-three percent of 200 major companies that have adopted the Code of Ethics operate hotline services and have elaborated reporting regulations [11].

• Ethical monitoring
Ethical monitoring is as crucial as an annual financial control since this allows assessment of how fundamental principles and behavioural rules laid out in the Code of Ethics are applied in everyday practice. The evaluation of ethical performance provides a basis for future planning and management [16]. Eighty-eight percent of 200 major companies that have adopted the Code of Ethics monitor compliance with the code and 66% prepare reports [11].

• Ethical audit
An ethical audit is a process that analyses and measures corporate activities in ethically sensitive areas [17]. External ethical auditing strengthens the efficiency and trustworthiness of efforts made by a company in the field of ethics. An ethical audit can be one of the tools for introducing ethics standards. The criteria set in the Social Accountability 8000 (SA 8000) standard established in 1997 by Social Accountability International is applicable to employers in such issues as bans on child labour; provision of safe and healthy work environments; facilitation of freedom of association and the right to bargaining; prohibition of discrimination based on race, gender, religion or political affiliation; limitations on working hours and regulation of minimum wages. At present there are about 2,150 qualified audit organizations in 60 countries all over the world encompassing 67 industrial sectors employing about 1.2 million workers [18]. There is another standard, the AccountAbility's AA1000, which helps organizations become more accountable, responsible and sustainable. The standards encompassing all values are the outcomes of multi-stakeholder consultation in 2008 [19]. The next standard is the German ValuesManagementSystem, a standard specifically adapted to German and European culture, whose objective is to provide overall safeguard for a firm and its development in all dimensions [20]. Forty percent of the surveyed two hundred major companies prepare external audit reports [11].

Any of the above listed ethics institutions can be introduced or can be a part of an extensive corporate ethical programme. These elements can be supplemented by punishing unethical and rewarding ethical behaviour [21]. According to empirical research, all ethics institutions have a favourable impact on ethical corporate culture [12].

Codes of ethics in the oil and gas industry

The objective of this analysis of ethics codes and ethics management in the oil and gas industry was to identify the specific features of codes adopted in this sector, to compare them and to detect similarities and differences between ethical practices in particular companies. It must be emphasized that there are no bad or good practices, since the quality and the effectiveness of ethics codes and ethics institutions depend on corporate culture and other specific corporate features of a particular company. The samples cannot be considered representative, as their results are only valid for a specific circle and cannot be generalized to the whole of the oil and gas industry.

Ethics documents and ethical conducts of 15 corporations were compared in the study:

- the top 10 oil companies ranked by revenue and listed by Fortune Global 500 on the list of 2010 [22]: Shell, Exxon, BP, Chevron, Total, ConocoPhillips, Eni, Statoil, Valero Energy, Lukoil
- OMV (also listed in Fortune Global 500 of 2010) [22]
- companies rated A+ or A by OEKOM Research in the category of "Corporate Governance and Business Ethics" [23]: Suncor Energy, Norsk Hydro, Woodside Petroleum
- MOL Group.

Table 1 shows main features of the evaluated companies and their codes. The analysis is exclusively based on information available from the corporate websites when the analysis was conducted [24-37], but in case of MOL Group the information was supplemented by the Ethics Council of MOL Group.

GENERAL FEATURES OF THE CODES

As for the prevalence of codes in the circle of companies under analysis, the results are very positive since 100% of the companies have their own code.

The technical literature and corporate practice alike use different names for the code containing corporate ethics and norms. Forty percent of companies involved in the analysis have a "Code of Conduct" (Shell, Eni, Valero Energy, MOL Group). In the documents of 30% companies both "Ethics" and "Conduct" are used (Chevron, ConocoPhillips, Statoil, Lukoil) mostly in the form of „Code of Business Conduct and Ethics". This document is named "Standards of Business Conduct" by 10% of the companies under analysis.

Some companies possess several ethics documents under different names. In the case of Shell and Valero Energy the Code of Ethics is an ethics document applying to particular managers (Executive Directors, Senior Financial Officers), which supplements the generally effective code. The survey conducted by KPMG shows that a growing number of companies create a short ethics document that can be easily communicated and that includes corporate values and/or the mission, in addition to a more detailed code of conduct [11]. Among the companies under analysis Shell and Total used this practice. Shell formulates its general principles in its General Business Principles, whereas Total does this in its Ethics Charter.

Only partial information is available on the time of launching the code or its review. Shell points out that its general business principles were formulated as early as 1976 and last modified in 2005.

Eni points out that it was one of the first European companies to adopt an ethics code in 1994. MOL Group adopted its first ethics code even earlier, in 1992.

Several companies have recently updated codes. The Shell Code of Conduct underwent substantial changes in 2010 since it became half as short as it had been. More emphasis is laid on fundamental principles. Its style avoids legal wording and has become more 'user friendly'. Changes in the codes placed on the websites of Chevron, Statoil, Suncor Energy and Lukoil in 2010 can also be found. Lukoil introduced its Code of Business Conduct and Ethics in August 2010. In 2010 MOL Group also updated its integrated ethics code adopted in 2007. Codes were revised by Woodside Petroleum in 2009, by Eni and Norsk Hydro in 2008 and by OMV in 2007. As for the other companies, there are no references regarding any modifications made in their codes in the last three years.

Although several companies indicate that their codes are accessible in several different languages, the majority of the codes under examination were written in two languages (in the national language of the country and in English) and can be downloaded from corporate websites (Total, Eni, Statoil, Lukoil, OMV, Norsk Hydro, MOL Group). For companies whose native language is English the code is available only in English except for BP, where the code

Company	Shell	Exxon	BP	Chevron	Total	Conoco Phillips	Eni	Statoil	Valero Energy	Lukoil	OMV	Suncor Energy	Norsk Hydro	Woodside Petroleum	MOL Group
Headquaters	NL	US	UK	US	FR	US	IT	NO	US	RU	AT	CA	NO	AU	HU
Global ranking by revenue (2010)	2	3	4	11	14	17	24	74	85	90	333	385	n.a.	n.a.	n.a.
Number of employees (2009)	101, 000	102, 700	80, 300	64, 132	96, 387	30, 000	78, 417	29, 000	20, 920	143,000	34,676	12,978	19,000	3,000	17,963
Name of the ethics documents	-Code of Conduct -General Business Principles -Code of Ethics for Executive Directors and Senior Financial Officers	Standards of Business Conduct	Code of Conduct	Business Conduct and Ethics Code	-Code of Conduct -Ethics Charter	Code of Business Ethics and Conduct	Code of Ethics	Ethics Code of Conduct	-Code of Business Conduct and Ethics -Code of ethics for senior financial officers	Code of Business Conduct and Ethics	-Code of Conduct-Our Values - Corporate Social Responsibility- -Corporate Directive Business Ethics	Standards of Business Conduct	Code of Conduct	Code of Conduct	Code of Ethics
Size of the ethics document	-40 pages -12 pages - 1 page	33 pages	64 pages	32 pages	-30 pages - 1 page	28 pages	28 pages	44 pages	-9 pages -2 pages	60 pages	-36 pages - 7 pages	24 pages	6 pages	14 pages	15 pages
Detailedness	Less detailed	Less detailed	Detailed	Less detailed	Less detailed	Detailed	Detailed	Less detailed	Not detailed	Detailed	Detailed	Detailed	Not detailed	Less detailed	Detailed
A principle- or rule-based	Mixed, rather principle-based	Mixed, rather rule-based	Mixed, rather rule-based	Mixed, rather principle-based	Mixed, rather rule-based	Mixed, rather rule-based	Mixed, rather rule-based	Rule-based	Rule-based	Mixed, rather rule-based	Principle-based	Principle-based	Mixed, rather rule-based	Mixed, rather rule-based	Mixed, rather rule-based
Use of words	"we" in Principles "Y" in Code of conduct	Directors, officers, employees	"Y"	"we"	"we" "Employees"	All employees	„Eni" „Eni's People"	"Statoil" „The individual"	"Y"	„The Company" „Y"	„we"	„we" „Y"	„Y"	„Y"	„A MOL employee"

Table 1. Main features of ethics code of companies under analysis

can be downloaded in 11 languages. Another positive example is Shell, where the code can be read in 17 languages.

As for the size of the codes, there are significant differences. The shortest is 6 pages (Norsk Hydro), the longest is 84 pages (BP), so the average is 32 pages. The higher number of pages does not necessarily mean that it is more detailed, since this depends on the number of topics and on the layout. About 45% of the codes under analysis deal with information in detail (BP, ConocoPhillips, Eni, Lukoil, OMV, Suncor Energy, MOL Group).

The amount of detailes partly depends on whether the code is principle- or rule-based. Practices of major corporations show that a relatively low number of companies (13%) apply purely rule-based codes, 35% of them use principle-based codes and the majority of the codes (52%) are mixed, that is, they contain both principles and rules [11]. This tendency is clearly reflected in the analysed codes of the oil and gas industry, since 70% of them contain both principles and rules. However, in the majority of cases of mixed codes (80%); rule-based codes dominate and only a small part of them (20%) is rather principle-based. Rule-based codes are usually more detailed; however, in our case only half of the analysed rule-based codes contain detailed topics (BP, ConocoPhillips, Eni, Lukoil, MOL Group). The codes of Shell, Chevron, OMV, and Suncor Energy rather belong to principle-based codes; of these, the OMV and Suncor Energy codes are detailed.

Experience show that the words used in the codes also act as indicators of the detailedness of the code, since in the case of principle-based codes 'we' is often used, whereas in the rule-based ones 'you' is preferred [11]. The studied codes confirm this tendency in most cases. When rules are described, apart from the pronoun 'you' such words as 'the individual' or 'employees' are often used. Purely rule-based codes can be characterised by use of passive voice (Statoil). In Eni's code common norms are emphasised by "Eni's People" while MOL Group uses expressions like "a MOL employee".

SPECIFIC FEATURES OF THE CODE CONTENTS AND FORMS

Some companies have mottos at the beginning of their codes, which express the essence of the code. Shell states: "Helping you live by our Core Values and our General Business Principles" [24, p1]. For BP it reads "Our commitment to integrity" [26, p1]. Eni says: "A renewed commitment to excellence" [30, p2] and Suncor Energy's motto is "The Way We Do Business" [35, p1].

The main purpose of establishing ethics codes in the studied oil and gas corporations is to provide guidelines to employees and help them with conduct in everyday life (Shell, Exxon, BP, Chevron, Total, Statoil, Suncor Energy, Woodside Petroleum, Norsk Hydro, MOL Group). Another important purpose is to protect and to improve the company's reputation (Shell, Total, ConocoPhillips, Statoil, Lukoil, OMV, Norsk Hydro, MOL Group). The third aim is to comply with legal requirements (Shell, Exxon, ConocoPhillips, Statoil, Lukoil, Norsk Hydro, Valero Energy) and to meet stakeholder expectations (Shell, Eni, Statoil, Lukoil, OMV, Woodside Petroleum, MOL Group). The purpose of creation of shared company structure takes the fourth place (Chevron, Statoil, Norsk Hydro, OMV, MOL Group), which is followed by becoming a responsible company (Eni, Statoil, OMV, Norsk Hydro, MOL Group) and strengthening the company's competitive position (Exxon, Total, Statoil, Lukoil, MOL Group).

In all companies under analysis the ethical values are integrity, honesty, respect, trust and responsibility, and in many cases there are such values as transparency, openness, co-operation, teamwork and care. The fundamental concern of business ethics is whether striving to maximize profits can be in line with ethical behaviour. In its code Eni highlights that "The belief that one is acting in favor or to the advantage of Eni can never, in any way, justify – not even in part – any behaviours that conflict with the principles and contents of the Code" [30, p15]. Suncor Energy also points out that "We must always conduct our business in a highly principled manner and never sacrifice our ethics for the sake of achieving a business or financial target" [35, p2].

The support of managers is of utmost importance to the success of ethics codes and ethics management. In 70% of the codes under analysis the top manager(s) express(es) their commitment towards the code (Shell, Exxon, BP, Chevron, Total, ConocoPhillips, Eni, Lukoil, Suncor Energy, MOL Group). On Total website there is a piece of information saying that the CEO wrote a letter to the company managers asking them to support the successful introduction of the Code of Conduct [38]. ConocoPhillips' homepage cites their Chairman

and CEO emphasizing the importance of personal responsibility: "Our reputation and integrity depend upon each of us assuming a personal responsibility for our business conduct" [39].

The topics of the surveyed codes show considerable similarities. In the 15 companies involved in the survey, out of 25 topics about 84% were similar. All corporate codes discuss the following topics: asking questions, raising concerns and reporting unethical conduct, bribery and corruption, competition and antitrust, conflicts of interest, correct accounting and financial reporting, dealing with government officials, equal opportunity, avoiding discrimination, gifts and hospitality, political activity, protection of company assets, safeguarding information. Ninety percent of the codes deal with the issues of health, safety, security and the environment, intellectual property and copyright of others, prohibiting retaliation, data privacy and protection. A substantial number of codes contain human rights (73%), digital systems use and security (66%), alcohol and drug usage (60%), forced and child labour (60%) and sustainable development (53%) issues. Fewer codes deal with export and import control (33%) and money laundering (20%). Table 2 shows the list of topics by companies where the red point (•) indicates issues discussed in the code of the company concerned.

Some companies indicate that the content of the code is supplemented by another regulation where a circle of issues is discussed in more detail (Valero Energy, Lukoil, MOL Group). Total and Woodside Petroleum, apart from the code, have a whistleblowing policy, Statoil has an Anti-corruption Compliance Programme, and OMV in its Corporate Directive Business Ethics discusses conflicts of interest, gifts, donations, invitations, hospitality. From Suncor Energy website documents can be downloaded on issues like policy guidance and standards.

Highlighting important ideas in the code texts helps the reader understand the code more easily. In practice one sentence or a whole paragraph is repeated or more emphasized, as occurs, for instance, in the codes of BP, ConocoPhillips, Lukoil, and Suncor Energy. Shell lays emphasis on employees' responsibilities ("Your Responsibility"), principles ("The principles"), uses imperative sentences ("Challenge yourself"), and lays stress on further information available ("Where you can find out more and tell Shell"). In the BP code all topics indicate basic rules to be followed ("Basic rules you must follow"), and what is to be 'always' done and is 'never' allowed to be done. ConocoPhillips, Chevron and Suncor Energy codes also inform readers about norms and provide assistance with their application in practice. MOL Group's information booklet on the code contains questions on different topics and provides answers to them. Quick testing also helps readers understand the code and is also applied in the codes of BP, Chevron, Valero Energy and Suncor Energy. Suncor Energy offers the following checklist for solving ethics dilemmas: "Before taking action in any situation, ask yourself:

- Is anyone's life, health or safety, or the environment endangered by the action?

Topics	Shell	Exxon	BP	Chevron	Total	ConocoPhillips	Eni	Statoil	Valero Energy	Lukoil	OMV	Suncor Energy	Norsk Hydro	Woodside Petroleum	MOL Group
Asking questions, raising concerns and reporting unethical conduct	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•
Bribery and corruption	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•
Competition and antitrust	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•
Conflict of interest	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•
Correct accounting and financial reporting	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•
Dealing with Government Officials	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•
Equal opportunity, avoiding discrimination	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•
Gifts and hospitality	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•
Political activity	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•
Protection of company assets	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•
Safeguarding information	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•
Communication	•	•	•	•	•	•	•	•	■	•	•	•	•	•	•
Harassment	•	•	•	•	•	•	•	•	•	•	■	•	•	•	•
Insider trading	•	■	•	•	•	•	•	•	•	•	•	•	•	•	•
Health, Safety, Security and the Environment	•	•	•	•	•	•	•	■	•	•	•	•	■	•	•
Intellectual property and copyright of others	•	■	•	•	•	•	•	•	•	•	■	•	•	•	•
Prohibiting retaliation	•	•	•	•	■	•	•	•	•	•	■	•	•	•	•
Data privacy and protection	•	■	•	•	■	•	•	•	•	•	■	•	•	•	•
Human rights	•	■	■	•	•	•	•	•	■	•	•	•	■	•	•
Digital systems use and security	•	■	•	•	■	•	■	•	•	•	■	•	■	•	•
Alcohol and drug usage	■	•	•	•	■	■	•	•	•	•	■	■	■	•	•
Forced and child labour	■	■	•	•	■	■	•	■	■	■	•	■	■	•	•
Sustainable development	•	■	■	■	•	■	•	■	■	•	•	■	■	•	•
Export, import control	•	•	•	•	■	•	■	■	■	■	■	■	■	■	■
Money laundering	•	■	•	■	■	•	■	■	■	■	■	■	■	■	■

Table 2. Main topics of the analysed ethics codes (• = the topic is mentioned in the Code)

- Is it legal?
- Does it feel fair and honest?
- Does it compromise trust or integrity?
- Could I justify it to the public?
- What would I tell my close friend to do in a similar situation?" [35, p5].

As for the layout, it has been briefly mentioned above. Apart from the discussed features there are some examples that demonstrate the user-friendly form of the codes. In Shell's code there are symbols indicating which chapter the user is actually reading (Figure 3).

BP's code uses symbols that help users choose the chapter they would like to read. Lukoil summarized the 'dos' in green and 'don'ts' in red rectangles. Suncor Energy, Lukoil and OMV use photos to illustrate their message, thus making the code even more attractive to readers (Figure 4).

Fig. 3. Symbols in the Shell's Code of Conduct

Fig. 4. Front Page of Suncor Energy's Standards of Business Conduct

ETHICS INSTITUTIONS SUPPORTING THE INTRODUCTION OF THE CODE

The first step in the introduction of the code to the employees who acknowledge the receipt of the code by signing for it (e.g. Shell, MOL Group). ConocoPhillips and Woodside Petroleum emphasize that their employees are required to certify their personal compliance with the code. Statoil requires that its business partners adopt an ethical standard consistent

Fig. 5. Ethical illustration in MOL Panorama

with theirs. MOL Group strives to include its ethics code into its contracts with suppliers. Total's webpage informs the readers that since October 2000 nearly 450,000 copies of the code have been distributed, not including versions downloaded from intranet and Web sites. Both Valero Energy and Suncor Energy consider the role of the intranet highly important in promoting communication of the code. Since MOL Group introduced its integrated code of ethics, the corporate newspaper has been publishing articles each discussing a topic from the code in the Hungarian, Slovak and Romanian languages. It also provides illustrations in the form of comics on ethics issues on a regular basis in order to actively involve readers in discussing that problem (see Figure 5).

The information available about the companies under analysis shows that ethics training events are one of the most important institutions promoting the introduction of the code. Shell, Exxon, ConocoPhillips, Woodside Petroleum and MOL Group require their employees to regularly participate in training courses on their ethics policy. Exxon provides training to their employees every four years, ConocoPhillips every other year and MOL Group employee participate in trainings on ethical issues every third year. A photo taken of an ethics training event at Chevron is illustrated in Figure 6.

Exxon provides annual training on anti-corruption law for employees in sensitive positions. In 2009 over 7,000 employees received this focused training. Between 2003 and 2005 Total conducted around 30 seminars on ethics, attended by more than 2,000 line and corporate managers. Since 2006 with the support of Université Total the company has developed the dedicated training programmes "Our Ethical, Environmental and Social Responsibilities" for corporate managers and "Ethics and Business" a one-and-a-half-day training event for senior executives and line and corporate managers. Every year around 2,500 Total managers receive ethics training. Several companies promote e-learning courses (ConocoPhillips, Statoil, OMV, Suncor Energy, MOL Group). Shell highlights that the e-learning option provides assistance to employees, contract partners and suppliers in understanding and meeting the expectations raised by the code.

The hotline ethics institution has been introduced in a number of companies under analysis under various labels (Shell's Global Helpline, Exxon's Hotline, BP's OpenTalk line, Chevron's Hotline, ConocoPhillips' HelpLine, Statoil's ethics helpline, Valero's business abuse hotline "The Network", OMV's ethic help line, Suncor Energy's Integrity Hotline, Woodside Petroleum's Woodside's Helpline, MOL Group's ethical channels). At Shell, BP and ConocoPhillips it is possible to report concerns through their webpages. ConocoPhillips encourages reporting by placing the menu Commonly Asked Questions on their webpage where answers to the frequently asked questions are also provided: Shouldn't I just report violations to my supervisor, Security, or Human Resources and let them deal with it? Why should I report what I know? What's in it for me? Does management really want me to report potential ethics issues? Where do these reports go? Who can access them? Should I identify myself? What if I face retaliation? How is my anonymity maintained? [39].

Fig. 6. Chevron ethics training

Providing Hotline assistance gives rise to legal concerns. Shell points out that "For legal reasons, this facility is not currently available for use from the following countries or by anyone in relation to any person residing in the following countries: Austria, France, Germany, Iran" [40]. ConocoPhillips also expresses legal concerns related to HelpLine: "For individuals in the European Economic Area, the Ethics HelpLine only allows you to ask questions or make reports on issues relating to Accounting and Auditing, Bribery or Other Improper Payments, and Fraud or Falsification of Company Documents or Records. Should you wish to ask questions or report other matters such reports should be made directly to your local management, Human Resources or in-house Legal counsel" [39].

Anonymous reports on ethical issues are considered in all companies except Lukoil, whose code stipulates the following: "the Company will not consider anonymous reports on a violation of the provisions of this Code, but the Company will guarantee confidentiality during the performance of an investigation" [33, p55].

Organizations and individuals, who are in charge of introducing the code of ethics, controlling and promoting the application of the rules play an essential role in institutionalizing ethical

attempts. All companies under analysis have ethics committees, but their names differ: Exxon - Hotline Steering Committee, Total - Ethics Committee, ConocoPhillips - ethics office, corporate compliance and ethics committee, Statoil - Ethics committees, Valero Energy - Conflicts of Interest Committee, Lukoil - Business Ethics Commission, OMV - compliance organization, MOL Group - Ethics Council. Some also have the position of ethics officers under various names: BP - group compliance & ethics officer, ENI - Guarantor, Statoil - Corporate compliance officer, OMV - Corporate Compliance Officer, MOL Group - ethics officer.

All companies emphasize that individuals who breach the code of ethics will face serious disciplinary action. According to Eni's code "Respect of the Code's rules is an essential part of the contractual obligations of all Eni's People pursuant to and in accordance with applicable law. Any violation of the Code's principles and contents may be considered as a violation of primary obligations under labour relations or of the rules of discipline and can entail the consequences provided for by law, including termination of the work contract and compensation for damages arising out of any violation" [3, p55]. Very few companies make ethical cases available to the public on their webpages. In 2009 Shell reported 165 violations of the code of ethics and terminated contracts with 126 employees and contract partners. The ethics committee at Total annually receives and deals with 60 ethical notifications. MOL Group annually conducts 5-7 ethical investigations and publishes the topics of notifications and their results on its webpage.

The ethical evaluation practice at Total is a good example of ethical monitoring. The ethical assessment programme is based on an innovative methodology developed by the U.K. accreditation company GoodCorporation and validated by the Institute of Business Ethics in London. To develop a benchmark for the process, the action principles in the Code of Conduct were divided into six stakeholder categories – shareholders, employees, customers, suppliers and contractors, business partners and host countries – and then broken down into 87 compliance criteria, known as evidence points, whose front-line application is verified externally by an external team. To date, more than 80 units have been assessed. In 2009, more than 60% of ethics processes were operating satisfactorily, 25 to 30% could use improvement and 10 to 15% were in need of strengthening. At MOL Group the ethical evaluation is a constituent part of the annual Assessment Reports made by the Country Chairmen in which ethical expectations are embodied in KPI (Key Performance Indicator). Prior to Statoil starting up activities in new countries, it is a general requirement that an assessment should be carried out to show the extent to which the business, political and social environment in the country is characterized by unethical or corrupt practices. Reference should be made to reputable information sources and indicators, such as Transparency International's Corruption Perception Index, as well as mapping the existence, quality and observance of local laws. There is little information about ethical audits in the selected companies. OMV has already adopted SA 8000 standards. The integration of ethical audit into the strategy and into the company's decision making processes is one of the most important elements of the management system of the company.

This ethical management analysis of the selected companies operating in the petroleum industry has provided valuable information about corporate practices. The writer of the article hopes that the conducted analysis allows ethical codes to become a living document and contributes to their successful implementation on the basis of best practice.

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Geology and petroleum systems of Akri-Bijeel Block, Kurdistan region of Iraq

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Abstract

The studied area in Kurdistan region of Iraq lies across an apparent important topographic/structural boundary between southern lowlands and northern, folded and imbricated mountains. Geological mapping and structural observations both in the mountains (Mesozoic – Paleogene) and in the lowlands (Neogene) led to the following conclusions. The oldest recorded deformation is a layer-parallel shortening, coupled with south-vergent shear that was followed by major folding of ca. 10 km wavelength and ca. 1,000 m amplitude. Even the Upper Miocene – Pliocene Bakhtiari Formation has steep to overturned beds in some parts, and synclines preserve growth strata of Neogene – Pliocene age. En echelon fold relay patterns suggest left-lateral shear along the E-W oriented segment and right lateral shear along the NW-SE oriented segment. The general structural setting of the area is certainly linked to the northeastwards - northwards propagation of the Arabian Margin beneath Eurasia. The ca. 30° curvature of the mountain chain may be explained by the original shape of the Arabian margin, or by pre-existing tectonic zones of E-W orientation in the northern part. The changing shortening directions (first NE-SW shortening, followed by N-S shortening) generated structural combinations of linear and en echelon folds on both the NW-SE and the E-W segments of the arc. Spectacular bitumen seepage in Upper Cretaceous and Paleocene limestones comes from fractures or geodes. Many of the voids filled by bitumen are clearly linked to the above-described Late Neogene – Recent shortening-folding process; therefore petroleum migration into these voids should be very young, synchronous to, or post-dating major folding. This contradicts earlier ideas about massive Late Cretaceous breaching-bleeding off of hydrocarbons. Wells drilled by MOL or Partners discovered significant volumes of petroleum in at least 5 different petroleum systems. The most important of these are the Jurassic and Triassic systems, which contain movable oil and gas-condensate. The younger systems contain only unmovable tar, due to under-mature state of the source rock and/or to biodegradation. The good quality petroleum in Triassic corresponds to the late oil-wet gas maturity state of those rocks at present. The quality of the Jurassic oil does not correspond to the oil window maturity state measured on Jurassic source rocks. Regional studies are needed to solve the origin and migration of this oil. Our observations would rather support a local migration due to Tertiary burial, versus a Late

Cretaceous, long range lateral migration due to tectonic loading of the obducted ophiolites.

Összefoglalás

A kurdisztáni (Észak-Irak) Akri-Bijeel blokk földtani felépítése és szénhidrogén-földtana

Észak-iraki, kurdisztáni kutatás során, terepbejáráson szerkezetföldtani és szénhidrogén-földtani megfigyeléseket végeztünk. A kurdisztáni terep hosszú, keskeny, az előterük fölé 800 m-rel magasodó mezozoos anyagú redőkből-hegyekből és deformált tercier előtérből áll. A merev mezozoos karbonátok néhány szurdokban jól feltártak és számos deformációs bélyeget megőriztek. Még a legfiatalabb, pliocén konglomerátumok is erősen deformáltak.

A legidősebb megfigyelt szerkezet rétegzéssel párhuzamos (általában dél felé irányuló) nyírás volt. E rétegzéssel kis szöget bezáró szerkezeteket a későbbi általános redőződés meghajlította. E fő redőződés hullámhossza kb. 10 km, amplitúdója kb. 1000 m és a mezozoos – pliocén rétegsor minden elemét érinti. Vastagságváltozások és belső diszkordanciák miatt e folyamat bizonyíthatóan a kései miocén – pliocénban érte a területet. A folyamatos déli irányú rövidülést lapos, az előző szerkezeteket átmetsző feltolódások és az igen fiatal domborzat jelzik. A feltolódások helyenként a pliocén rétegeket is átbuktatják.

A fő redőződés mellett kései, eltolódáshoz kapcsolható nyírásokat, redőződéseket is észleltünk. Ezek a K-Ny-i szerkezetek csapása menti balos nyírásról tanúskodnak.

A töréses szerkezetek ÉK-DNy-i, É-D-i és ÉNy-DK-i kompresszióra vezethetők vissza. Ugyanilyen deformációk találhatóak az iráni Zagros előterében is.

A terület általános fejlődésmenetét a Zagros kollízió (paleogén) utáni, délnyugati irány felé haladó feltolódási front szabta meg. Az általunk tanulmányozott terepen is ez és az É-D-i rövidülés volt a meghatározó. A Zagros feltehetően követte az Arab-tábla szegélyének lefutását, azaz sosem volt lineáris. Különböző szakaszokon a kombinált szerkezetek a két eltérő feszültség-főirány miatt jöttek létre.

A lemélyített fúrásokban és a felszíni szelvényekben több (legalább 5) szénhidrogén-rendszert lehetett elkülöníteni. Úgy tűnik, hogy a kréta rendszer még éretlen bitument tartalmaz, de az alatta levő kora-kréta és jura, triász rendszerek már érett olajakat, sőt gáz-kondenzátumot eredményeztek.

Felszíni szénhidrogén-földtani megfigyelések szerint a kréta karbonátokat legalább két olaj-átitatás érte. Az első a kristályokat átitató sárszerű anyag, mely biztosan a fő betemetődés (harmadidőszak) előtt került a kőzetbe. A másik olaj-bitumen következetesen ásványi kéreggel bélelt üregek belsejében, vagy a fiatal tektonikai elemek mentén található. Ezek a megfigyelések arra utalnak, hogy a második olajáramlás a mélybetemetődés alatt-után, a szerkezet-alakulással egy időben vagy utána történt. Annak kiderítésre, hogy a mélyszinti olajfelfedezés a korai, vagy a kései migráció terméke további vizsgálatok szükségesek.

Introduction

In 2007 MOL through its subsidiary, Kalegran Ltd. got exploration rights for Akri-Bijeel Block, located in the Kurdistan Region of N Iraq (Fig. 1 and Fig. 2), in the Zagros Mountains. Primary geologic information was gathered during a 3 week long field trip, completed by acquisition of a 440 km 2D seismic network in the Akri-Bijeel Block. The first phase of exploration was terminated by successful drilling of the Bijell-1 exploration well, proved to be a major onshore discovery of 2010. We also drew conclusions from the surface and subsurface observations to arrive at a hydrocarbon system model.

Fig. 1. Structural subdivision of Zagros on Google Earth map (after [1-2]) and position of the study area

Fig. 2. Position of the Akri-Bijeel Block in Kurdistan Region of Iraq

Akri-Bijeel Block has a total area of 889 km^2. From a topographic point of view, the Block is bipartite: in the northern part, there is a mountain range with roughly E-W orientation, and with heights reaching 1,500 m, while the southern half is a gentle hilly, plateau-like area, with an average height of 500 m (Fig. 3). Similar to topography, the vegetation and landscape also differs in northern and southern parts of the Block. The northern mountains are characterised by nice Mediterranean forest, or bush, with barren rock surfaces. The southern lowland is almost totally barren of trees and is covered by grass. While the northern mountain area abounds in water (especially in gorges, but also in form of karstic wells), the southern lowlands have mostly dry wadis with very limited water flow. The Zab River makes a natural boundary in the eastern part of the Block.

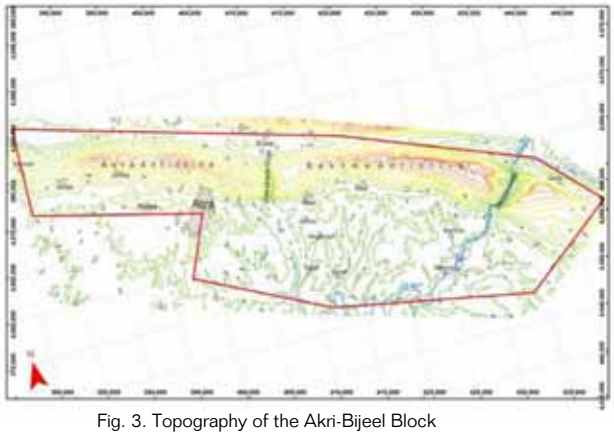

Fig. 3. Topography of the Akri-Bijeel Block

General geology of Zagros

The Zagros forms a major mountain system in the Middle East, ranging from Southern Turkey through the Kurdistan region of Iraq to Iran. It has direct links to the Oman Mountains of the Arabian Peninsula and hosts one of the richest petroleum provinces of the world.

The mountain chain consists of a southern foreland (Simply Folded Zone), two parallel ophiolite belts (green and blue on Fig. 1), the Sanandaj-Sirjan zone in between these belts and the Urumqieh-Dokhtar magmatic belt in the north (cross-hatched), on top of various Internal Iranian blocks, forming the northern edge of Zagros.

The southern foreland is the NE edge to the Arabian Platform, with stratigraphy and structures very similar to Iran and Arabia. This is the hub of the major petroleum deposits. The southern, Late Cretaceous ophiolite belt was obducted in the Late Cretaceous and is the direct equivalent of the Oman ophiolite. The Sanandaj-Sirjan zone is a complex of nappes, often composed of metamorphic Mesozoic sediments and volcano sediments, and stands for an internal continent/volcanic arc between the two ophiolite belts/oceanic tracts [3,1]. The northern ophiolite belt was obducted in Paleocene. Collision probably occurred only in Eocene, testified by ample volcanics of a magmatic arc (Urumqieh-Dokhtar), on the margin of the northern continental margins of the northern oceanic tract.

General stratigraphy

The stratigraphy of the area ([4,5] Fig. 4) is characteristic for the whole Iraqi Simply Folded Zagros. The bulk of the succession was deposited on the southern shelf of Tethys Ocean, from the Permian to Eocene.

The whole sedimentary succession is possibly more than 10 km thick and quite probably begins with a ductile Late Precambrian series. This is topped by several thousand metre thick Paleozoic – Lower Mesozoic succession, of which the shallow water carbonates of Chia Zairi (Permian) and Kurra Chine (Triassic) form thicker, more rigid units with locally anhydrites.

Jurassic begins by a several hundred metres thick neritic carbonate. In the Middle Jurassic this dolomitic platform passes laterally to evaporites (Alan, Adaiyah Formations). In the higher Middle Jurassic, Upper Jurassic, there is a widespread, yet thin basin facies, divided into Sargelu and Naokelekan Formations, which are black shales and limestones. In the Late Jurassic this basin passes either to neritic dolomites (Barsarin Fm) or to evaporites (Gotnia Fm).

In the Early Cretaceous yet another basinal black shale, marl, the Chia Gara Formation was deposited. It passes upwards into the Sarmord/Balambo marl and into the Qamchuqa neritic carbonate. After a not really marked unconformity in the mid-Cretaceous, an Upper Cretaceous platform carbonate, the Aqra-Bekhme carbonate was deposited. This platform passes laterally into basinal sediments (Shiranish and Tanjero marls). The upper part of the deep-marine marl may be also Paleocene in age (Kholosh Formation; [6]). The Cretaceous neritic carbonates (Qamchuqa, Bekhme and Aqra) form a stiff, ca. 600 m thick resistant structural level of the area. Most fold cores are formed of the Qamchuqa-Bekhme Formations in the region.

In the Paleogene a carbonate bar (Khurmala/Sinjar Formation) is followed by a characteristic brick-red Eocene clay forming a detachment horizon (Gercus Formation) and by a thin and chalky-dolomitic Eocene carbonate (Pila Spi Formation).

Neogene is represented by the sometimes evaporitic, variegated Lower Fars Formation (Middle Miocene), the mostly sandy, fluviatile Upper Fars (Middle-Upper Miocene) and the conglomeratic Bakhtiari Formation (Upper Miocene-Pliocene). All these formations are rarely and poorly dated [5] and have a cumulative thickness above 1,500 m.

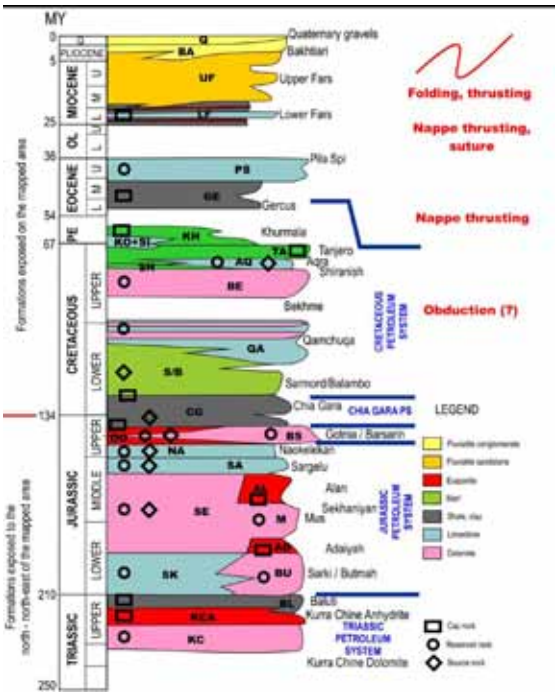

Fig. 4. Stratigraphy of the study area (pre-Triassic formations are omitted). Blue lines separate different petroleum systems. Main tectonic events are marked in red

Summary of structural observations

Geological mapping and structural observations led to the following conclusions:

1, The oldest deformation is due to the Late Cretaceous obduction of ophiolite nappes onto the Arabian margin. It has only created a characteristic, forebulge-linked sedimentary pattern in the region. In our area the shallow water Upper Cretaceous limestones were deposited on the forebulge. This deformation was preserved only in stratigraphy and did not leave observable structures.

2, The oldest observed deformation is a layer-parallel shortening (Fig. 5), coupled with south-vergent shear that was followed by a

3, major folding event of ca. 10 km wavelength and ca. 1,000 m amplitude (Fig. 6). Even the Upper Miocene – Pliocene Bakhtiari Formation has steep to overturned beds in some parts, and synclines preserve growth strata of Neogene – Pliocene age (Fig. 7). On the southern limb of the major folds thrusting of variable offset can be observed. En echelon fold relay patterns suggest left-lateral shear along the E-W oriented parts (Fig. 8) and right lateral shear along the NW-SE oriented parts.

Fig. 5. Layer-parallel thrusts in Eocene carbonate on the southern limb of Bekhme and northern limb of Aqra anticlines. The beds are tilted to sub-vertical or to steep now, due to later major folding

Fig. 6. Major folding in the Aqra anticline

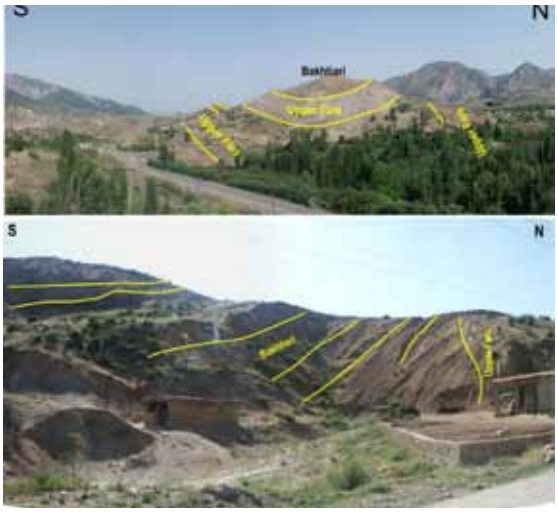

Fig. 7. Successive unconformities in Upper Fars and Bakhtiari Formations in the Dinarta syncline. General view and close-up of gradually changing dips

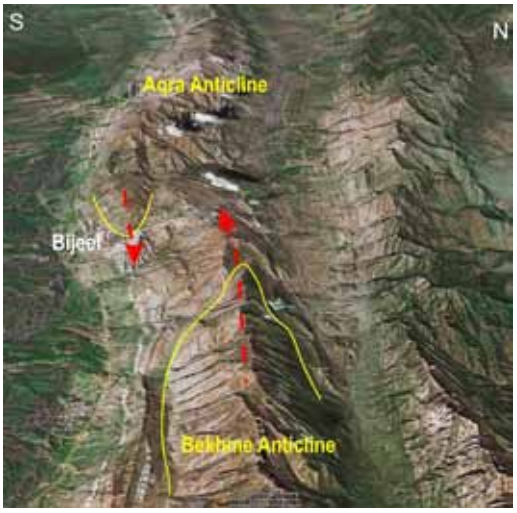

Fig. 8. En echelon pattern of Aqra and Bekhme folds in the Akri-Bijeel region, Google Earth satellite oblique view. Note the left lateral relay pattern

The general structural setting of the area is certainly linked to the north-eastwards-northwards propagation of the Arabian Margin beneath Eurasia. The ca. 30° curvature of the mountain chain (Figs 1,2) may be explained by the original shape of the Arabian margin, or by pre-existing tectonic zones of E-W orientation in the northern part.

In the study area we observed traces of a first NE-SW shortening and a second N-S shortening. These results corroborate with similar results in Iran [7,8]. From GPS measurements we know that the present shortening between Arabia and Eurasia is N-S oriented [9].

The apparently changing shortening directions from NE-SW to N-S generated several structural combinations on both the NW-SE and the E-W segments of the arc, many of which are still preserved (Fig. 9). During NE-SW compression (Fig. 9a), one may find only linear folds on the NW-SE oriented segment, while en echelon folds would be found on the E-W segment. During N-S compression (Fig. 9b), linear folds would be expected on the E-W segment, while right lateral en echelon folds would be found on the NW-SE segment. We believe that we observe superposition of both combinations on both segments.

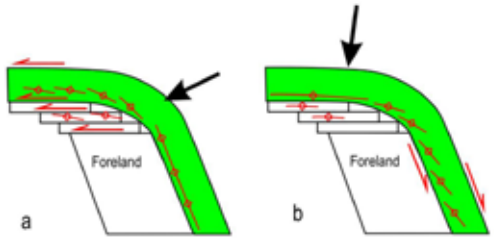

Fig. 9. Explanation of complex shortening and shear related structures on the different segments of Zagros. Note that main shortening direction probably changed from NE-SW to N-S in Pliocene

Petroleum geology

Petroleum fields discovered in Iraq so far are almost exclusively found in the plateau-lowland area, where the targeted structures have generally a good, thick Fars cover. The basal part of this succession (Lower Fars) has very good sealing capacity. Since folding deformation affected even Plio-Quaternary beds, the resulting folds are well seen and measurable in these younger sediments. All these features were already recognized by the first exploration geologists; therefore a common method of exploration was to drill the apex of the anticlines. Kirkuk is a prominent, very long anticline, which was among the first to be drilled [10]. The huge reserves discovered in carbonate reservoirs gave a positive feedback to the aforementioned exploration strategy, and in the following years a great number of topographically well-expressed anticlines were drilled. Although most of these structures contained very big quantities of hydrocarbons, there are some unexplained exceptions (Quwair), or many variations regarding reservoir rocks and their effectiveness. In some fields oil of variable quality, or gas and condensate was discovered in the same reservoirs.

During field work we documented spectacular bitumen seepage in Upper Cretaceous and Paleocene limestones. The bitumen is found 1, in shear related fractures (Fig. 10); 2, fold-related systematic fractures (Fig. 11) or 3, geodes of these formations (Fig. 12). These seeps are found in the heart or on the limbs of exposed anticlines. The shear-related fractures, fold-related fractures and some voids are clearly linked to the described Late Neogene – Recent shortening-folding tectonic process, therefore hydrocarbon migration into these voids should be also very young. This contradicts earlier ideas about massive Late Cretaceous breaching-bleeding-off of hydrocarbons.

Fig. 10. Bitumen in lozenge shaped shear related slip surface. Note that the bitumen infill formed after the movement

Fig. 11. Systematic joints in Shiranish Marl linked to the formation of major folds. Note bitumen injected in the sub-millimetric separations along joints

Fig. 12. Geodes with mineral coating. Note the innermost position of bitumen, suggesting a late infill (post-mineral coating)

Microscopic investigations of Cretaceous carbonates [11,12 (exclusive studies for MOL)] showed that beside the above-mentioned late migration event, an early, pre-diagenetic migration also occurred, that created a mud-like substance in the carbonate crystals. The time of this early migration is not known, but it most probably precedes the major Tertiary burial.

Bijell-1, the first well in MOL-operated area was spud on an anticline hidden beneath thick Tertiary sediments. A similar well (Shaikan-1) operated by our partner, Gulf Keystone International was spud on an exposed Mesozoic anticline. The two wells discovered significant amount of oil, and smaller gas volume.

Based on our surface and subsurface observations five petroleum systems were recognized (see Fig. 4):

Cretaceous system with
- Multiple potential Cretaceous carbonate source rocks,
- Aqra, Bekhme and Qamchuqa fractured carbonates (mostly dolomite) as reservoir,
- Tanjero and Kolosh marl as seal,
- containing 6-10° API unmovable tar;

Chia Gara system with
- Chia Gara shale as source rock,
- Chia Gara carbonate interbeds as reservoir layers,
- Chia Gara shale and overlying Sarmord shale as effective seal;

Gotnia system with
- potential independent source rock layers within Gotnia Fm, or alternatively, Sargelu Fm,
- Carbonate stringers in Gotnia Fm as reservoirs. This system is similar to the Ara Formation hydrocarbon system in Oman,
- Thick anhydrite interlayers of Gotnia Fm are efficient seal,
- Possibly 18° API oil with minor gas is contained in the reservoir beds;

Main Jurassic system with
- Sargelu and Naokelekan black shale and marl as source rocks,
- Naokelekan, Sargelu, Sekhaniyan and Sarki fractured carbonates as reservoir,
- Gotnia anhydrite as seal,
- containing 12-13° API oil in upper, and 6-10° API unmovable tar in lower part;

Triassic system with
- Kurra Chine dolomite as possible source rock,
- Kurra Chine fractured dolomite reservoir,
- Kurra Chine anhydrite and Baluti Shale as seal,
- this system contains good quality oil, gas and condensate.

MOL geochemists performed maturity studies on both the surface and well samples. It turned out that Cretaceous sources are marginally mature. The oil stored in Cretaceous is derived from a Cretaceous source. It is biodegraded in the exposed sections and non-biodegraded in the deep sections; however, even at depth the tar is unmovable.

In consent with other regional studies [13] the Jurassic source rocks are rich and are/were in the oil window. The carbonate source may explain the high sulphur content and relatively high viscosity, but the derived oils should be much better quality than found. It was supposed that a fractionation or gravitational separation occurred. Anyway, more volatile fractions seem to be absent from these oils.

The Triassic system should be late oil to wet gas matured, and the petroleum found there corresponds to the suggested maturity of the source.

Surface seeps and discoveries prove that the mentioned petroleum systems work, charge occurred. There are two possible charge models related to the tectonic evolution of the area (Fig. 13).

1, The first model suggests that the first important burial-maturity event happened in Late Cretaceous, due to the tectonic load of the ophiolite nappes. Jurassic-Cretaceous source rocks depressed by those nappes could be mature at that time. Since that area lies relatively far from the investigated Block, a long lateral migration should be proposed. The generated petroleum should have migrated towards the forebulge, i.e. our study area. This region was still uncovered (shallow water carbonates were being deposited), and the generated petroleum should have massively seeped away (Fig. 13a). We have found massive seeps, but all related to Late Tertiary structural features. However, the generated petroleum could have been preserved in Jurassic and Triassic reservoirs. The early, mud-like migration substance might be the result of this primary, long distance migration.

2, The second model suggests that all local source rocks were matured during the massive Tertiary sedimentary burial, and the generated petroleum should have migrated into the freshly formed structural traps (Fig. 13b). The migration is thus young, synchronous to (or post-dating) folding - thrusting and occurs as a local, possibly short distance process. We do have local, deep kitchens within the block. Since most of our field evidence points to Tertiary migration, we rather think that this model would fit better to our observations. Most maturity data and resultant oil qualities in agreement with their present positions also suggest that they have been generated by the Tertiary burial. However, the high viscosity Jurassic oil needs another explanation. Its relation with the other products is also questionable. It seems that all depends on the sealing ability of the different petroleum systems, which may leak due to lateral facies changes or due to high intensity fracturation during Tertiary structural evolution. Therefore a more regional geochemical correlation work is needed to arrive at conclusive answers in the maturity-migration model.

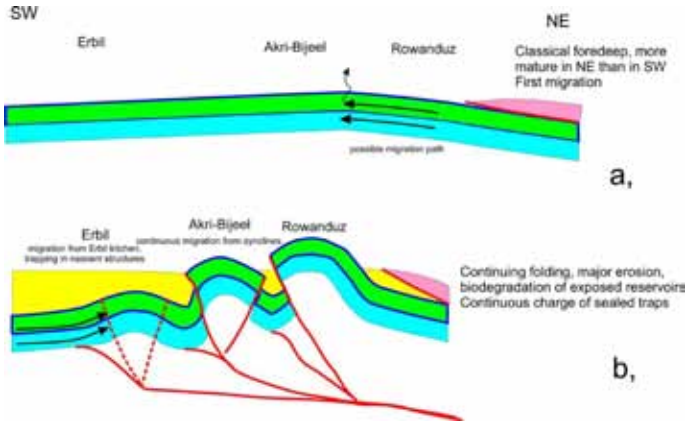

Fig. 13. Migration models of the area. Schematic structural section drawn at Late Cretaceous (a) and Pliocene (b) times. Note the changing direction of charge

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Co-operation of MOL - INA E&P – Registration of petroleum substances under REACH

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Abstract

The so-called REACH compliance is one of the most co-operative project task of MOL Group, in which all legal entities take parts. As its name refers, REACH deals with Registration, Evaluation, Authorization and restriction of Chemical substances; it is the European Community Regulation on chemicals and their safe use. Our article gives brief review about the regulation, which holds and probably will hold significant challenges for MOL Group, similarly to other oil industrial companies. All legal entities (LE's) of MOL Group have submitted their registration dossiers before 30 November 2010 for substances needed to be registered by this deadline. Co-operation of MOL E&P and INA E&P can be an example of how extensive and fruitful co-operation could be among colleagues from different divisions of MOL Group.

Összefoglalás

A MOL - INA Kutatás-Termelés együttműködése – szénhidrogén anyagok regisztrálása a REACH rendelet szerint

Az ún. REACH-megfeleltetés a MOL Csoport egyik leginkább együttműködést igénylő projekt-feladata, melyben minden tag és leányvállalat külön jogi személyként vesz részt. Mint ahogy az angol elnevezés is mutatja, a REACH a vegyi anyagok regisztrálásával, értékelésével, tiltásával, engedélyezésével és felhasználási körük engedélyezésével foglalkozik. A REACH az Európai Közösség rendelete a vegyi anyagokról és biztonságos használatukról. Munkánk rövid áttekintést ad e szabályozásról. A MOL Csoport számára, a többi olajipari vállalathoz hasonlóan, szintén jelentős kihívásokat jelentett és várhatóan jelent a továbbiakban is a REACH megfeleltetés. Azon anyagok regisztrációs dossziéit, melyek határideje 2010. november 30-a volt, a MOL Csoport minden jogi személye határidőre benyújtotta. A MOL KTD és INA KT együttműködése példa arra, hogy a MOL Csoport különböző divízióiban tevékenykedő kollégák között milyen széleskörű és gyümölcsöző együttműködések jöhetnek létre.

Introduction

The European Parliament and the Council of the European Union, as a result of continuous preliminary and conciliatory processes of several years, entered into force the so-called REACH regulation on 1 June 2007. The Regulation (EC) No 1907/2006 concerning the Registration, Evaluation, Authorisation and restriction of

Chemicals (REACH), establishing a European Chemicals Agency, (amending Directive 1999/45/EC and repealing Council Regulation (EEC) No 793/93 and Commission Regulation (EC) No 1488/94 as well as Council Directive 76/769/EEC and Commission Directives 91/155/EEC, 93/67/EEC, 93/105/EC and 2000/21/EC), unified the regulatory system of use of chemicals which was regulated earlier by different laws in the member countries. The regulation is in force already and legally binding in all member countries of the EU, it concerns every chemicals manufactured within the EU or imported into the EU in quantities above 1 tonne per year [1].

The REACH regulation gave hard tasks on industrial level, since the regulation radically transformed the responsibilities of industry and of the authorities for the control of chemicals. In particular, the responsibility for undertaking the health and environmental hazard and risk assessment on substances will shift from the authorities to industry [2].

REACH regulation holds and probably will hold significant challenges for MOL Group, similarly to other oil industrial companies.

As a first step of REACH compliance, as individual legal entities, MOL and its subsidiaries needed to identify substances, preparations and articles which are obliged to be registered or notificated. Determination of these materials is not simple already, considering for example the wide scale of product flow of oil refineries and composition of products, goods that depends on the composition of base materials. Most of substances identified by MOL and its subsidiaries fall into the quantity category of 1,000 tonnes or more per year, according to the REACH classification. The regulation determined the most closer deadline for these substances to submit registration documents (by 30 November 2010). The registration deadline for substances manufactured or imported in quantities of 100-1,000 tonnes per year is 1 June 2013, while for quantity range of 1-100 tonnes per year is 1 June 2018. The first registration deadline (30 November 2010) also applied on phase-in substances classified as carcinogenic, mutagenic or toxic for reproduction, category 1 or 2, in accordance with Directive 67/548/EEC and manufactured or imported in quantities reaching one tonne or more per year and on phase-in substances classified as very toxic for aquatic organisms which may cause long-term adverse effects in the aquatic environment (R 50/53) in accordance with Directive 67/548/EEC, and manufactured or imported in quantities reaching 100 tonnes or more per year.

Of course individual identification of every product, different type of intermedier, article, monomer, polymer, catalyst, products of research and development activities etc. was obligatory for MOL and its subsidiaries. The identification was done according to the REACH nomenclature. In many cases it was simple. For example a n-pentane/iso-pentane mixture can be characterized with clearly determinable composition; this is a so-called multiconstituent substance. However, quantitative and qualitative identification of natural gasoline separated at E&P site is not so easy. As we analyse a substance, which is composed of some thousand components, individual identification of each compound is impossible. These are classified as UVCB (substances of unknown or variable composition, complex reaction products or biological materials) by REACH. The presented substances just illustrate the diversity of substance types, since classification of a catalyst or refinery intermedier requires solving of other kind of problems.

One of the most important question come up even at identification of materials: forming the communication among MOL and its subsidiaries pursuing the same activities. This task was taken on by REACH Central project management team of SD&HSE Central Team and Project Management organization. After this, analyses of substances of different MOL Group legal entities and sharing information have been started. During project implementation one of the most important elements is the daily communication among legal entities, which is significantly facilitated the common work and problem solving. MOL Group level REACH team is composed by internal teams [e.g. Central Internal Team, SDS&CLP (safety data sheet and classification, labelling and packaging) Core Team, Analytical Core Team, Customer Communication Core Team, Supplier Communication Core Team, Dossier Preparation Team, IT Core Team, IUCLID Core Team (IUCLID-International Uniform Chemical Information Database is a key software application that assists in submission of registration documents and data to the Agency under REACH legislation) and external consultants]. All divisions have a legal entity coordinator (LEC); LECs compose the central internal team together with business unit coordinators and members of project management.

After identification of substances, main task was to do the so-called preregistration, that means practically granting to ECHA the materials

shall be registered. (ECHA is the European Chemical Agency, which has coordination and implementation roles in REACH.) MOL Group has successfully preregistered 221 substances and intermediates in 2008, then have started to prepare for registration. This task required significant persistence and vocation from each colleague involved in REACH relevant work, since it was often necessary to find information which was not available in information databases of the companies.

During preparation of the registration documents main task was to collect the necessary information (e.g. see below). Complete collection was possible in many cases only with significant pastime and after laboratorial background work.

- Identification of substances based on their compositions
- Information regarding to manufacturer and distributor of substances
- Information concerning classification and labelling of substances and mixtures (CLP)
- Guide for safe storage and usage of substances
- Exposure properties
- Physical-chemical properties
- Toxicological properties
- Ecotoxicological properties of substances.

REACH gives possibility for joint registration of the same type substances by different legal entities; consequently communication among oil industrial companies would be required. Consortia are an efficient form of their co-operation. They are international organizations which connect with the given industry in some manner. These have a thorough knowledge of the given industry, their products, and characteristics of products, hereby consortia form a connection with generally concurrent industrial companies and their activities.

For example CONCAWE, which was established in 1963 by a small group of leading oil companies carries out research on environmental issues relevant to the oil industry. Its membership has broadened to include most oil companies operating in Europe. CONCAWE currently has 39 members, together representing practically 100% of the total crude oil refining capacity within the European Union. CONCAWE member companies decided to make best use of CONCAWE's comprehensive risk assessment programme for petroleum substances in the preparation of the joint parts of REACH registration dossiers. They therefore also agreed to fully collaborate in the registration process and to exploit the possibility of joint submission of joint parts of the registration dossier to the maximum possible level under the REACH regulation. CONCAWE has volunteered as the SIEF (Substance Information Exchange Forum) formation facilitator for all petroleum substances that require registration and for sulphur. CONCAWE member companies have agreed to invite non-members to participate in the joint submission of the common parts of the registration dossier. CONCAWE has therefore offered the joint parts of the registration dossiers, including the chemical safety reports, under a suitable contractual framework, i.e. in the form of licence agreements, available for a certain fee. Furthermore, CONCAWE was providing IUCLID5 CLP notification files, consisting of Sections 1.1 (Substance identifiers) and 2.1 (CLP/GHS classification) that can be used for the notification of petroleum substances under the CLP regulation [2].

CONCAWE has completed the common parts of the registration dossiers to cover almost 600 individual petroleum substances. A full inventory of these substances can be found on REACH Implementation page of CONCAWE website. An extensive database of the properties, hazards, classification/labelling and safe use of petroleum products has been assembled with the significant help of CONCAWE's member companies and other organizations, such as the American Petroleum Institute (API). Using the common parts of the registration dossier the lead registrant then registered with ECHA [3].

MOL legal entities are also members of some more specific consortia (exactly nine Consortia), for example MOL E&P is a member of HCSC (Hydrocarbon Solvents) consortium, and MOL and INA are members of CONCAWE as well.

As MOL and INA E&P activities are the same, the identified material flows can also be classified in the same way. Similar problems arose during identification and classification of substances, as well in the course of preparation of registration documentation. Consequently efficient co-operation of the two organizations proved to be a key to effective problem solving. Solving the REACH relevant tasks rendered more difficult when during data collection period the CLP regulation [Regulation (EC) No 1272/2008 of the European Parliament and of the Council of 16 December 2008 on classification, labelling and packaging of substances and mixtures, amending and repealing Directives 67/548/EEC and 1999/45/EC, and amending Regulation (EC) No 1907/2006] has been put into force [4]. The CLP regulation refers to substances identified

by REACH, and determines the classification, labelling and packaging requirements of substances and mixtures to be used by the members of the European Union.

According to the provisions of the CLP regulation review of each identified substance was needed for MOL and its subsidiaries. It was therefore necessary to determine which of the substances come under the regulation. Several legal entities come up against the challenge, that some of their substances which shall not be registered under REACH (because these occur in nature, if they are not chemically modified) [7], shall be reclassified and relabelled. These kinds of substances in E&P are for example crude oils, natural gases, liquefied petroleum gases and natural gas condensates. Since for upstream divisions the new CLP regulation means much more tasks.

In the next chapters we try to present briefly charges of MOL and INA E&P Divisions, working practices, problems arose during completion of REACH- and CLP-related tasks. We emphasize those main linkage points that facilitated efficient co-operation of the two organizations.

REACH & CLP relevant tasks till 2011

REACH REGULATION

As we mentioned earlier, MOL Group has preregistered 221 substances and intermediates in 2008, which shall be registered in due time (in 2010, 2013 and 2018). Figure 1 summarizes the number of substances (total of 165) registered in 2010 by legal entities. INA's substances (to be imported to the EU) were registered by MOL Plc within the frame of Only Representative Agreement. Hereinafter it will be mentioned just INA registered substances.

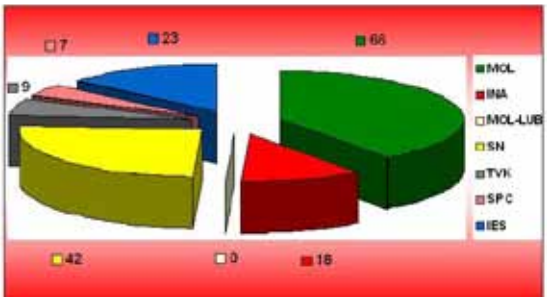

Fig. 1. Number of registered substances of MOL Group in 2010

REACH compliance is the task of the given legal entities (e.g. MOL E&P, INA E&P). All fees and costs (e.g. management, analyses, registration, consortium membership) are covered in separate project budgets of the concerned business units. Consequently the LECs work individually within their teams, which are coordinated by the SD&HSE Central Team and Project Management. INA has REACH budget on SD&HSE Sector, for all concerned business units.

MOL US registered 4 substances. Just two of them were easily identifiable substance, namely iso-pentane (EC 201-142-8) and n-pentane (EC 203-692-4). The others were UVCBs: low boiling point naphtha (EC 232-443-2), solvent naphtha (petroleum) light aliph. (EC 265-192-2).

However, it was really hard to give compositional data for UVCBs. A number of analytical techniques are available at different laboratories in MOL Group for determining specific properties of these substances. The most common are chromatography (e.g. LC, GC) and spectroscopy (e.g. IR). One problem can be assigned to analytical techniques, if the samples are analysed with different equipments, by different methods, standards, etc. We used chromatography as main method to isolate major groups of organic compounds from petroleum substances and quantify the presence of common and hazardous compounds. In case of UVCBs it is often impossible to give accurate quantities for some compounds; sometimes it was also difficult to give ranges.
According to CONCAWE, UVCB substances cannot be uniquely specified by the IUPAC names of the constituents, since these may not all be known. Instead, the composition should be provided in a more generic way:

- Known constituents present at 10% or greater should be identified by IUPAC name and – where available – by CAS registry number;
- Typical concentrations and concentration ranges for the known constituents;
- Constituents relevant for hazard classification, e.g. marker substances for the classification as CMR (carcinogenic, mutagenic and toxic for reproduction);
- Constituents relevant for PBT (persistent, bioaccumulative and toxic) assessment;
- Unknown constituents identified by a generic description of their chemical nature;
- Stabilizing additive(s) completely specified;
- Other information e.g. chromatographic or spectral images that show a characteristic peak distribution pattern [5].

INA E&P registered only three substances,

and all of them were easy to identify: propane, liquefied C_3H_8 (EC 200-827-9), butane, pure C_4H_{10} (EC 203-448-7) and isobutene (EC 200-857-2). These three substances are so called "mono-constituents", meaning that they have one main constituent with concentration of min 80% w/w, and the rest are impurities. Purity of INA E&P substances is in range of 97-100% w/w. According to downstream LEs, upstream divisions needed to register (Figure 2) much less substances.

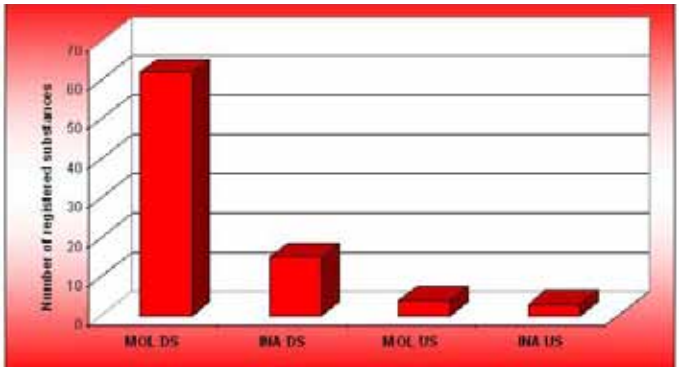

Fig. 2. Number of registered substances of downstream and upstream divisions of INA and MOL in 2010

INA will register rest of the substances (ethane, n-pentane, iso-pentane, etc.) when Croatia becomes an EU member state. Crude oil, natural gas and natural gas condensate are exempted from registration [6]. Due to the fact that crude oil, natural gas and natural gas condensate are not exported to the EU INA E&P did not notify any substance. Immediately Croatia becomes a member state of the EU, it will fall under community regulation, consequently INA shall meet its registration and notification obligations. INA will be able to fulfill easily this obligation, since it has been an active participant in solving of REACH relevant tasks of MOL Group since the beginnings.

CLP REGULATION

By 3 January 2011 deadline, ECHA received 3 114 835 notifications of 24 529 substances for the classification and labelling inventory. By this deadline, industry had to notify the classification and labelling of all chemical substances that are hazardous or subject to registration under the REACH regulation and are placed on the EU market. The largest number of the notifications, over 800 000, came from Germany. Over 500 000 notifications were submitted from the United Kingdom and nearly 300 000 from France. All together over 6 600 companies notified at least one substance [7].

All hazardous substances regardless of the tonnage band and substances which are exempted of REACH regarding Annex IV and Annex V, have to be notified regarding CLP. The following substances had to be notified: crude oil, natural gas, coke, natural gas condensate, some LPGs. These substances will be notified by INA E&P when Croatia becomes an EU member state, as they are currently not exported to the EU.

MOL US has classified further 4 substances, crude oil (232-298-5), natural gas (232-343-9), natural gas condensate (272-896-3) and LPG (270-681-9). Some problems occurred during data collection. In case of production quantities collection of only natural gas condensate was little problematic, due to the different Hungarian condensate nomenclature.

For example crude oils have more thousands components. How can we determine them realistically? There is no way to make average for crude oil composition, because of the natural variability of crude oils from different sources, the detailed chemical compositions vary (both from field to field, day to day and between manufacturing sites, and can also be altered due to numerous physical, chemical and biological processes, biodegradation, maturation, etc.). As a consequence, we needed constructive co-operation from laboratory experts, in order to make real data from the large amounts of analytical results. When the concerned organizations could not give proper analytical data, we needed new measurements.

IMPACT OF REACH AND CLP ON SDSS

Colleagues working on implementation of REACH cannot relax after submission of registration and notification documents, as the regulation obliges all manufacturers and importers to compile and

Fig. 3. Examples of new hazard pictograms according CLP Regulation

supply safety data sheets (SDSs) in due time. In the following part we give a brief summary about impact of REACH and CLP on SDSs.
SDSs are governed by REACH Regulation 1907/2006 (Annex II). Due to the CLP regulation former symbols become hazard pictograms (Figure 3).
After registration and notification some new and additional information has to be added as a mandatory content of the SDSs.

a) SDSs main changes regarding REACH (Annex II)
- Headings 2 and 3 swap around
- An e-mail contact address should be included in section 1, for competent person(s) able to respond with appropriate advice.
- A SDS should be supplied in an official language of the Member State(s) where the substance or mixture is placed on the market (unless the relevant Competent Authority in the Member State(s) concerned has indicated otherwise).

In addition, SDS for substances or mixtures containing substances that have been fully registered under REACH will require:
- Inclusion of registration numbers (where appropriate)
- Inclusion of Exposure Scenarios (ES) including any risk management measures, where required, in an Annex to the SDS. (Exposure Scenario is a set of conditions that describe how a substance is manufactured or used during its life-cycle and how the manufacturer or importer controls or recommends downstream users to control exposures of humans and the environment [1].)

b) SDSs changes regarding CLP
1. Normal SDS without CLP elements
2. Normal SDS with CLP elements according to Annex II
3. Extended SDS (eSDS) with CLP elements according to Annex II

One of the most important aims of REACH regulation, besides unifying the regulatory system of use of chemicals, is that the information in the supply chain, the monitoring of this regulation and its modifications, and use of chemicals under controlled circumstances become part of everyday practice of companies. It can be realized only by establishing and operating an adequate and efficient controlling system.

As mentioned above, all LEs have submitted their registration dossiers before 30 November 2010 for substances needed to be registered by this deadline. Currently ECHA is starting the evaluation of certain number of dossiers (selected randomly). It must be emphasized that approximately 20% of all dossiers submitted to ECHA came from oil industry. Therefore, there is a good probability that several dossiers from the oil industry will be selected for evaluation.
Evaluation means that dossiers will be checked manually by ECHA experts, because until now all dossiers were checked for validity

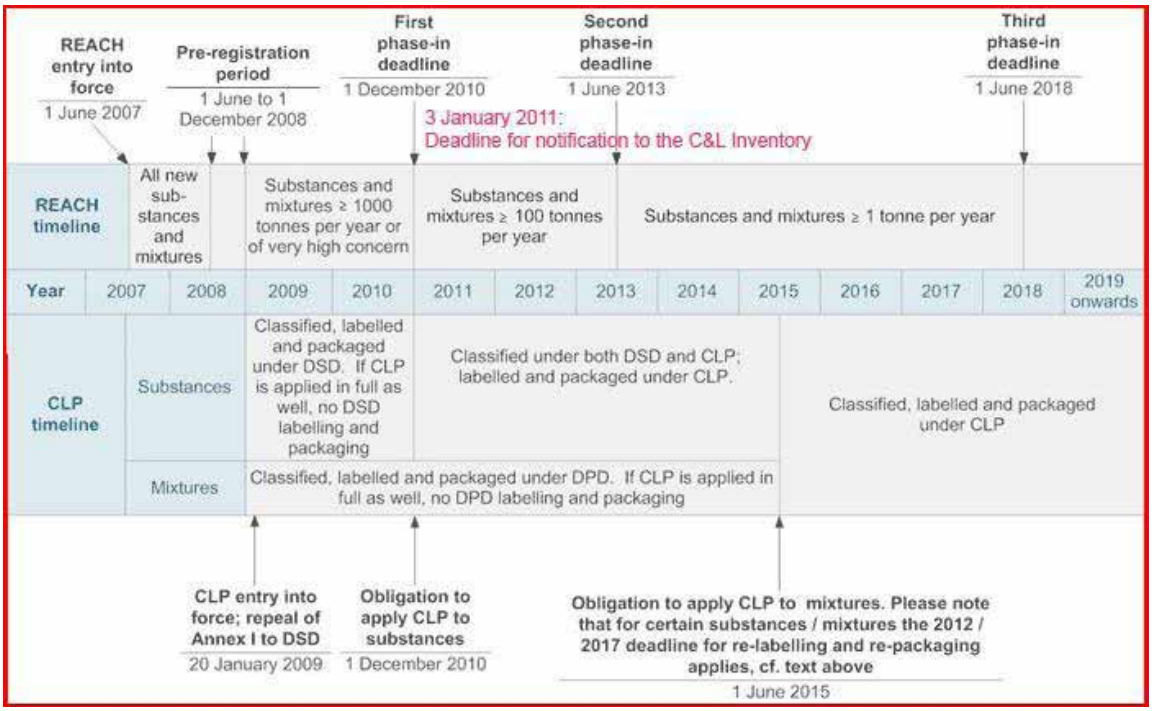

Fig. 4.Timelines for REACH and CLP [8]

only electronically after they were uploaded by registrants on REACH-IT (ECHA portal for dossier submission on internet). For all dossiers submitted after 30 November 2010 ECHA has 90 days to validate dossiers.

If dossier needs to be updated/corrected, registrant receives notification from ECHA and must respond in given time period. During this period, substance in question is considered registered, so there is no interruption in manufacturing/delivery process.

Now, when registration process by the first registration deadline is finished, it would seem for outsiders as a relatively easy process, but MOL Group experts started work on this process more than 4 years ago. Team work within MOL Group is a key of successful registration of all concerned substances. Authors of this paper never before experienced so extensive and fruitful co-operation among colleagues from different LEs. As team members come from several countries, working on this project helped all of us to get closer and understand each other better.

But REACH is not finished yet! Figure 4 shows timelines for REACH and CLP. Registration is just the beginning, e.g. all REACH-substances that do not fall in the first deadline will be registered in 2013 and 2018. Furthermore, all substances that are manufactured by INA but not sold to the EU can and will be registered only after Croatia becomes an EU member state.

Besides that, we need to keep close look on new ECHA guidances that will be published after the first registration deadline. First four new guidances were published already, on 2 December, 2010. It can be expected that some of them will request update of already submitted registration dossiers.

It is also very important to point out that now, after the first substances were registered, REACH competent authorities in every member state will start to check more frequently REACH-compliance. That means not only that contracts with customers need to be revised and new clauses included [usually about registered uses, and request for SCC (strictly controlled conditions), confirmation in case of intermediates], but also assortment of REACH-related documentation should be in place on manufacturing sites and other organizational units responsible for REACH compliance.

Acknowledgement

The authors thank every colleague of INA and MOL laboratories who participated in data collection and/or analytical tasks. The help provided by REACH project team and its managers is appreciated. And of course we render thanks for colleagues of MOL and all subsidiaries, because not only the two US organizations co-operated together, but also every legal entity. We wish lots of success in performing the forthcoming REACH relevant challenges for each colleague working with REACH.

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[2] http://www.concawe.be/content/default.asp?PageID=554 (06.01.2011. 15h 57)

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Keywords: EC regulation, REACH, CLP,

Object-based modelling in a turbidite type reservoir *

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Abstract

The three medium size turbidite systems (Földvár Felső A-1, Földvár Felső A-2, Földvár Felső A-3), summarized as the Földvár gas reservoirs (Hungary), have been captured in a 3D geological model on the base of a layer cake modelling technique. Unfortunately, the first model did not meet one's expectation; a reasonable history match only could be achieved after serious modifications and the aim to better understand the reservoir was not accomplished.

A reassessment of the geophysical well logs resulted in the idea, to summarize the three reservoirs into one system and simulate the turbidite environment based on an object-based algorithm. This new facies model enabled the geologists to uncover intra-body porosity trends. A consequent differentiation between the trends and residual porosity in the well log data facilitated to simulate the entire model with only two facies but still preserving the complex inner architecture of the turbidite system. The generated 3D parameter thus managed to reproduce the turbidite's porosity distribution in a very realistic way and gave the geoscientists the possibility to study its flow dynamical behaviour comparable to the original, natural environment.

The reservoir engineer was able to achieve a history match after minimal modification and reasonable time which confirmed the model's consistency. Consequently, the workflow applied was adequate for the simulation of this specific gas reservoir.

Összefoglalás

Objektum alapú modellezés turbidit típusú tárolónál

A három, közepes méretű turbidit rendszerből álló (Földvár Felső A-1, Földvár Felső A-2, Földvár Felső A-3) Földvár gáztárolók jobb megértése érdekében 3D geológiai modell készült, a hagyományos „torta-modellből" kiindulva. Sajnos ezen modell esetén az elfogadható múltillesztést csak jelentős módosítások árán érhettük el.

A geofizikai szelvények újraértékelése során vetődött fel a három tároló egy rendszerként való kezelésének ötlete és az objektum alapú modellezési algoritmus alkalmazása. Az ebből létrejött fácies modell lehetővé tette a homoktestekben (objektumokban) a porozitás trendek tanulmányozását. A porozitás trendek és a maradék (reziduál) porozitás szétválasztása azt eredményezte, hogy a szimuláció során elegendő volt két fácies használata, de a turbidit rendszer komplex belső struktúrája sem veszett el. A létrejött 3D paraméter felhasználásával a valósághoz igencsak jól közelítő porozitás értékek születtek, melyek segítségével a természetbeli rendszer áramlástani viselkedése kiválóan tanulmányozható.

Kisebb módosításokkal a múltillesztés

* Presented on the "How to maximize the value of mature HC fields" SPE Conference, 18th November 2010, Budapest, Hungary

rövid idő alatt elvégezhető volt és ez igazolta a modell helyességét. Következésképpen elmondható, hogy az adott gáztároló megfelelően szimulálható az ismertetett módszerrel és munkamenettel.

Introduction

Reliable reservoir models are consistent 3D representations of a wide range of data and knowledge relevant for the understanding of a hydrocarbon system. The capability to customize each model to the purpose of the exercise, simulate multiple scenarios and quantify the uncertainty makes them invaluable tools for improved reservoir management decision making. In addition, an accurate model of the reservoir geology is a crucial input to the complete field development planning process. While in the old days models have been built as continuous layers with interpolated reservoir properties (deterministic method), more sophisticated tools are nowadays available to capture the system's heterogeneity. In the past decade, computation time in computer technology improved tremendously, offering huge opportunities to software engineers. New facies modelling techniques have been developed based on stochastic or object-based algorithms. One of sudden, geological features like river channels, deltas, belts or even turbidites could be captured which not only produces results which look geological, but unlike the other techniques, explicitly preserves connectivity.

Out of MOL Plc's exploration targets, located in the South Trans-Tiszanian region (Hungary), nine can be classified as deep water turbidite type reservoirs. These medium porous, sand rich sediments belong to the Szolnok Formation. Ms Györgyi Juhász described the Szolnok Sandstone Formation as Miocene deep water turbidites, composed of alternating, laminated, fine grained sandstone, aleurolite and clayey-marl, frequently collateral interrupted by strata-bounded carbonized plant relicts [1]. The following study focuses on three medium size turbidite examples (Földvár Felső A-1, Földvár Felső A-2, Földvár Felső A-3), separated by pelagic marker horizons (seals) which can be summarized as the Földvár gas reservoirs.

In order to get a better understanding of the Földvár's reservoir behaviour and fluid dynamics, a 3D geological model was requested and built on the base of Roxar's IRAP RMS 2010 modelling solution. The reservoir geologist's first approach was based on a layer cake modelling technique (Facies model: Sequential Indicator Simulation; Petrophysical model: Sequential Gaussian Simulation) which assumed three continuous sand rich layers embedded in a pelagic environment. Unfortunately, serious modifications, often difficult to explain by a natural system, needed to be implemented to achieve a reasonable history match. Therefore, the model did not meet one's expectations and the concept, delineating the three different turbidite reservoirs based on carefully mapped isochors, emerged not to be adequate.

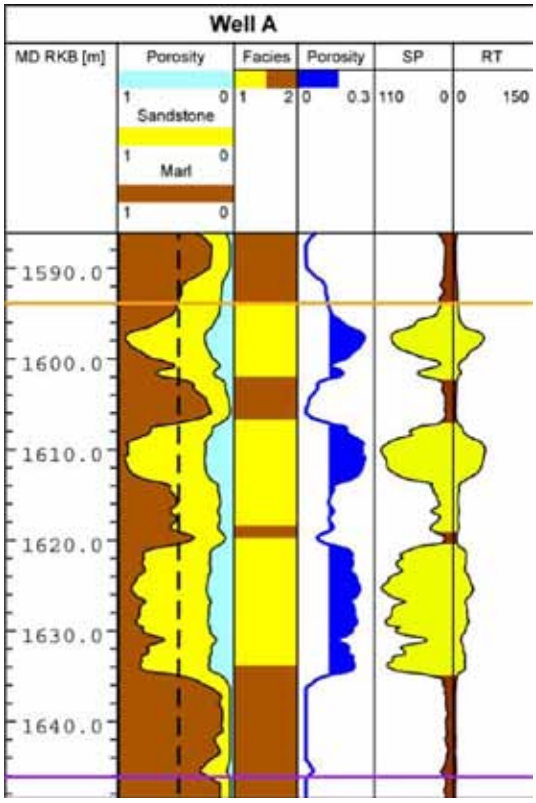

Fig. 1. Well log of Well A visualizing the three distinct sand intervals with cyclicity inside the packages. Porosity higher then 12% is highlighted in blue, the orange line defines the Földvár Felső reservoir top, the purple the reservoir bottom. Abbreviations: SP - Spontaneous Potential, RT - Total Resistivity, MD RKB – Measured Depth Rig Kelly Bushing

A carefully conducted well analysis resulted in the idea to summarize the three turbidites in one single system. Although the majority of the well logs indicated three distinct sand intervals, cyclicity could be observed inside the sand packages in particular in the Spontaneous Potential (SP) logs (Figure 1).

Other well logs consist of up to eleven sand intervals (Figure 2), where even a very careful analysis failed to group them into the before described intervals and correlation to neighbouring wells was all but impossible. The system therefore must have been formed by

hundreds or even thousands of underwater avalanches, triggered one after the other with passive periods in between. This new conceptual model describes the geological environment therefore rather as dynamic compared to static, continuous assumed before and enabled to capture the reservoir settings on the base of an object-based turbidite model.

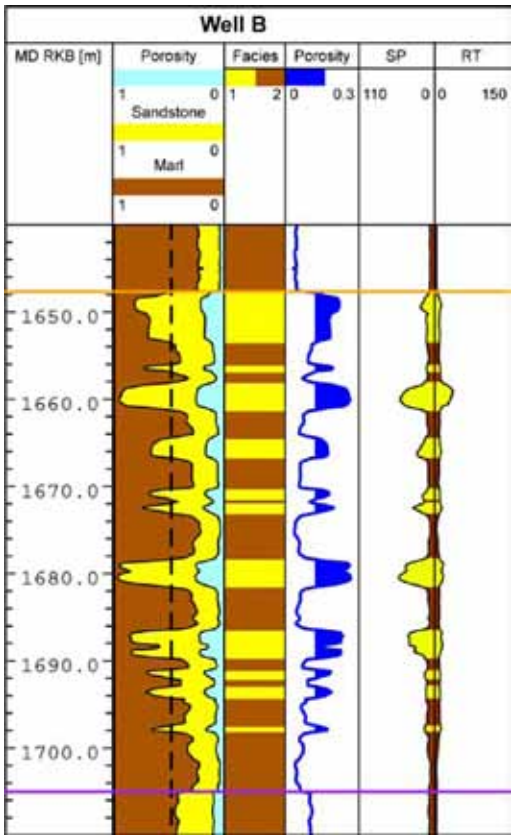

Fig.2. Well log of Well B with eleven sand intervals. Porosity higher then 12% is highlighted in blue, the orange line defines the Földvár Felső reservoir top, the purple the reservoir bottom. Abbreviations: SP - Spontaneous Potential, RT - Total Resistivity, MD RKB – Measured Depth Rig Kelly Bushing

Input data for 3D modelling

The Földvár reservoir model has been built based on the following input data:

- A low quality 3D seismic cube and 2D seismic lines have been processed providing the top map of Földvár Felső A-3
- 160 vertical wells with geophysical logs: Gamma Ray (GR), Spontaneous Potential (SP) and Resistivity (RT)
- Petrophysical quantitative interpretation (porosity, water saturation, permeability and clay volume) for the reservoir section in each well
- Core measurements of porosity and permeability
- Capillary pressure curves
- 46 years of production history data.

Object-based facies modelling

The possibility to treat the three reservoirs as one system obliged the geologists to reassess the location of the reservoir bottom. In case of the layer cake model, the bottom of the reservoir has been defined as the last sand occurrence in each of the three intervals. This approach was good enough for a Sequential Indicator Simulation (SIS) but unfortunately insufficient in case of the object-based modelling technique. The paleotopography heavily influences the distribution of the turbidite fans and in addition, the erosive behaviour of this high energetic system should not be neglected.

Again, a careful analysis of the available well log data has been accomplished with the aim of better understanding of the turbidite system. The study concluded that the favourable reservoir sediments must have been deposited on a thick marl base. The known geological rule that an even thick marl layer has been sedimented over a much longer time period compared to a sandstone interval motivated the geologists to define the bottom of the reservoir 10 m below the last sand occurrence. After the definition of the reservoir top and bottom in the well logs, an isochor map has been created, analysed and the bottom marl thickness, if necessary, adjusted in each well. Combining the low sedimentation rate of marl with the erosive habit of turbidites justifies the thickness modification with the aim to produce a continuous and realistic environment. This raw map, even though it was constructed based on a very simple approach,

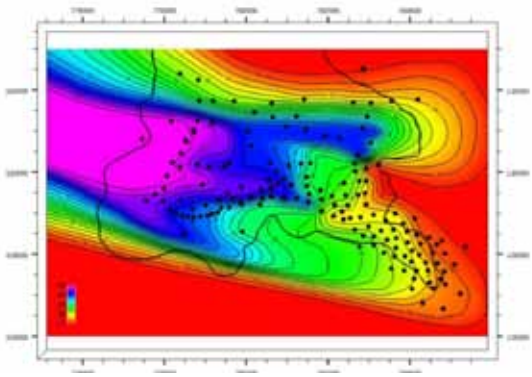

Fig. 3. Isochor map of the Földvár reservoir. The black line represents the original gas-water contact, the black points the position of the wells. The map is a plane projection in the Unified Hungarian Projection (Egyseges Orszagos Vetuleti - EOV) coordinate system

already gave a good insight in the inner structure of the turbidite system. Areas, which have not been delineated correctly due to missing well information, have been modified by honouring the main concept of the raw map. Finally, the resulting isochor map (Figure 3) has been used to construct the reservoir bottom and together with the top map Földvár Felső A-3, the extent of the sedimentation space delineated. The resulted framework has been captured in a pillar grid which forms the foundation stones for the subsequent modelling workflow.

The cyclicity of the SP and porosity logs inside the sand intervals, observed during well log study, became now the main focus of attention. It was concluded, that the distinct arc shapes represent different turbidite currents and therefore, the sand intervals have been split into different bodies (Figure 4). Very small fluctuations (nano-cycles) have been neglected to keep the system as simple as possible for a smooth simulation. This assumption does not affect the quality of the result because the described effect can be later compensated with noise during the petrophysical modelling process. Obviously, it is not a matter of classical turbidite. The increasing porosity at the beginning of each current is not typical for a bouma cycle [2]. It stands for another process which has not been fully understood yet.

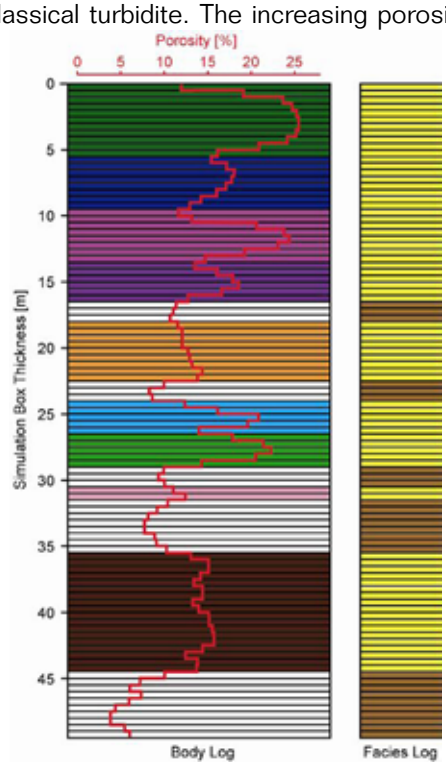

Fig. 4. The distinct arc shape porosity log enabled to split the sand intervals into different turbidite currents. Small fluctuations (nano-cycles) have been neglected to keep the system as simple as possible. Facies log: yellow - sandstone, light brown - marl. Body log: each colour represents a turbidite body

Based on the final isochor map, the generated body log and the production history of the field, the turbidite dynamic system has been analysed. A careful study was indispensable for the understanding of such a complex environment and facilitates the design of important input parameters, like relative intensity map and azimuth vector field, for an object-based facies model. A closer look to the sand body thicknesses as well as their vertical distribution in the wells gave the reservoir geologist an idea about the architecture of the turbidite system. The high frequency of sand intervals in the north-western part of the reservoir (Figure 2) developing to mainly three intervals (Figure 1) in the centre and a thin out trend towards the south-east uncover the main dynamic of the target area. With this understanding of the turbidite's inner structure, wells at first sight outliers could now be incorporated and the vector field generated, defining the average azimuth of the turbidite main axes (Figure 5).

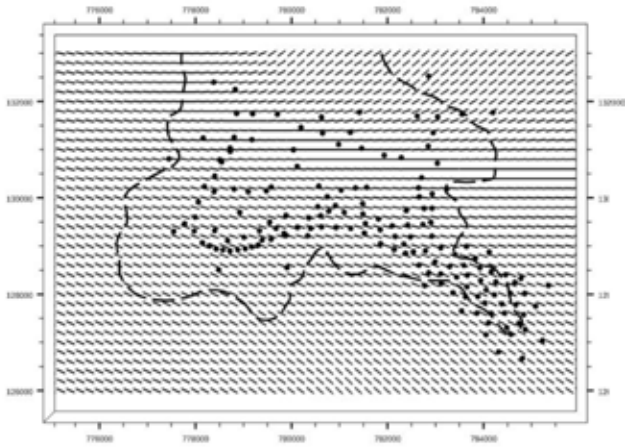

Fig. 5. Vector field, defining the average azimuth of the turbidite main axes. The main deposition trend is NW-SE with convoluted deviation towards each side. The black dashed line represents the original gas-water contact, the black points the position of the wells. The map is a plane projection in the EOV coordinate system

The generated map impressively highlighted the main deposition trend as NW-SE with convoluted deviation towards each side. This predefined vector field, including a variability of 5°, was eventually the main driver for the direction of the sand spreading inside the modelling grid.

The trigger probability of the turbidite currents has been captured in a relative intensity map (Figure 6). The concept of one point source, located at the north-western sector of the

model failed to generate a simulation which was consistent to the well data. Therefore, a multisource model was taken into consideration. It has been assumed that the turbidites has been fed from a wide range of the north-western continental shelf without excluding the possibility to trigger turbidites closer to the abyssal plain. The definition of the turbidites triggering probability was the main aim of this output, but it furthermore enabled to customize the facies model to the reservoir's requirements. Local sand content adjustments or barrier incorporation could be easily performed without modifying the modelling grid which saves a lot of time. The relative intensity map was a product out of the concept, elaborated during the different analysis of the input data. Due to missing soft data (seismic attributes), the incorporated uncertainty was substantial and a calibration during the facies modelling workflow indispensable.

The elaborated input parameters have been used

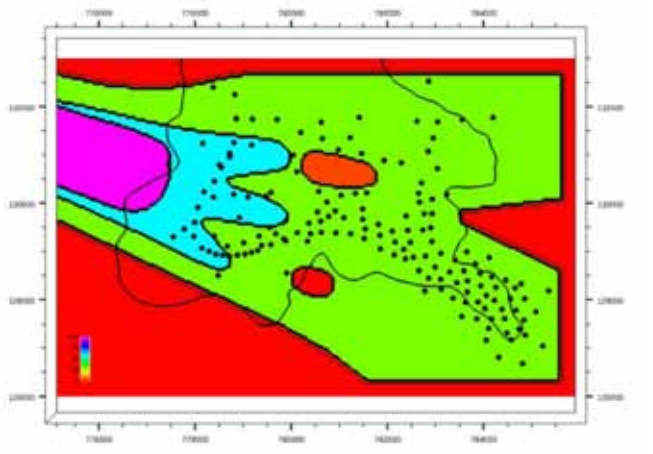

Fig. 6. Relative intensity map defining the trigger probability of turbidite currents. It has been considered that multiple sources, distributed over a wide range of the north-western continental shelf, fed the system without excluding the possibility to trigger turbidites closer to the abyssal plain. If necessary, local sand volume adjustments (orange ellipse) or flow barrier (red ellipse) have been incorporated to customize the environment to the reservoir's requirements. The black line represents the original gas-water contact, the black points the position of the wells. The map is a plane projection in the EOV coordinate system

for a 3D simulation with the help of the Facies Composite module of IRAP RMS 2010. The sand content in each grid layer has been specified based on the Vertical Proportion Curve (VPC), generated out of the 160 well logs of the field. The design of turbidite body geometry emerged to be the most challenging part of this workflow. Several text books and publications were studied for an adequate delineation of the bodies shape and size, with the deflating result, that most scientific work was focused on the physical flow behaviour and inner architecture of turbidites nature including very unspecific definitions about its dimension. Therefore, a typical lobe shape for the sand bodies has been assumed and amplitudes and rugosities implemented to guarantee each body's uniqueness and a close approach to nature. The size of the geometry and the corresponding variability could not be estimated out of the available information. Again, soft data would have been a tremendous advantage to minimize uncertainty, but the low quality of the 3D seismic cube made the generation of such a parameter impossible. The body's height has been estimated based on the sand thicknesses, specified in the body log. However, the finally used length and width distribution resulted from a calibration process based on geological understanding of a turbidite system, visual control in 3D as well as the help of the VPC. These aspects provided an excellent insight into the system and allowed to achieve a satisfying result.

The first runs of the facies simulation have been conducted based on relative big bodies with the aim to keep the system as simple as possible. Astonishingly, the model behaved directly opposite. The simulation struggled to condition the facies model to the well data and created all but not a realistically looking output. In addition, the VPC, generated from the resulted facies model, differed tremendously form the one used as an input which let the experts conclude, that the specified body dimension need to be reassessed. A satisfying result was finally achieved by relatively small turbidites, where the length was specified as truncated normal distribution with a mean of 2,500 m (std. = 1000, min. = 500 m and max. = 5,000 m), the width as truncated normal distribution with a mean of 200 m (std. = 300, min. = 100 m and max. = 800 m) and the height as truncated normal distribution with a mean of 3 m (std. = 2.5, min. = 0.5 m and max. = 17 m). The reservoir geologists were aware that the normal distribution would not be the most adequate representation of such a natural system, but their hands were tied due to the restriction of the simulator. On the other hand, by implementing truncations, the shape of the distribution could be customized to a certain extend and a more realistic approach could be obtained.

The calibrated object-based model finally honoured correctly the 160 wells and managed to reproduce the different features as observed in the available well logs. In addition, it enabled the geologists to combine different analyses in a 3D representation of the Földvár Felső turbidites system (Figure 7) and created an impressive insight in its unique architecture.

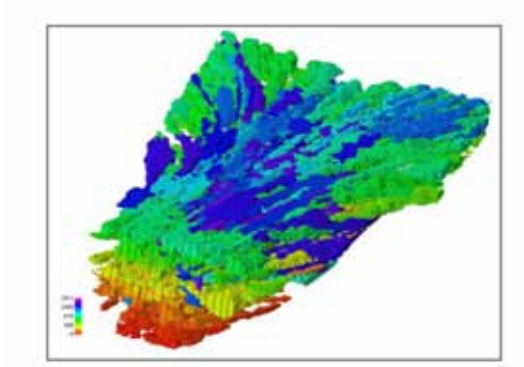

Fig. 7. Object-based facies model visualizing the distribution of 1957 turbidite events. With the aim to improve visibility, the marl has been filtered out and a z-scaling factor of 50 implemented. Line of sight towards East

Petrophysical modelling based on 3D intra-body trends

The object-based facies model not only preserves explicitly the reservoir's connectivity, but also allows to specify exactly the position of the well logs inside the simulated turbidites bodies. The advantage of this possibility is tremendous compared to a simple layer cake modelling approach because it enables to analyse intra-body porosity trends originated due to the dynamic behaviour of turbidite currents. This spatial information is inexistent in pixel-based simulation and therefore the trend analysis was limited to global trends in x, y and z directions.

The most dominant trend in each turbidite event of the Földvár environment has already been discussed during process of splitting the sand intervals into different bodies. The distinct arc shape of the porosity logs (Figure 4) could be observed in almost all wells and the facies model permits now to specify its exact location inside a turbidite body. In IRAP RMS, this data can be analysed as three different scatter-plots:

- Normalized intra-body vertical thickness vs. porosity
- Normalized intra-body lateral along length vs. porosity
- Normalized intra-body lateral normal width vs. porosity.

This allows a complete new insight into the inner architecture of turbidite events and guarantees a better understanding of this natural system. However, nature does not stick to simple rules and the observed shape of each turbidite event (Figure 4) seems somehow to be unique. The software can handle the complex, non-linear trend with a piecewise linear approach, but it is limited to one lookup function per trend. Consequently, the diversity in the system will result in a high noise level of the residual.

After the reduction of the above-described intra-body vertical trend, with high porosity in the centre and decreasing values towards the top and bottom of the body (Figure 8), minor trends get visible. The intra-body architecture of porosity is thus a superposition of three trends (Figure 9); the step by step trend reduction accentuated a linear intra-body lateral normal trend (Figure 10) and an arc shape intra-body lateral along trend (Figure 11), both showing increased porosity in the centre. The result of this analysis fit nicely into the physical behaviour of a high density turbidite current [3], where coarser grained sediments were deposited as a result of decreasing energy in the system.

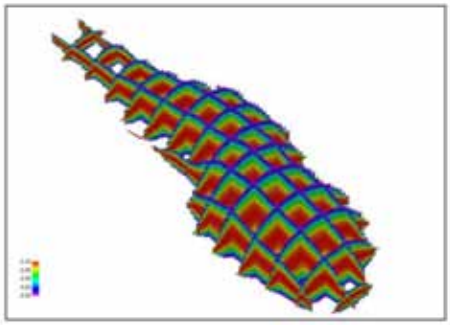

Fig. 8. Artificial turbidite body representing the conceptual model of the intra-body vertical trend with high porosity in the centre and decreasing values towards the top and the bottom of the body

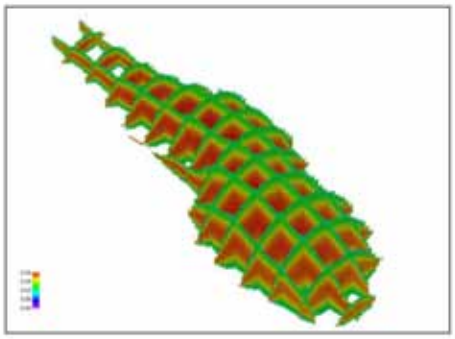

Fig. 9. Artificial turbidite body representing the conceptual model of the intra-body porosity distribution in 3D. It visualizes a superposition of three individual trends, where the intra-body vertical was assumed to dominate over the intra-body lateral normal and lateral along

After the trend reduction with the aim to separate the residuals for further simulation and a normal score transformation, variography could be

applied, which gave directly a feedback about the quality of the data transformation.

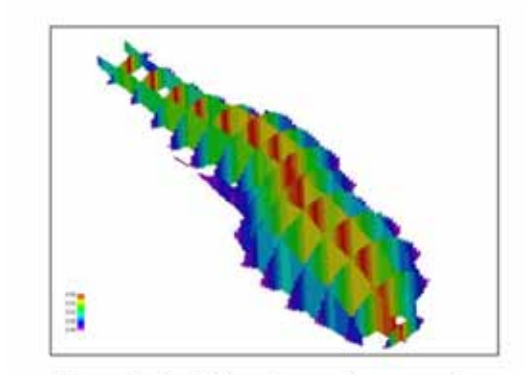

Fig.10. Artificial turbidite body representing the conceptual model of the intra-body lateral normal trend with increased porosity in the centre and decreasing values towards each side of the body

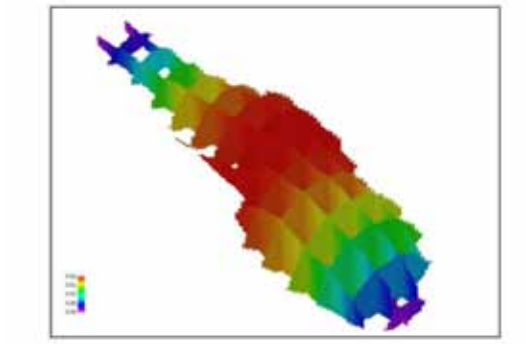

Fig. 11. Artificial turbidite body representing the conceptual model of the intra-body lateral along trend with increased porosity in the centre and decreasing values towards the distal and the proximal part of the body

Main focus of attention was the vertical experimental semi-variogram. In general, it represents the highest data density and it is therefore very sensitive to remaining trends. The variances of the point-pairs in vertical direction have been calculated and plotted in a semi-variogram. The visualized point distribution already indicted the typical shape of the semi-variogram and could be easily reproduced with an exponential type model (Figure 12). The excellent fit, the good stability and the low scatter were an indication, that all trends have been correctly deducted.

Even though the amount of data pairs was lower for the semi-variograms in horizontal directions, the exponential type model still fitted to the calculated points and the semi-variogram stability was remaining good except of some fluctuation towards long lag distances. The almost isotropic behaviour in the horizontal directions as well as the good stability of all three experimental semi-variograms confirmed that the data transformation was realistically and correctly conducted.

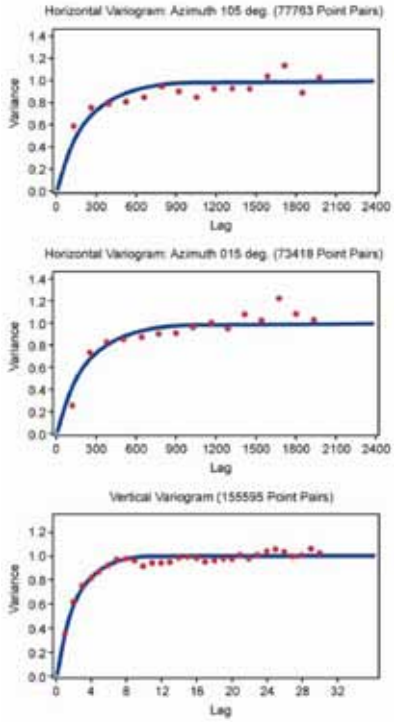

Fig. 12. Results of the porosity residual semi-variogram analysis of the sand facies. It gave directly a feedback about the quality of the data transformation and confirmed the applied conceptual model due to stable semi-variogram in all three directions

The analysis results have been finally fed into the Petrophysical Modelling module of IRAP RMS 2010 and the porosity parameter was simulated.

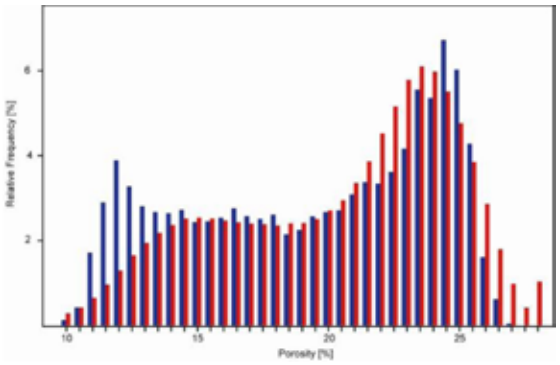

Fig. 13. Histogram of the turbidite sand's porosity. Blue: well log porosity, red: 3D porosity parameter from simulation

The workflow presented enabled to handle the complex environment with only two facies. The careful conducted intra-body trend analysis facilitated to characterize the porosity distribution. The subsequent, consequent trend reduction exposed the sandstone porosity's residuals and made therefore a more detailed facies differentiation unnecessary. Without any modification, the simulation managed to reproduce a similar porosity distribution as observed in the well log data (Figure 13). A local maximum around twelve percent, observed in

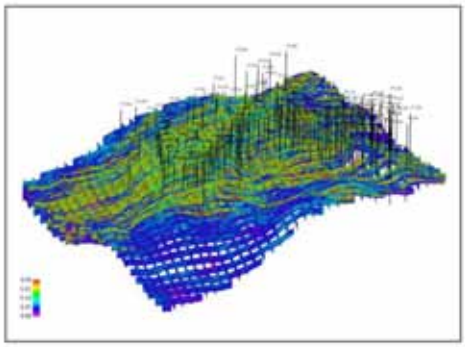

Fig. 14. Final 3D porosity parameter, honouring the conceptual model with high porosity in the centre of the turbidite bodies and decreasing reservoir quality towards its sides

the well logs but not in the simulation was the only discrepancy emerged. Due to the fact, that the mismatch was close to the cut off porosity, prior defined as twelve percent, the influence of this error to the porosity model was regarded as minimal and therefore its existence was neglected.

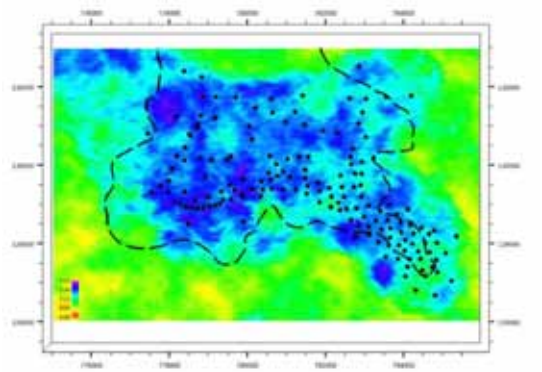

Fig.15. Average porosity map of the Földvár layer cake model. The black dashed line represents the original gas-water contact, the black points the position of the wells. The map is a plane projection in the EOV coordinate system

Results

The 3D porosity parameter (Figure 14), resulted from the simulation, gave an impressive insight into the inner architecture of the Földvár gas reservoir.

At first sight, the porosity parameter looks very noisy and the elaborated conceptual model (Figure 9) could not be clearly seen. But taking into consideration that younger turbidite events will erode predecessors, clarified this issue. Intact bodies on the other hand nicely captured the implemented trend with high porosity in the centre and decreasing values towards all sides. Therefore the model managed to reproduce the turbidite porosity in a very realistic way and enabled the geoscientists to study the reservoir behaviour similar to the original, natural environment.

The difference between the layer cake model compared to the object-based approach can be impressively illustrated based on average porosity maps (Figures 15 and 16). While the first approach captured the good reservoir rocks in some sort of lobe structure, difficult to recognize as a turbidite system, the new model looks very natural. The good reservoir rocks are concentrated in elongated, sometime convoluted bodies with decreasing rock quality towards the turbidite's sides. The former almost isotropic system, allowing the gas to flow radial to the producer wells, emerged now to be an anisotropic system with directional flow. Even though the bulk volume as well as the Gas Initially in Place (GIIP) was comparable and differed only in the range of percentages, the flow dynamic behaviour changes completely and enables a better understanding of the reservoir.

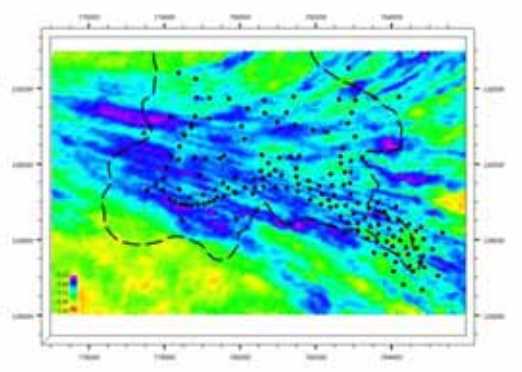

Fig.16. Average porosity map of the Földvár object-based model. The black dashed line represents the original gas-water contact, the black points the position of the wells. The map is a plane projection in the EOV coordinate system

Conclusions

The workflow presented has a more complex theoretical background than the classical layer cake modelling approach, but is not necessarily more costly in terms of time. The challenge of this method is to elaborate the different input parameters like vector field, relative intensity map, general turbidite body shape and turbidite size distributions, however various calibration methods supported the geologist to facilitate a realistic result.

The reservoir engineer was able to achieve a good history match after minimal modifications and reasonable time which confirmed the model's

consistency. In case of the classical approach a comparable result was only achieved after serious modifications which often where difficult to explain by a natural system. On the other hand, the object-based facies model facilitates to analyse and capture intra-body trend, which could not been discovered and reproduced in the previous model. This aspect provided an excellent insight into the reservoir's flow dynamic which allow especially in mature fields a more accurate study of the reservoir's behaviour.

Acknowledgment

The authors would like to express their sincere gratitude to the management of MOL Plc. for providing the data used in this study and the permission to publish this conducted work.

Furthermore, it is our privilege to express our sincerest regards to the Reservoir & Technology Engineering Department for their valuable inputs, guidance, encouragement and constructive criticism throughout the duration of our project.

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Keywords: object-based modelling, non-classical turbidites, IRAP RMS, Szolnok Formation, intra-body trend modelling

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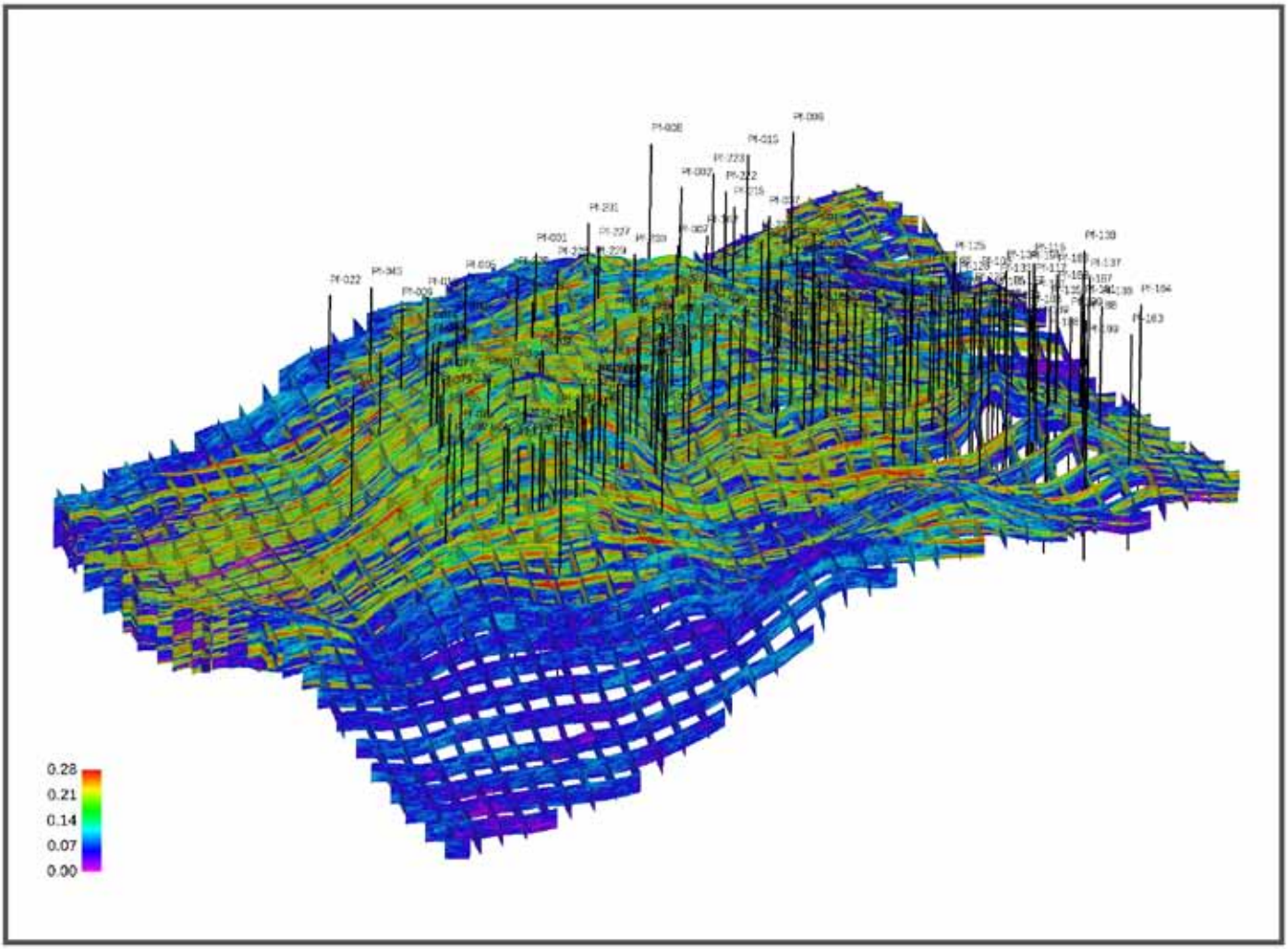
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The sand of time in the pump –

An introduction to a new type of tubing pump:

Farr Plunger Plusz (B&Sz)

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Abstract

During the extraction of oil fields, numerous factors can worsen the efficiency of down hole pumping. Both the gaseous and foamy produce and the solid material content of the produce can affect the efficiency of abstraction. In many cases, this makes the use of sucker rod pumps impossible, and it is more difficult to utilize the tubing pipes, too. The decrease in production does not only result in loss of revenue, but the frequent costs of well repairs also have negative effects on production. These production problems occurred in the tubing pipes of the wells in the following areas: Upstream Division, Algyő Gas Technology: Kardoskút-Battonya, Pf. Békés-Pf.FA, Csanádapáca, Mezőhegyes (all in Hungary). The problems varied depending on the particular oil field. In some wells, the occurrence of solid materials, in other cases, the gases in the pumped fluid caused a problem. A large number of technical innovations have been created in the research laboratories of the world's leading oil companies so that the efficiency of pumping can be increased. One of these new technologies has been developed by using the working principle of the Farr Plunger sucker rod pumps. It has been adapted to the use of tubing pipes, and so we can develop a new piece of equipment which is completely different from the original Farr Plunger regarding its technical solutions. However, it offers a solution to the above-mentioned pumping problems. It is especially suitable for production conditions in Hungary. In the following, we intend to demonstrate this new type of equipment, which has already been operating efficiently in a few wells in Hungary.

Összefoglalás

Az idő homokja a szivattyúban, azaz új típusú termelőcsőszivattyú bemutatása: Farr Plunger Plusz (B&Sz)

Az olajtelepek leművelése során, a mélyszivattyúzás hatásfokát számtalan tényező rontja. A gázos habos termelvény éppúgy hatással van a kiemelés hatékonyságára, mint a termelvény szilárdanyag tartalma. Ez sok esetben a rudazatszivattyúk használatát lehetetlenné teszi, de megnehezíti a termelőcső szivattyúk működését is. Nem csupán a termelés volumenének csökkenése jelent bevételkiesést, de a gyakori kútjavítás költsége is rontja a termelő mező fedezetét. Ezek a termelési problémák a KTD Algyői

Gáztechnológia Kardoskút-Battonya művezetési területén is jelentkeztek a Pf. Békés-Pf. FA, Csanádapáca, Mezőhegyes mélyszivattyús kútjain. Telepenként és területenként más probléma adódott. Egyes kutaknál a szilárd anyag jelenléte, más területen a szivattyúzott folyadék gázos volta okozott problémát. A világ nagy olajipari cégeinek kutató-laboratóriumaiban sok műszaki újítás született a szivattyúzási hatásfok növelésére. Egyik ilyen új típusú technológia, a Farr Plunger rudazatszivattyúk működési elvének felhasználásával és annak adaptálásával termelőcső szivattyúra, nyílt lehetőség olyan új eszköz kifejlesztésére, ami műszaki megoldásaiban teljesen más, eltér az eredeti Farr Plunger típusú rudazatszivattyúktól, ugyanakkor az eddig tárgyalt szivattyúzási problémákra együttes megoldást kínál. Különösen alkalmas a hazai viszonyok közötti mélyszivattyúzásra. Az alábbiakban szeretnénk bemutatni ezt az új típusú eszközt, ami már néhány hazai kútban üzemel, az eddigi tapasztalatok alapján megfelelő hatásfokkal.

Pumping problems in Hungary

The down hole pumping conditions in Hungary are extreme compared to other parts of the world in terms of:

- the quality of the fluid,
- the GLR (Gas/Liquid Ratio),
- the quality of the associated gases (CO_2, H_2S, etc.),
- solid material content (sand, metal chips, corrosion, etc.),
- inflow conditions: extraordinary physical properties of rocks and
- temperature (very high).

THE QUALITY OF THE FLUID

In our area, we have pumping wells, which produce paraffin-base oil with high viscosity. As a result of frequent paraffin precipitation, the wells needed to be washed with hot water, which strongly influenced the choice of pump types. The use of sucker rod pumps became impossible because, during the washing, we often lifted the whole pump from the landing nipple as a result of which the seals were damaged, and the sealing line did not work after we put back the pump. Only after repair could we use the well again.

THE GLR OF THE FLUID

We thought it was essential to decrease the clearance of the cylinder of the sucker rod pump because of the gaseous and foamy product. We realized it by changing the fixing and the fixing position of the standing valve (see above gas/liquid ratio, etc.).

In order to lessen the clearance, we completely omitted the lower part of the piston; consequently, the piston can be fixed on the standing valve considering the operating conditions of the down hole pump (rod elongation, dynamic fluid level change, etc.) (Figure 1). However, there is a disadvantage of this technical solution. When the well is being repaired, it has to be configured with „burst", or the tubing pipe needs to be punched out before configuration (e.g. wireline).

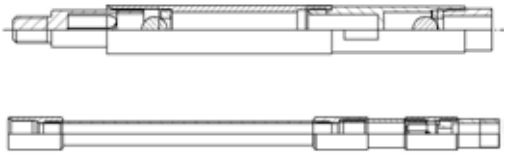

Fig. 1. Structural drawing of the Farr Plunger Plusz pump

THE QUALITY OF THE ASSOCIATED GASES (CO_2, H_2S, ETC.)

Due to the chemical effect of associated gases, the previously used pistons showed signs of corrosion. These mechanical damages led to an early failure of the pumps (Fig. 2).

Fig. 2. Corrosion of the ball valve

To prevent it, the piston of the Farr Plunger Plusz is constructed with hard facing (Fig. 3).

Fig. 3. Hard facing piston and the cylinder

SOLID MATERIAL CONTENT (SAND, METAL CHIPS, CORROSION, ETC.)

Other problems, which occur during the down hole pumping, are piston sticking, the solid material content of the product and other contamination from the well construction (e.g. rust, scale, metal chips). We attempted to avoid these problems by configuring the Farr Plunger Plusz as follows.

The piston has two valves. The upper cage is open, and sunk into the piston. The upper edge of the piston has an inner cone. This way, the solid contamination is conducted into the inner part of the piston during dynamic and static state; thereby, reducing the chances of the solid contamination's getting between the piston roll and the cylinder. The sinking has to be done so that there is no diameter difference at the connection of the valve cage and the piston. The two valves in this pump type are essential because the upper valve should take the fluid load preventing piston elongation. As a result, the original split size of the cylinder and the piston remains unchanged (e.g. 0,002"). Using sand anchor in the piston offers further protection against solid contamination (Figure 4).

Fig. 4. Piston with opened upper cage and sand anchor

INFLOW CONDITIONS

Since there is a small amount of inflow and gaseous fluid in certain areas, the down hole pump needs to be installed into or under the perforation (gas separation). In traditional API (American Petroleum Institute) pumps, there was frequent solid material sticking in this case. As previously described, the Farr Plunger Plusz pump can be installed into that particular depth. Up to this point, this type has proved to be working excellently (Pf-157, Pf-45). The fluid production of the wells has increased, and, according to the dynamometer diagrams, there is no sign of "gas disturbance" and fluid loss (Figure 5).

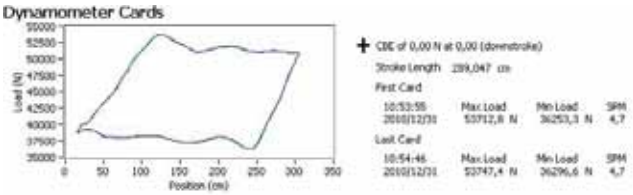

Fig. 5. Farr Plunger Plusz pump ideal functional diagram

TEMPERATURE (VERY HIGH)

The average temperature of producing fields ranges from 117 to 136 C°. That is why, the PCP (Progressing Cavity Pump) pumps have failed to work, and only metal-base pumping equipment can be used. High temperature requires a great deal of attention, and a careful selection of the type and quality of the pump parts (e.g. cylinder, piston, valves). The Farr Plunger Plusz meets these criteria perfectly.

Comparison of Farr Plunger Plusz tubing pump with API tubing pump

The original API tubing pump, which was used in Hungarian production conditions, was modified several times over the years; however, in most cases, the most common problems of down hole pumping could not be prevented (e.g. the presence of solid material and gas). We attempted to avoid these problems and increase the efficiency of pumping by developing the Farr Planger Plusz pump.

The modifications of this pump can be divided into two categories: modifications of the cylinder and the piston.

THE CYLINDER

In our area, the tubing pipes in the wells have the so-called divided cylinder, and the material of the cylinder is casting. The standing valve of the original API pump can be lifted with the lifting part of the piston, so, during well servicing, the lifting part of the piston and the standing valve can easily get stuck together. The frequent phenomenon can often result in repeated configuration of the tubing pipe equipment increasing well servicing costs. Another disadvantage of this technical solution is that the standing valve can be moved by fluid flow during the higher speed of aggregator operation. It requires a complicated operation to put it back to its original position. With this technical solution, the so-called clearance cannot be decreased because of the size of the lower moving part of the piston and upper valve, and so the possibility of gas lock is relatively high. This makes the pumping parameters worse with respect to its mechanism (the break of the rod) and efficiency (saturation). In order to prevent these phenomena, we developed a cylinder where the clearance is decreased. We

Fig. 6. Farr Plunger Plusz piston and cylinder

modified the size and fixing mode of the standing valve, and the lower part of the piston (Figure 6). The advantage of this modification is that we are capable of minimizing the clearance at the bottom of the pump: in case of precise calibration, it can even be zero. This has made the efficient recovery of gaseous fluid possible. During aggregator operation, the standing valve cannot be lifted because it is fixed with a thread. This way, we eliminated the above-mentioned two major failures of API pumps.

THE PISTON

The biggest modification has been made on the upper part of the piston because the valve cage has been sunk into the inner part of the piston, and we have developed an inner cone on the top of the piston. There is no diameter difference at the connection of the active part of the piston and the cylinder, so solid material cannot settle there, and there is a small chance of becoming stuck between the cylinder and the wall of the piston. Since there is a cone on the upper part of the piston, the fluid flows toward the inner sector, and the solid material also floats towards it. This gains significance when the down hole pump is re-set (upper dead centre), and the fluid flow moves the solid contamination upwards. When the pump is not moving, the fluid moves the contamination, which is settled down on the upper valve (Figure 7).

Fig. 7. Conical piston design

The piston has two valves. This is vital because the upper-valve takes the load, and so the piston does not elongate, and the split size remains unchanged. In this way, the solid material cannot go between the cylinder and the piston (Figure 8).

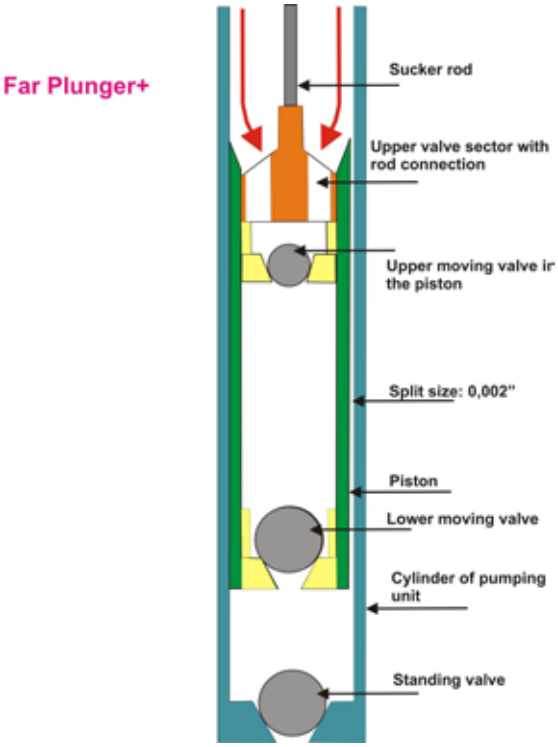

Fig. 8. The structural elements of Farr Plunger Plusz

When developing the piston, we kept the so-called sand anchor and hard facing, which offer further protection.

Production experience

After technical configuration, the pump was manufactured, and the patent process also started. With the permission of the area's leading manager, it was installed into several wells where the above-mentioned pumping problems occurred. By installing this new pump type, we had the following goals: we intended to reach product excess by increasing pumping efficiency, and reduce the costs of well repairs in the long-term.

We had the chance to do so in two fields. Among the wells of Pusztaföldvár-Békés, Well Pf-103 was a well, where more frequent rod and tubing pipe breakdowns occurred than in the rest of the field due to the solid material content of the product (Békés Conglomeration Formation). The amount of associated gases in the cylinder significantly worsened pumping efficiency. The following diagram shows a rod split owing to the aforementioned problems (Figure 9).

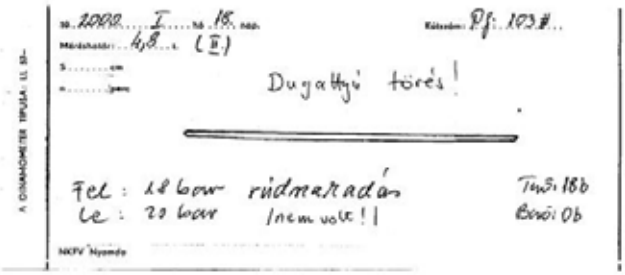

Fig. 9. Dynamometer chart of conventional rod breakage

The Farr Plunger Plusz tubing pump was installed in December 2009. Before that, a 44/3000 ZTS pump operated, the running-in depth was 1,200 m. According to calculations, the running-in depth of the new pump was 1,100 m, and it has a 59 mm piston. The size of the casing was 5 ½", and the perforation was located in 1,754-1,764.5 m.

The following diagrams (Figure 10) show the state of the wells after cleaning.
The figures show that that the tubing pump operates well, there is no „gas disturbance" in the cylinder, and the valves operate suitably. The improvement of pumping efficiency has also influenced the production of the well: the amount of pumped fluid and oil has increased

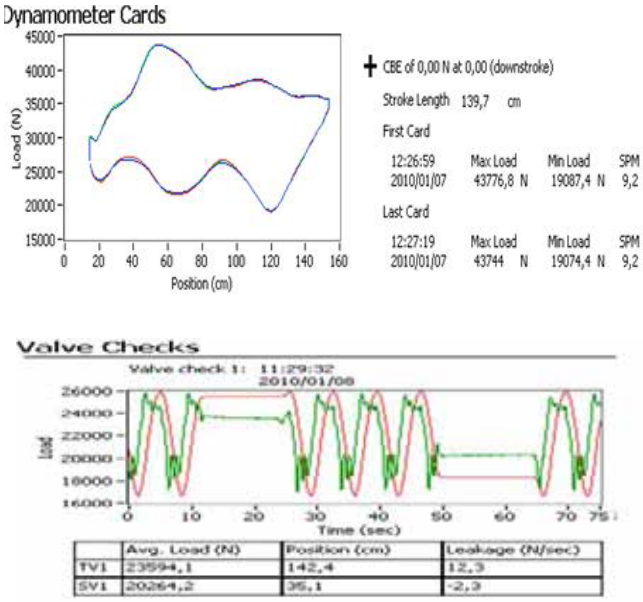

Fig. 10. Dynocard and valve checks after static operating conditions

(Figure 11). Until today, the pump has been operating appropriately. It re-started again even after some longer breaks, and there is no sign of damage caused by solid material contamination. However, it should be noted that the new type of pump operates with highest efficiency if the ideal production parameters of the deep wells (the operating point of the well) are configured properly.

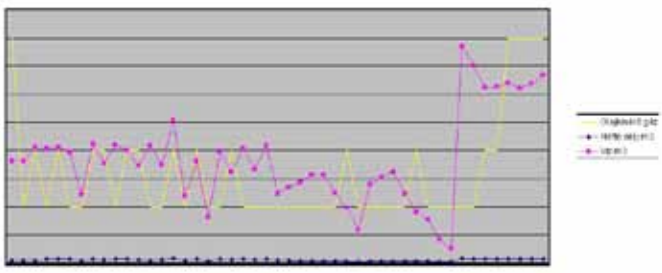

Fig. 11. Production chart before and after installation of new type of pump

In the other field, in Pusztaföldvár Földvár-Alsó, there were also numerous pumping problems. The fluid flow was relatively small: 1-3 m^3/day, accompanied by 400-600 m^3/day associated gases. Due to the strongly decreased reservoir pressure, the solution gases practically dissolved at the well bottom. The soft sand from reservoir rocks caused mechanical damage in the pump, and so there was frequent piston sticking, and, as a result, rod splits. In fact, traditional pumps should have been installed into or under the

perforation (gas separation); yet, these attempts proved to be unsuccessful (Well Pf-150). The Farr Plunger Plusz allowed us to do the above. In the fourth quarter of 2010, we installed the pump into the perforation.

Well Pf-157. Open perforation:
1,688 – 1,689.5 m Földvár Alsó – I, Lower-Pannon sandstone
1,694 – 1,697 m
1,698.5 – 1,702 m
1,659 – 1,661 m
Casing 4 ½". Running-in depth of the pump: 1,684.5 m (38 mm piston).

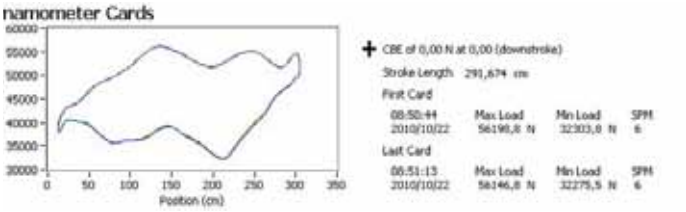

Fig. 12. Dynocard of Pf-157

The following diagram (Figure 12) shows the operating conditions after the pump was set:

Well Pf-45. Open perforation:
1,709.0 – 1,716.0 m Földvár Alsó – I sandstone
1,703.0 – 1,707.0 m Földvár Alsó – I sandstone
Casing 5 ½". Running-in depth of the pump: 1698 m (38 mm piston).

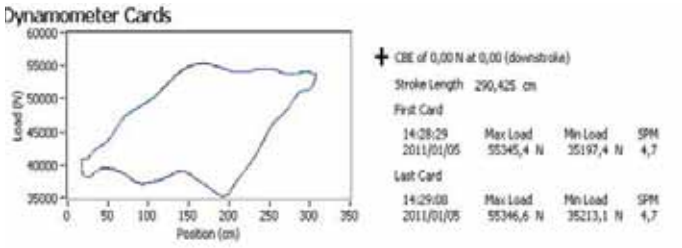

Fig. 13. Dynocard of Pf-45

The following diagram (Figure 13) shows the operating conditions after the pump was set:
In order to divert the gas excess on the casing walls resulting from gas separation, we are installing Beam Gas Compressor in both wells.

Conclusions

The Farr Plunger Plusz tubing pumps, which were installed in the wells of Pf. Békés, Földvár-Alsó, Demjén, have proved to be working suitably. In general, there is production excess; however, we do not have data whether the costs of well repairs have decreased since they have not been used for a long time. We suggest using Farr Plunger Plusz pump at those fields where the previously discussed problems occur. At present, this pump does not cost more than a traditional API pump, but it depends on the quality of the material. It meets special needs; however, it can also be used in ordinary circumstances. This pump can be manufactured in every standard size which can be found in Hungary.

Keywords: Farr Plunger, artificial lift, sucker rod pumping, rod pump, tubing pump, dynamometer, efficiency, production

Reviewed by Andras Blaskó-Nagy

Hydrocyclone separation in the oil industry – Part 1

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Abstract

The oldest traditional method employed in the oil industry for the separation of different fluid phases is settling. Partly the gradual inundation of production wells and partly the ever more stringent environment protection regulations have enforced all over the world the research and development of new more efficient separation processes, among others the employment of hydrocyclones. The purpose of this paper is to characterize the complex turbulent flows curling downwards along the shell and moving upwards spirally along the centerline taking place in separation vessels operating with the field of centrifugal forces as well as to outline the situation of employing hydrocyclones in the oil industry and to direct the attention of design and development engineers to the opportunities of utilizing this modern separation technology within MOL Group in the areas of both refining and mining by reviewing the latest development results – including our own research and development work.

Összefoglalás

Hidrociklonozás az olajiparban

Az olajiparban a különböző fázisok szétválasztására alkalmazott legrégebbi, hagyományos módszer az ülepítés. Részben a termelő kutak fokozatos elvizesedése, részben a szigorodó környezetvédelmi előírások világszerte kikényszerítették új, hatékony szétválasztási eljárások, többek között a hidrociklonok kutatását és kifejlesztését. Ezen dolgozat célja, hogy a centrifugális erőtérrel működő szeparációs készülékekben zajló, a köpeny mellett lefelé csavarodó és a tengely vonalban spirálisan felfelé mozgó bonyolult turbulens áramlások jellemzése mellett felvázolja az olajipari hidrociklonozás helyzetét, továbbá a korszerű fejlesztések áttekintésével – ideértve a saját kutató-fejlesztő munkát is – ráirányítsa a tervező és fejlesztő szakemberek figyelmét ezen korszerű szeparációs megoldás jövőbeni alkalmazási lehetőségeire a MOL NyRt.-n belül, akár a finomítás, akár a bányászat területén.

Introduction

A cyclone is the simplest continuous operation separation equipment operating by utilizing a field of centrifugal forces in respect of its design. The field of centrifugal forces inside the cyclone is generated as the result of fluid flow introduced tangentially under pressure. In respect of their system of operation cyclones may be gas cyclones, i.e. dust separator gas cleaning equipment containing G-S (gas & solids) phases, and hydrocyclones, i.e. systems containing L-S (liquid & solids) or L-L (liquid & liquid) phases as well as operating units treating complex three-phase flows, i.e. L-L-S or G-L-S or G-L-L phases.

Hydrocyclones are named in the oil industry

depending on the nature of utilization as follows: desander when the operating objective is to remove solid particles, dewaterer when the objective is to enrich the oil phase by removing the dispersed water phase, and deoiler when the oil content of produced water has to be reduced to the limit specified by environment protection regulations. Naturally, all types of hydrocyclones can be ordered as pressure vessels rated in accordance with the requirements of the particular technology.

The suitability of hydrocyclones for a particular process should be judged by evaluating their benefits and disadvantage. The benefits of hydrocyclones are as follows:

- Uninterrupted operation equipment with high unit capacity;
- Simple design, low capital and operating expenses;
- No rotating or moving parts requiring complicated maintenance and electric power supply;
- Small space requirements, installable not only vertically but also in inclined or horizontal position;
- Can be retrofitted flexibly in existing plants;
- The shear forces associated with high tangential velocities enable even the grading of slurries with tixothropic and Bingham-type plastic flow properties;
- They are suitable even for the separation of the fine, so-called secondary dispersions of fluids immiscible in each other;
- The most variable structural materials may be used for the manufacture;
- The construction of multi-stage cyclones connected in series or the installation of several cyclones in parallel can be realized without any difficulty.

Based on the above features the field of application for hydrocyclones is very wide-ranging and they are competitive with traditional settlers and high-volume gravitational separators.
Disadvantages may include the following features:

- Similarly to clarifier centrifuges, the separation effect is not distinct;
- Erosion has to be taken into consideration when separating abrasive particles;
- The bottom outlet opening of dewatering hydrocyclones may become plugged especially when the solids concentration of the feed is high;
- Hydrocyclones are not suitable for the separation of flocculent fluid system due to the eddy currents generated in the field of centrifugal forces.

The first patents granted for a gas cyclone (Morse, 1886) and hydrocyclone (Bretney, 1891) are more than a hundred years old. The application of gas cyclones for dust removal has become widespread quickly. On the contrary, the interest of the industry turned to L-S type hydrocyclones only after World War II. The application of commercial hydrocyclones for oil containing L-L phases has intensified even later, only in the seventies-eighties of the last century, and this may be explained by two reasons. Partly by the fact that the water content of crude oil produced from the wells has increased at an ever higher rate. For example, in the United States the annual volume of produced water has reached already 15 billion barrels. This water is the highest volume by-product of the oil industry and – what is more – it is permitted to be released to the environment only with oil concentrations less than 3 mg/liter by environment protection regulations. The second reason has been provided by the ever increasing number of offshore platforms. It was discovered that the operation of traditional gravitational settlers has become unreliable due to movements caused by waves and wind. The installation of large volume settling tank was problematic anyway because of the chronic shortage of space typical of offshore platforms. Hydrocyclones having small space requirements and high centrifugal indices have become more and more parts of the basic treatment technology beyond initial purifying pretreatment. Beyond their suitability for the process a non-negligible consideration is also that hydrocyclones installable with lower capital expenses can partially compensate for the ever higher expenses of production operations.

The flow pattern in a simple cylindrical-conical shell hydrocyclone is very complex and, thus, there is no theory known to this way which would describe uniformly the complex turbulent flows curling downwards along the shell and moving upwards spirally along the centerline. Therefore it is not surprising that the L-L type hydrocyclones used for the removal of water from oil and of oil from water, respectively, have come on the market as commercial products only after 10 to 15 years of R&D work. The details of this widespread research & development work can be well followed in the proceedings of the conferences held on hydrocyclones at Southampton in 1992 and Cambridge in 1996 [1,2].

The development work for improving the efficiency of hydrocyclones, reducing the pressure loss arising in them and identifying new applications by experiments for them is ongoing

even now. More and more researchers deal with the numerical simulation of turbulent flow at theoretical level [3-5]. The purpose of this paper therefore is give a short review of up-to-date de-velopments – including our own research work – beyond outlining the situation of employing hydrocyclones in the oil industry.

L-S type hydrocyclones

Figure 1 illustrates a typical hydrocyclone used for the separation of suspensions with the indi-cation of the dimensions of the main geometrical parameters [6]. It can be seen that the refer-ence basis for all other dimensions is diameter D_c of the cylindrical shell in accordance with the common practice for the application of hydrocyclones.

According to Gusztáv Tarján [7] the hydrocyclone is a hydraulic flow classifier in which the governing fluid flow determining the granulometric composition of the solid phase is the radial velocity component evolving opposite to the direction of the centrifugal force. Ever since the fundamental works of Kelsall [8], Rietema [9] and Bradley [10] most of the publications deal with the clarification of the complex flow conditions evolving in the hydrocyclone even today. The hydrodynamic complexity is enhanced by the fact that the 3D eddy motion is neither isotropic nor axially symmetric and the flow pattern varies even in time due to the recessive movement of the air core formed along the centerline.

The conditions for free settlement will not be satisfied anymore at higher solids concentration. The interaction between particle motions and liquid flow is also among the questions to be clarified.

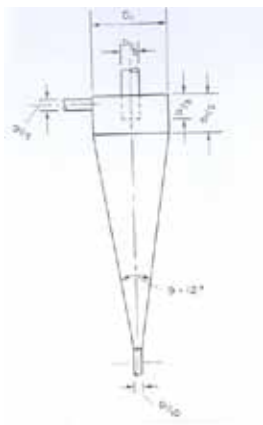

Fig. 1. Dimensioned hydrocyclone

Several researchers [3,5 and 11-13] have undertaken in recent years to describe and treat theoretically the very complex flow pattern outlined on the basis of the development achieved in the field of numerical hydrodynamics: CFD (Computational Fluid Dynamics). The validation of turbulence models has to be performed in every case during the numerical treatment of turbulent flows but this is possible only by using the resultant data of detailed and carefully conducted experiments. At the same time, the validity of any simulation model is limited by the fact that theoretical models can be used only up to the point where the application conditions sat-isfy the threshold conditions of the model.

Description	G-S cyclone	L-S hydrocyclone
D_c, mm	1750	50
ΔP, mm.WC	5	20000
Q_i, kg/h	2160	2500
Limiting particle, μm	25	25
Centrifugal index	9.1	1650

Table 1. Typical data of gas cyclone and L-S hydrocyclone

The source of the remarkable data in Table 1 is Trawinski's paper [14]:
Table 1 shows the typical data of a gas cyclone and an L-S type hydrocyclone. Among the cy-clones with the same 25 μm separation limiting particle size and nearly identical performance the gas cyclone is characterized by large diameter, low pressure loss and small centrifugal index while for the hydrocyclone these values are just reversed: small vessel body and high in-dex ensured by 2 bars feed supply pressure. There is another characteristic difference be-tween the two systems. The driving force of settling, i.e. the density differential of the fluids is lower by an order of magnitude in respect of the hydrocyclone compared to the gas cyclone. These differences are the reason why the design scheme developed for gas cyclones cannot be applied without modification to hydrocyclones.

The Fejes – Tarján textbook [7] contains useful data for the throughput capacity Q_i and the classification or separation limiting size "x" of solid particles for hydrocyclones. Note that "x" (marked as cut size d_{50} in other publications) means the limiting size of particles exiting from the vessel through the bottom and top outlets, respectively, with equal probability.

The high number of test series conducted with the 75 mm diameter hydrocyclone Rietema al-ready mentioned has confirmed that the optimal relative dimensions of L-S type hydrocyclones are as follows [9]:

$$D_i/D_c = 0.28 \quad D_o/D_e = 0.34 \quad l/D_e = 0.4$$
$$L/D_c = 5h/D_c = 0.75 - 1.0 \text{ and}$$
$$D_o/D_u = 1.33\text{-}1.66,$$

where D_i is the diameter of the tangential inlet nozzle, D_o the diameter of the vortex finder pipe, l the penetration length of the vortex finder pipe into the cylindrical chamber, h the length of the cylindrical chamber, L the total length of the hydrocyclone and D_u the diameter of the bottom outlet opening. The author working at Shell research department has demonstrated also more distinct separation can be achieved with a hydrocyclone having 10° cone angle than one where this angle is 20°.

Based on the latest investigations related to hydrocyclone design it can be regarded as proven that the separation efficiency of the hydrocyclone is higher with rectangular cross-section tangential inlet than with circular cross-section inlets as well as that involuted configuration inlets – although more expensive – are better than simple tangential connections.

It may be also be concluded as a rule of thumb [2, 6-7] that the optimal dimensions of hydrocyclones are D_c = 300 - 450 mm and L = 1,000 - 1,500 mm when operated as classifier, D_c < 100 mm when operated for thickening suspensions and diameter 10 - 15 mm for clarifying finely dispersed suspensions and operated as multi-cyclones. Additional information useful in respect of design engineering can be found in the Chemical Engineers Handbook [15]. The particle size range when operated for wet classification is 5 - 297 µm and the usual solids content of the feed is 10 - 60% at 0.35 – 4.2 barg supply pressure.

The linear velocity of the feed stream is generally 10-14 m/sec. At the same time the average residence time is 0.024 – 6.3 sec. The lower value is associated with a 10 mm diameter hydrocyclone while the higher one with larger diameter vessels.

L-L type hydrocyclones

The findings and geometrical optimums stated in the previous section for L-S type hydrocyclones cannot be applied directly to L-L type hydrocyclones used for separating liquids immiscible in each other. The size of the liquid droplets dispersed in the continuous phase is not constant, contrary to solid particles, and – as a consequence – the distribution of the droplets of the fluid introduced into the hydrocyclone is not constant either. The droplets disintegrate, break up and even coagulate sometimes because of the eddy motion developing

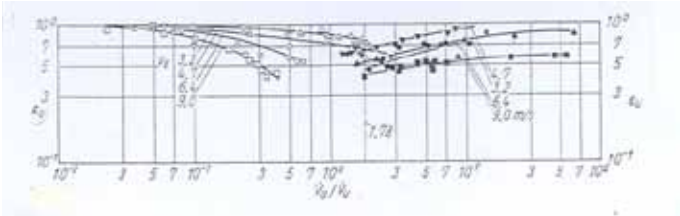

Fig 2. Separation efficiency of 36% water-oil emulsion

after entry and the shear stresses acting due to the high tangential velocities inside the vessel (10-15 m/sec, see [8]).

Bohnet et al have analyzed these features in detail in several publications [16-18]. They have proved by experiments that the liability of the droplets to disintegrate decreases if the surface tension differential between the two liquids or the viscosity of the disperse phase increases.

Analyzing the measurement results shown in Figure 2 supports the finding that the simultaneous clear separation of the light and heavy phases cannot be achieved by a single hydrocyclone. The intersection line of the two sets of curves at X = 1.78 illustrates this. The left-side ordinate (ε_o) indicates the separation efficiency for the light phase exiting through the vortex finder pipe while the right-hand one (ε_u) refers to the heavy phase exiting at the bottom. V_o/V_u values shown along the horizontal axis represent the volumetric ratio of the top to bottom outlet flows. This term

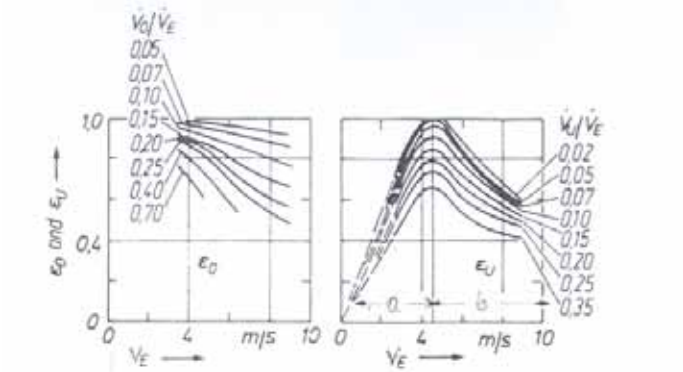

Fig. 3. Curves characterizing the separation of 36% water-oil emulsion

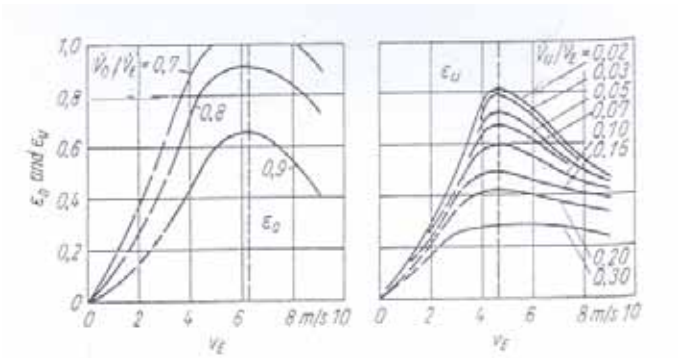

Fig. 4. Separation efficiency of 10% water-oil emulsion

is the inverse value of the "Split" (S) distribution coefficient widely used in the literature about hydrocyclones. The variable in this figure is the v_E inlet velocity. It can be observed in this figure that clean oil begins to exit at the top when $V_o/V_u < 10^{-1}$. At the same time, clean water will be obtained as bottom product at $V_o/V_u > 10^1$ distribution coefficient of volumetric flows. Note that virtually identical figure was published earlier by Bradley [10] for a water / kerosene system on page 185 of his book.

Important conclusions can be drawn also from Figures 3 & 4 where the horizontal axis represents the inlet velocities while the ordinates the compositions of the phases exiting at the top and bottom, respectively, as before. The variable in these figures is now the ratio of top and bottom outlet volumetric flows V_o and V_u, respectively, to the inlet volumetric flow V_E. The term V_u/V_E is otherwise known under the name Flow Ratio (R_f), representing a partial flow ratio, and its interrelation with the split value mentioned above can be defined by the following formula:

$$R_f = S / (I + S)$$

The left-hand diagram applies to ε_o and the right-hand one to ε_u. It can be seen that the separation efficiency of the light phase deteriorates above 3 m/sec inlet velocity practically independently of this parameter. At the same time the efficiency of water separation has its maximum at 4.5 m/sec. Lower velocities here mean the feasibility range of separation but at velocities above the critical value the process changes to emulsification. Figure 4 corresponds to Figure 3 with the only difference that the water content of the emulsion introduced was reduced to 10%. It can be seen in this figure that the critical velocity in respect of oil increased here to 6.2 m/sec since less water has to be removed from the feed having higher oil content. The majority of the water droplets having a lower total mass precipitates of the wall of the shell and simply no water droplets subject to the effect of shear forces remain anymore. As seen in the right-hand figure, the critical velocity in respect of water has not changed: its value remained 6.2 m/sec.

The differing critical velocities make it understandable why the product lists of companies manufacturing hydrocyclones distinguish deoiling and dewatering hydrocyclones.

The development of critical inlet velocities in the case of L-L type hydrocyclones is a novel phenomenon since in the case of L-S type hydrocyclones increasing the inlet velocity improved the separation efficiency and only the higher pressure drop and the associated rise in energy consumption imposed a limitation on the velocity rise at the most. The foregoing indicate also that the critical inlet velocities are lower than the values common for L-S type hydrocyclones. The separation efficiency in the case of L-L type hydrocyclones depends not only on the geometrical dimensions and flow conditions but also on temperatures. The relationship is inversely proportional. Efficiency increases with decreasing temperatures.

The air core formed in hydrocyclones has been investigated by several researchers but a precise explanation for this phenomenon is still not available. The following facts are known for the characterization of air cores.

An air core will be formed inside the hydrocyclone in every case if either top or the bottom outlet is in contact with the atmosphere since the rotational flow velocity near the centerline increases to such a value at which the pressure drop will result in vacuum according to the Bernoulli equation and its value may range from a few millimeters of water column up to 1,000-2,000 mm.WC and this vacuum draws air in from the environment to the core. A core may be formed also with the outlets connected to closed vessels when steam/vapor or gas released from the liquids fills the core. This generally accepted explanation is, however, contradicted to some extent by the paper published by the researchers of Southampton University in 1996 [2]. They investigated in a 70 mm diameter and about 1.8 m long Model Vortoil-F deoiling hydrocyclone (D_o = 2 mm!) to what extent gas dissolved in the liquid, CO_2 in the given case, would expand under the effect of the pressure (vacuum) present in the core. To their surprise they observed that a negligibly little quantity of fine gas bubbles was released from the liquid saturated with carbon dioxide into the core in contact with the atmosphere through the top outlet opening. At the same time, when the diameter of the line connected to the bottom outlet of the hydrocyclone was enlarged and the flow ceased to be spiral, the expansion (release) of dissolved gas became significant. The authors explained this phenomenon by the fluid becoming supersaturated in the hydrocyclone due to spiral flow and this inhibited the expansion/release of gas. The gas-saturated liquid reduced the efficiency of the deoiler hydrocyclone model mentioned but the deoiling operation became stable in the case of a slightly reduced liquid distribution ratio (split). The adverse effect of gas dissolved in liquid or present in free state can be minimized

if the supply pressure is the highest possible and the pressure drop across the hydrocyclone is minimal. Another option is to increase the diameter of top outlet pipe to $D_o \geq 3$ mm.

The diameter of the core is constant in an irregular/unexpected manner along the total height of the hydrocyclone and varies from 0.06 D_c to 0.33 D_c. The higher value is associated with a higher tangential velocity.

As evidenced by the review of related literature on the internet developments related to the dimensions of L-L type hydrocyclones is concentrated to so-called **mini-hydrocyclones**. The D_c = 10 - 25 mm diameters units numbering several hundreds are installed in multi-cyclones for various applications. Two solutions have become common in practice. According to one central feed is distributed radially among the hydrocyclones installed in inclined positions. According to the other solution the multi-cyclone is built like a shell-and-tube heat exchanger. The shell design allows also the use of high supply pressures. At the same time, however, the entire equipment has to be disassembled upon the failure of any cyclone.

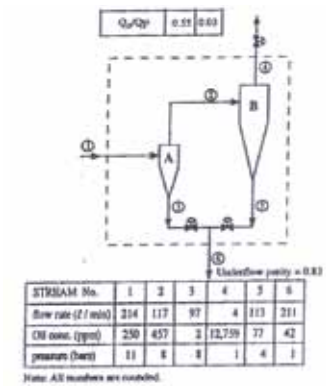

Fig. 5. Connection scheme of two-body hydrocyclone

In parallel with the concentrated research work carried out at Southampton University for the development of the Vortoil type hydrocyclone wide-ranging research activities were ongoing also at Michigan University in the United States. 20 different types were investigated in the course of many years of research work. Their new technological solution related to mini-cyclones is shown in Figure 5. This figure shows the connection scheme of two-body hydrocyclones [19]. By the deoiling equipment according to this figure the initial 250 ppm oil content of the feed supplied at 12.84 m^3/h volumetric flow rate could be reduced to 42 ppm while the pressure dropped from 11 barg to atmospheric. The oversized throughput of equipment **A** consisting of 61 mini-cyclones (diameter 10 mm) was twice as much as that of the single 76 mm diameter hydrocyclone **B** thus the two-body design was able to deoil even the higher water volume encountered upon the inundation of the same quality. The density difference between petroleum and water was 150 kg/m^3 and the difference in surface tension 35 dyn/cm. The cone angle of hydrocyclone **B** was 10° and that of the mini-cyclones 6°. A so-called tailing pipe having the same diameter as the outlet opening was connected to the bottom outlet of both types for flow stabilization but – naturally – with different lengths: 684 mm and 135 mm, respectively. No liquid droplet disintegration could be observed at volumetric feed rates below 0.12 m^3/h.

In respect of geometric ratios the D_i/D_c ratio for L-L type hydrocyclones is the same as that recommended for L-S type equipment. The choice of l/D_c = 0.33 – 0.4 is advised for the intrusion of the vortex-finder pipe and a shorter cylindrical section – i.e. $h/D_c < 1$ – is more advantageous for lower pressure loss. D_o/D_c = 0.13 for dewatering hydrocyclones while this value is 0.04 for deoilers. D_u/D_c = 0.18 – 0.26 ratio is recommended for bottom outlet openings. The diameters of deoiler hydrocyclones manufactured at the present are 75 and 100 mm, respectively. These are capable of removing 98% of 30 μm size oil droplets during operation. The cone angles of dewatering hydrocyclones varies from 10° to 20° while this angle range for deoilers is 2° to 10°. According to the information given in references [1,2] it is more advantageous to introduce the liquid mixture not through one but through two tangential pipes installed opposite to each other.

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APC optimization project in Fractionation unit of Algyő Gas plant

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Abstract

In Algyő Fractionation plant (Hungary) of MOL Hungarian Oil and Gas Company Emerson Process Management has executed an APC (Advanced Process Control) optimization project in order to reduce energy consumption. The specialists of Emerson have reviewed the control structures, evaluated the pre-step tests, and worked out the Functional and Detailed Designs. After the build phase of process models the APC blocks were started columns by columns. Emerson experts defined the main possibilities of optimization (reduction of column pressure and reflux ratio within contracted limits of product qualities). MOL production experts have been heavily involved in final optimization. The APC project has been completed by the training of operators and finally a Post Audit has been executed.
The APC system resulted in a precise quality control, therefore product quality giveaway has been minimized and hot oil usage has been reduced. As a consequence, fuel gas usage in furnaces has proved to decrease, and CO_2 emissions decreased as well.

Összefoglalás

Optimalizálás végrehajtása fejlett szabályozási módszerek (APC) alkalmazásával az Algyői Gáztechnológia gázfrakcionáló üzemében
A MOL Nyrt. Algyői Gáztechnológiáján a Gázfrakcionálóban APC (Advanced Process Control) rendszer került beüzemelésre, az Emerson Process Management kivitelezésében, mely jelentős energiamegtakarítást eredményezett. Az Emerson szakemberei felülvizsgálták a szabályozási struktúrákat, elvégezték és értékelték a lépés-teszteket és kidolgozták a funkcionális és részletes terveket. Az APC-model kidolgozása után, toronyról toronyra indult a rendszer. Az Emerson szakértői meghatározták a fő irányokat a működés optimalizására (torony nyomások csökkentése, a reflux-arány csökkentése, a termékminőségek a szerződésben meghatározott határértékek közelében való tartása). Az optimális eredmény eléréséhez a MOL szakértői hatékony segítséget nyújtottak. Az APC-projekt végén megtörtént a kezelők oktatása, majd egy post-audit során kimérésre került az energiamegtakarítás, mely a rendszer üzemeltetésének az eredménye.
Az APC rendszer lehetővé tette a pontos termékminőség szabályozást, így az „ajándék-minőség" gyártásának minimalizálását. Továbbá jelentősen csökkent a tornyok forró olaj felhasználása, ennek következtében csökkent a csőkemencékben elégetett fűtőgáz mennyisége és így a CO_2 kibocsátás is.

Introduction

In 2006, in MOL Algyő Gas plant Fractionation unit (Hungary) a succesful LoopAudit was performed. This resulted in significant energy saving so we decided to explore further

optimization opportunities given by APC (Advanced Process Control). In 2008, MOL launched an energy saving project in Algyő Gas plant for the implementation of APC in order to improve process control and optimize energy consumption.

The first step was to change RS3 DCS for DeltaV in order to run APC on controllers and to make the system redundant.

Overview of the plant

Algyő Gas plant includes 2 trains of distillation columns, 3 columns in each train (Figure 1). The gas feed is supplied to both trains via a low temperature extraction unit and an oil absorption process. The distillation products are propane, propane-butane mix, iso-butane, normal-butane, iso-pentane and normal-pentane. These are drawn off as top/base products from different columns in each train. The quantity and the quality specification for each of these product streams changes with demand. Gas fractionation capacity is 56 tons/hour. The two trains are integrated with each other. The feed input for fractionation is considerably fluctuating, hence high reflux ratios are applied to maintain good products qualities.

Hot oil is heated in 4 furnaces. We also recover waste heat of the gas turbines of low temperature extraction units.

Fig. 1. The fractionation unit

DISTILLATION COLUMN OVERVIEW

There are five control loops on a column (Figure 2). Columns are heated by reboilers. The column temperature control loop is a cascade loop with hot oil flow. Pressure is controlled by top product outlet valve. Top product is cooled by air coolers. Reflux drum is a flooded vessel. Temperature of reflux is controlled by the frequency controller of air coolers. Reflux is pumped to the column through a flow control valve. Level control is established at base of column.

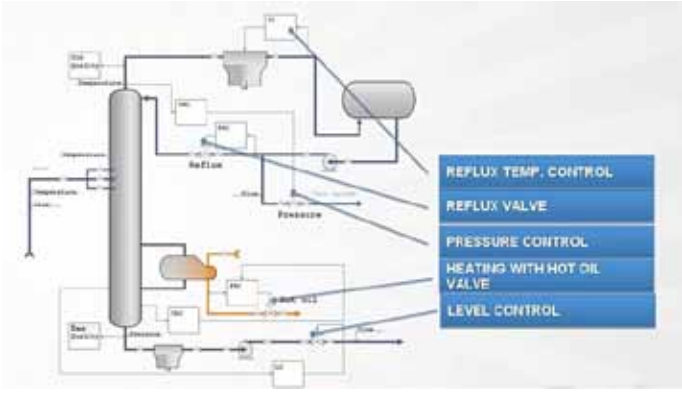

Fig. 2. Distillation column overview

Optimization goals

By reducing hot oil usage we save fuel gas in furnaces as well, and reduce CO_2 emissions (Figure 3). Electric energy can be saved at the air coolers. Main control objective of APC is to reduce pressure of columns. The lower the pressure is the lower the temperature needed to separate products. Lower reflux ratio decreases the hydrocarbon flow on top of column, so less air cooler power needed for condensation process. Product qualities are constraints against decrease of pressure and reflux ratio. APC approaches qualities from upper values with little margins through a continuous manipulation of controlled process values.

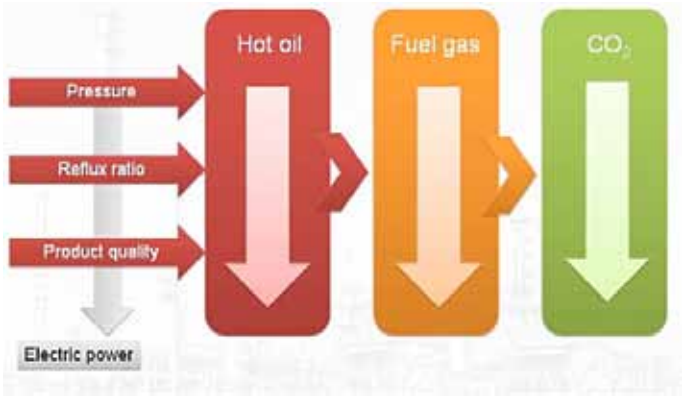

Fig. 3. Optimization process using APC

The main challenge was to improve energy efficiency. At the start we planned to save

734,000 Euros on fuel. Product quality and operational stability are important. The operators over-heated and over-refluxed the columns to maintain the correct quality of the products and keep operation very safe. Instead of the acceptable 95%, the product's purity was 99% (product quality giveaway). Using APC we can safely produce 95% purity with small safety margin.

Pre-requisite updates / repairs

As one of the first steps, accepting APC expert's early recommendations some modification has been implemented in instrumentation and control system of the plant. We built in 6 new pressure transmitters in column's top and base, three new valves, and three new gas chromatographs in order to provide all technical circumstances for best APC controls.

Solution – APC controller structure

Emerson designed, implemented and commissioned the APC application. Its SmartProcess® Distillation Optimizer has been installed and commissioned on 5 out of the 6 distillation columns. SmartProcess® applications are Emerson's pre-engineered Multivariable Predictive Control (MPC) templates. MPC includes DeltaV PredictPro, the Predict Pro is a function block, what contains the algorithm of multivariable control. Inferential composition analysis configured for key components in product streams as pressure compensated values.

The operators find easy to understand and use Emerson's solution. The APC project has resulted in a huge saving at our company. Some of the benefits we realized very early, at once after implementation.

Figure 4 shows the general structure of inbuilt predictive controllers from point of view of process. The controlled parameters are as follows: condensation Pressure Compensated Temperature (PCT, CV1), base and middle temperatures (CV3 and CV2). Disturbing factor is feed flow (DV1), limiting factor is product quality (CNTR1 and CNTR2). Interfering parameters are reflux flow (MV1), hot oil flow (MV3) and pressure (MV2).
The input parameters are feed temperature, feed flow, top quality, base PCT, top PCT and condensation PCT. PCT signals are obtained

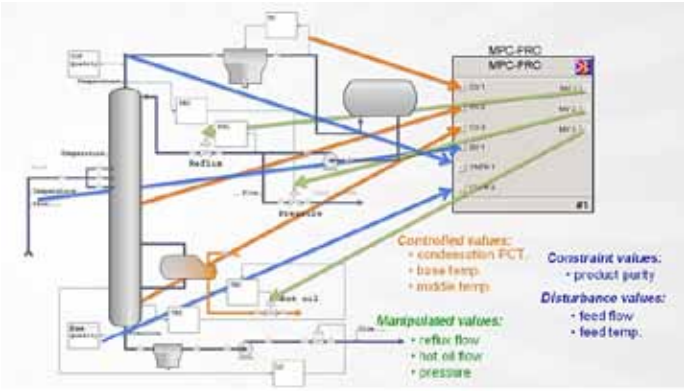

Fig. 4. APC structure

by inferential calculations in order to get the pressure compensated temperatures. The output manipulated values are remote setpoints to hot oil flow, reflux flow, and top temperature.
APC changes the column pressures. In general, distillation columns work better at lower pressures and so energy consumption can be reduced. The low limit of pressure will change depending on the outside temperature and rainfall. APC will reduce pressure as low as possible for the current conditions. When pressure of the column changes so do the tray temperatures. This effect can be predicted and so compensated for. This is the idea behind pressure compensated temperatures. The way to read a pressure compensated temperature is "the temperature the tray would have been, had the column been at its design pressure".

All components of APC run in DeltaV controller. APC predictive controller fits to DCS (Distributed Control System) structure. As the controller is redundant, the APC application is redundant as well. This also applies to the operator interface, because APC has the same DCS system functions, programmable in the same environment, works on the same operator interface. There's no need for independent OPC-linked (Object-linking and embedding for Process Control) workstation. The operators' training is easy in the same environment, the whole system can be upgraded at the same time, so it provides a simplier and faster solution. These facilities yielded for MOL a cost-effective solution in all phases of the APC project.

THE OPERATOR INTERFACE

Operators can modify the APC values: they can adjust the limits of controller's and main set point parameters. They can also check the processes and turn on and off APC. Laboratory samples of the products are taken in every two hours. Laboratory data are put in APC on this interface, too (Figure 5). The APC uses these data to

correct the inferential calculations.

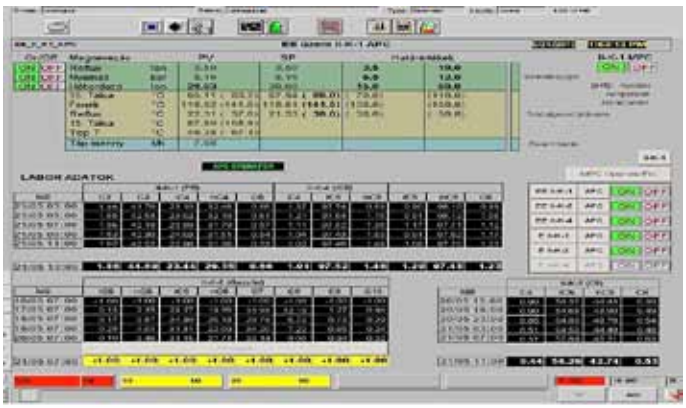

Fig. 5. The operator interface

Results

At the end of the implementation the project was followed by a post-audit. We compared the base line parameters with the optimized parameters set by APC. We calculated the benefit of the optimization.

As Table 1 indicates hot oil demand (calculated as hot oil / feed mass flows) decreased by 12 to 64%.

	E II-K-1 (C3)	E II-K-2 (C4)	EE II-K-1 (PB)	EE II-K-2 (C5)	EE II-K-4 (iC5,nC5)
Average (10 years) hot oil	2,75	2,05	9,06	4,15	16,00
/feed rate before APC (t/t)					
Hot oil/feed rate with APC (t/t)	1,57	1,68	3,28	3,64	11,63
Saving (%)	43,10	18,13	63,78	12,17	27,31

Table 1. Hot oil / feed mass flow rate before and with APC application

The parameters of the distillation columns have changed significantly (Table 2).

	Pressure (bar)		Reflux flow (t/h)		Hot oil flow (t/h)	
	No APC	APC	No APC	APC	No APC	APC
E II-K-1	15,3	9,5	13,5	8,5	33,5	22,0
E II-K-2	7,1	4,5	9,5	7,5	20,5	15,0
EE II-K-1	12,0	6,5	12,0	3,5	98,0	25,0
EE II-K-2	2,7	1,0	13,5	6,0	44,0	28,0
EE II-K-4	2,5	1,0	35,0	15,0	75,0	35,0

Table 2. Main parameters of the distillation columns without and with APC

As a consequence, the actual fuel gas usage has been reduced by more than 50%. The estimated energy saving accounts for 15%. We didn't install APC on the sixth, iso-butane column because MOL has decided to install new gas chromatographs on that column.

The 50% energy saving in equivalent natural gas saving means 1.2 million Euros/year. Pre-project saving goal was 734 000 Euros/year. This means a very quick return of investment for MOL.

Fuel gas volume reduction was not only due to APC related changes on fractionation columns. We also managed to decrease the temperature of EE train furnaces by 25 degrees. The pressure of oil absorbtion unit's desorber column decreased by 1.2 bar and the desorber's reflux flow decreased by 18 t/h.
What is more:

1. With APC the plant control is able to solve problems without operator action. This means reduced operator workload
2. APC improved process stability
3. Operators have real-time indication of product quality.

APC requires less frequent but more professional human interference. Optimization functions built in APC serve the most economic operation of the columns. We managed to decrease energy consumption by 40-50% through changing working parameters. Reducing hot oil usage means 40-50% less fuel gas consumption in furnaces. CO_2 emissions of Algyő Gas plant has been reduced by 6.5%. Lower reflux ratio and reduced temperature at the top of columns results in electric energy saving. The project resulted in very high benefit even without last column hence MOL accepted and closed the

project with satisfaction. We are working on to launch next APC projects.

"It's a long way to the top" – secrets of the project

We must admit there were debates between APC engineers and local experts. Emerson originally suggested a middle temperature controlled cascade-regulation. This principle is not applicable to the special product purity conditions in Algyő. In the new structure as a compromised and best solution the reflux ratio is controlled from upper-middle temperature and the hot oil volume for the reboiler is controlled from base temperature at some columns.

Having a well performing loop-audit, we did not really understand why the Emerson's APC-team started working with step tests.

When APC was switched on for the first time almost all parameters oscillated. Then Emerson's staff left us face to face with APC. We operated the system according to APC-team's directive and to our knowledge as best operators. Oscillations stopped soon.

We showed the returning Emerson team the results. We said: so far APC taught us and now it's time for APC to learn our best operator practice.

Both the technologist and APC had to learn. We have learned the APC's way of thinking: pressure and temperature reduction. APC worked out how to achieve these targets.

We agreed to apply instead of the designed version a new structure and it works perfectly. In the designed version columns' hot-oil flow was controlled by middle temperature.

In the new structure the columns' hot oil flow is controlled by base temperature and reflux flow is controlled by middle temperature. There is an exception. On isomeric separation the column's hot oil flow and reflux flow are controlled by signal (product quality) from process chromatograph and operators enter the required product quality only.

Emerson's engineers made a perfect job. Without this project we wouldn't understand how well our plant can perform, much better than the 30 year old designed parameters. Thank them for their enthusiastic job.

Final words

So far we have mainly realized a reduction in the fuel gas consumption. APC results in electric power saving only in the autumn, winter and spring months. Implementation of a new cooling system allows APC to optimize the parameters of operation during the summer months. This would result in a very quick return of investment (from saving of cooling water, electric power, fuel gas). We intend to develop and expand the system to achieve 60% energy saving in Algyő Gas plant.

Acknowledgement

The authors are thankful to Emerson's staff for reviewing this article.

Keywords: Advanced Process Control (APC), distillation, pressure compensated temperature

Reviewed by János Tamás

SIL project in Slovnaft Bratislava Refinery

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Abstract

Fulfilling of functional safety standard EN IEC 61 511 requires technical and organizational measures and financial resources as well. Till now, only big companies start to understand importance of functional safety for overall Process Safety Management.
Project of functional safety implementation in Slovnaft Refinery was split to more steps. Article is about our experiences from implementation steps and outputs of the project.

Összefoglalás

A SIL project a Slovnaftnál
Az EN IEC 61511 funkcionális biztonság standard teljesítése műszaki és szervezési intézkedéseket, valamint pénzügyi forrásokat igényel. Ezidáig csak a nagy társaságok kezdik megérteni a funkcionális biztonság fontosságát a teljes folyamat-biztonság menedzsmentben.
A Slovnaft Finomításnál a funkcionális biztonság projekt megvalósítása több lépésre tagolódott. A közlemény a megvalósítási lépések tapasztalatairól és a project eredményeiről szól.

Introduction

Safety is in mutual interest of the whole MOL Group.
The letter of law requires reducing of the threat of dangerous events to minimum.

Since 2006 MOL Group refineries have been involved in the project known under SIL abbreviation (Safety Integrity Level). The project was focused on the safe operation of refinery and petrochemical technology. It arose from the requirements of EU directive known under SEVESO abbreviation, which was introduced into the legal order of Slovak Republic by the law on prevention of serious industrial accidents. This law requires identification of all dangers connected with the operation and acceptation of such measures so that the risk connected with the dangerous events will be on the acceptable level.

Reduction of risk to the acceptable level

There are several ways how to fulfil the letter of law. The requirements of law for refineries are mentioned in STN EN 61 511 standard "Functional safety - Safety instrumented systems for the process industry sector". The standard has about 250 pages. It is relatively complicated and the application of its requirements in practice is sometimes difficult. The standard deals with functional safety. Functional safety can be understood as the set of technical-organizational measures to reduce the risk to the acceptable level, namely for those dangerous events which are connected with the controlling of technological processes. The functional safety is a part of the overall safety relating to the process and the BPCS which depends on the correct functioning of the safety systems and other protection layers. Dangerous events are those

which have an impact on:
- Health/lives of people,
- The environment,
- Technological equipments (loss from the repairs and manufacturing).

Dangerous events may arise not only from the point of view of process control, but also from the point of view of other aspects (missing railing, isolation, etc.); therefore the functional safety is the part of overall safety which is in Slovnaft company covered by PSM project (Process Safety Management).

The standard defines the so-called safety life-cycle of technological equipment. We can divide it into several phases (Fig. 1):
- Analysis of the risk, allocation of safety functions and specification of requirements,
- Design, assembly and putting of SIS (Safety Instrumented System) into the operation,
- Operating, maintenance and management of changes of SIS,
- Decommissioning of SIS (liquidation).

In Slovnaft Bratislava Refinery Project it was divided into two parts:
- Reviewing of existing safety systems and the proposal of measures,
- Realization of the proposal of measures.

Yokogawa company became the winner of the tender for the first part in 2006. The project required involving of the workers of production units, technologists and maintenance engineers, therefore the first step was training of the management and the workers who were to take part in the project.

Risk analysis

The risk analysis was divided into two steps: first for the technological furnaces and then for the rest of the technology. It was performed under the supervision of certified engineers for the functional safety in the form of HAZOP (Hazard and Operability Analysis) study. The analysis of risk has been performed on 51 manufacturing units and it was finished at the beginning of 2010.

It is mentioned in literature [1] that from 34 cases of industrial accidents which were analysed worldwide, improper specification of managing or safety system (Fig. 2) caused accidents in as many as 44% of cases. This shows that the analysis of the risk is crucial for the proposal of management and safety system.

The analysis performed in Slovnaft showed that it is necessary to introduce new safety functions. These safety functions are to be implemented in the protective layers (Fig. 3). One of the protective layers is an electronic/electrical safety system shown in the figure as SIS. It is necessary to define SIL value (Safety Integrity Level) for the safety functions implemented in SIS. Each safety function may have different SIL value.

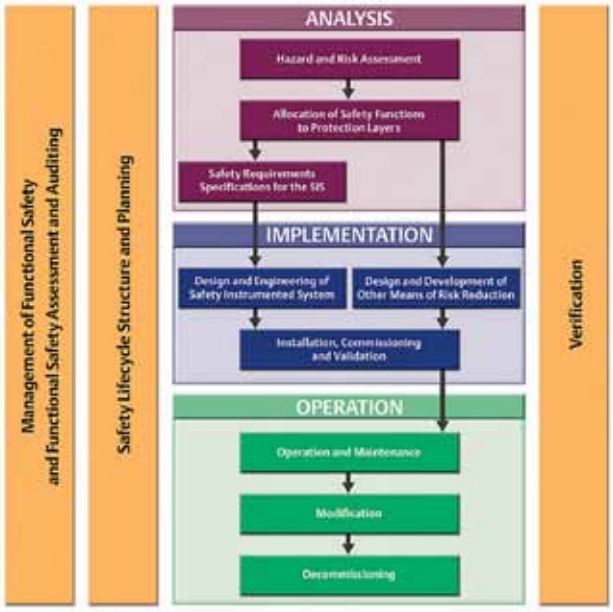

Fig. 1. Safety life-cycle (SLC), STN EN 61511 standard

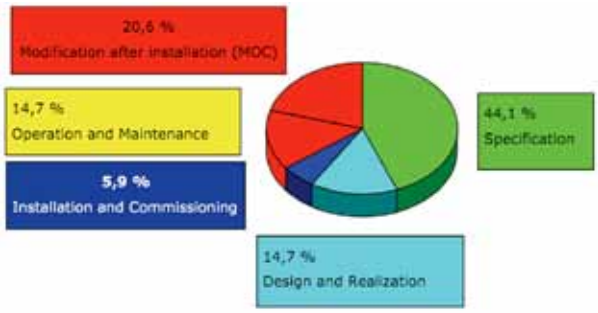

Fig. 2. Distribution of the causes of arising of accident in the world

The most important feature of SIL is its reliability. Reliability is expressed through probability of safety system failure on demand. The relationship between safety integrity level (SIL) and the reduction of the risk is shown in Table 1. Safety systems reduce probability of dangerous event occurrence, however they do not eliminate its consequences. So the electrical / electronic safety systems belong to preventive protection layer.

Two Slovnaft maintenance engineers were trained in functional safety within the project and they obtained TÜV functional safety certificates.

SIL	Probability failure on demand (years)	Risk reduction (SIL reciprocal values)
4	≥ 10-5 to < 10-4	> 10 000 to ≤ 100 000
3	≥ 10-4 to < 10-3	> 1000 to ≤ 10 000
2	≥ 10-3 to < 10-2	> 100 to ≤ 1000
1	≥ 10-2 to < 10-1	> 10 to ≤ 100

Table 1. Relationship between safety integrity level and reducing of the risk

In the project, proposal of modifications for existing safety systems were prepared and approved. The proposal will create the basic data of the second part of the project - design, assembly and putting SIS into operation.

Fig. 3. Example of protective layers in which the safety functions are to be implemented

Tender for the second part of the project

Realization of the proposal of approved measures will be the objective of the second part of the project. Separate tender will be announced for this part. Validation will be performed after the realization of the second part of the project, which is the inspection of the whole system in terms of the standard, whether the system fulfils all requirements:

- whether all safety functions were realized
- whether they are in compliance with the safety requirements of SIL.

Validation and verification are important concepts defined by the standard. Verification gives an answer whether we proceeded correctly in each step, while the validation gives an answer whether we realized correct system.

Great importance of maintenance

Probability of the failure of any component of the safety function inreases in the course of time, therefore it is necessary to perform so-called proof tests – i.e. verification of their functionality. The aim of the maintenance in the operation of the safety system is to ensure operational capability of safety functions according to the requirements of SIL level. Selfdiagnostics of the devices and final elements enables to reduce total maintenance cost and contributes significantly to the fulfilment of this aim.

Part of the first phase of the project was to define the requirements for the maintenance, i.e. which equipment is to be the object of the performance of maintenance and how often it is to be the object of the performance of the maintenance.

Directive on functional safety

The objective of the first phase of the project was also harmonization of the performance of trip tests in the Refinery. Two meetings were held, the object of which was acquaintance with the performance of trip tests at present and the agreement how to perform trip tests for technological furnaces and compressors. Elaboration of the local regulation of functional safety was the result of this.

To approach to the optimal state

Safety systems contain also override swithes for the needs of maintenance. The switches are to be activated only for the period necessary for the repair of some component of the safety function. If it is not possible to repair the component in the acceptable period, it is necessary to take technical-organizational actions and to put the safety function to the operational state as soon as possible.

Also the changes or modifications of machines and technological equipments are closely associated with the operation. In an optimal state the number of modifications is minimal. This fact is again closely associated with the quality of reviewing of the risk to consider all

possible aspects of the danger. However, it is not possible to achieve this optimal state in practice, because of for example:

- modern technologies are too complicated,
- limited knowledge of people performing HAZOP,
- shortage of finances.

We all have our role in the safety

MOL Group, including Slovnaft Refinery understand the impact of functional safety on the overall safety of PSM and together with the certificates ISO 9000 and 14000 constantly attempt to improve in the area of safety. Personal engagement of each employee is necessary in this process.

Reference

[1] Jozef Vass: Functional Safety aspects. AUTOMA, 02, (2003).

Keywords: functional safety, SIS, IEC 61 508, IEC 61 511

Reviewed by Vojtech Bartakovics

Typical problems of start run up period after turnaround

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Abstract

At the following production units: Residual Hydrocracker, Vacuum Gasoil Hydrotreater, Atmospheric and Vacuum Distillation 6, Fluid Catalytic Crack, Alkylation, ETBE, Sulphur Recovery, Amine Recovery, Sulphuric Acid Regeneration, Sour Water Stripping and Field Flares of Slovnaft Refinery in 2010 were realized planned turnarounds. The aim of this article is to summarize general problems, which occurred after the units' startups. The general problem description and summary should help in the future to avoid this kind of problems and should shorten the planned turnarounds or shutdowns.

Összefoglalás

A nagyjavításokat követő üzemindítások tipikus problémái
Jelen közlemény célja a Slovnaft Finomító több termelő üzemében (EFPA Blokk) végrehajtott tervezett nagyleállásokat követő, üzemindítások közben előfordult általános problémák összegzése. Az összegzés és a problémák okainak felderítése segítheti a jövőben az ilyen jellegű problémák elkerülését és a tervezett nagyleállások, vagy leállások idejének rövidítését.

Introduction

In Slovnaft refinery the turnaround (TA) cycle is 4 years. In period of May – June 2010 planned TAs of following production units: Residual Hydrocracker, Vacuum Gasoil Hydrotreater, Atmospheric and Vacuum Distillation 6, Fluid Catalytic Crack, Alkylation, ETBE, Sulphur Recovery, Amine Recovery, Sulphuric Acid Regeneration, Sour Water Stripping and Field Flares were realized.

All required works and materials have been provided by subsidiary corporation Slovnaft Montáže a Opravy a.s. (SMaO). The TA was realized based on the legislation requirement (expert inspections, expert tests and authority tests) of classified technical equipment (CTE), equipment repair cycle and required equipment cleaning.

Main aims of TAs are:

- to retain the functionality of production unit, retrieve its technical state to maintain safe and reliable operation and availability until next TA in 2014
- to ensure inspections and tests of CTE to be carried out so that all statutory requirements according to the Public Notice are observed
- to realize check and replacement of pipelines, check of static pressure vessels by measuring of wall thickness as a request of insurance company
- to ensure observance of HSE rules during the TA by all contractors
- realization of CAPEX projects.

The scope and budget of the TA 2010 was approved by Executive Board in December 2009.

Unit startup in general include following steps:

- check of equipments (instrumentation completeness, valves and fittings, pressure safety valves, field instrumentation, regulation, etc.)
- removal of blinds inserted during unit preparation to TA based on the blind list made by unit
- inertisation of equipments, tightness and pressure tests with nitrogen
- check of rotation equipment (instrumentation, oil filling, cooling, etc.)
- drying of furnace refractory
- catalyst loading to reactors
- catalyst sulphiding
- trip tests
- filling of equipments with hydrocarbons
- catalyst heating
- feed introduction
- stabilization of production unit operation to achieve the defined product quality.

During these operations continuous presence of persons realizing TA to eliminate failures which occurs during the startup period is required.

The TA 2010 in Slovnaft was atypical due to an incident happened at Residual Hydrocracker unit (leakage at flange of ebullating pump) on 9 April and caused the whole TA block earlier realization, see Table 1.

Unit	Planned date of unit shutdown	Planned date of end of TA	Modified date of unit shutdown	Modified date of end of TA
AVD 6	05.05.2010	20.06.2010	21.04.2010	06.06.2010
RHC	01.05.2010	29.06.2010	10.04.2010	09.06.2010
VGH	01.05.2010	09.06.2010	21.04.2010	30.05.2010
FCC	01.05.2010	26.06.2010	21.04.2010	19.06.2010
ETBE	05.05.2010	21.06.2010	26.04.2010	12.06.2010
SHU	05.05.2010	20.06.2010	05.04.2010	31.12.2010
ALK	05.05.2010	20.06.2010	26.04.2010	11.06.2010
SAR	03.05.2010	06.06.2010	23.04.2010	22.05.2010
AAR	08.05.2010	25.05.2010	08.05.2010	25.05.2010
SRU 200	02.05.2010	17.05.2010	02.05.2010	17.05.2010
SRU 100	10.05.2010	25.05.2010	10.05.2010	25.05.2010
SWS	03.05.2010	26.05.2010	27.04.2010	21.05.2010
PH bL98	09.05.2010	22.05.2010	14.05.2010	27.05.2010

Table 1. Influence of RHC unit incident to TA 2010 earlier dates (technology unit abbreviations are explained at the end of the article)

General problems

The overview of all problems which occurred during the TA 2010 and startup period is shown in matrix in Table 2. There you can see that the most frequent problems during the TA which caused also problems during startup are connected with the preparation phase of TA. As it was mentioned in introduction the TA 2010 realization started earlier than it was originally planned and usually the delivery time is very crucial, it has great influence on planned works and causes higher stress at the units. This article is dedicated to problems connected with unit startup therefore it is only mentioned to understand the complexity of TA. Most typical problems are summarized below.

SCREWS

Most common and probably most frequent failure before startup or during startup of the unit is that contractor forgets to or slightly tightens screws at valves, flanges, man holes, etc. If this failure is found during pressure tests with low pressure nitrogen it is easy to repair by tightening up the screws. When pressure tests are made at high pressure it is a little bit longer because at first pressure have to be released and after that it is possible to tighten screws. Here must be mentioned that this can be tricky because there is no guarantee that after tightening up screws it will be good due to the possibility of damaged or unsuitable seal. In such a case it is necessary to dismantle the flange which means to release pressure to atmospheric, check and replace seal, check surface of flanges and in case of necessity clean them. After completing the pressure test should be made again.

Next problem with tightening flanges is when contractors use wrong bolts. There are cases that contractor uses former bolts which should be replaced by new ones or uses unsuitable ones. Both cases can lead to flange leakage under higher pressure and temperature conditions. See rows 9 and 14 in Table 2.

BLINDS

Next frequent failure is caused by forgotten blinds in pipeline. Basically it can be said that when contractor installs blinds in co-operation with the unit's staff there is a list of all blinds which contains time and date of installations and removing. Mistake can occur when contractor has in his work order also execution of official pressure test. In this case contractor chooses place for each blind by himself and he is also responsible for removing all of them. Sometimes happens that contractor forgets removing some blinds even when he declares that all works has been concluded according requirements. This can be found out during final check before startup of unit and this can be usually solved quickly without any significant complication. When contractor forgets to

Activity	RHC	VGH	AVD-6	FCC	ETBE	ALKYL.	PH bl.98	SAR	SRU	AAR	SWS
1. Purchasing process											
2. Monitoring and commitment of realized works											
3. Order on the place after finished works by contractor											
4. Cranes											
5. Wet cleaning works											
6. Mechanical cleaning works											
7. Organizing of works and contractor's workers											
8. Tube bundles remover											
9. Usage of wrong seals and other materials (bolts, etc)											
10. Leakages on the pipes and valves after TA											
11. Purchasing through Corporate Service											
12. Advance payment											
13. Toilets and places for smoking											
14. Tightness tests during startup											
15. Forgotten blinds after tightness test											
16. Contractors do not know the scope and character of works											
17. Expert skills of contractor's workers											
18. Observance of HSE rules during the TA											
19. Spare parts delivery											
20. Inspection of realized works by contractor											
21. Claiming of realized works											
22. Realization of subtle changes and individual projects											

Color coding

	works shifted by at least 2 days or equivalent financial loss
	works shifted by at least 1 day or equivalent financial loss
	works shifted by less than 1 day or equivalent financial loss
	operative solving of problem

Table 2. Matrix with evaluated common problems at each unit

remove blinds without so called "ears" it is very difficult to find them during final check. Such a blind can be found only during pressure test or startup and this causes significant time delay from several hours till several days due to prescribed speed of pressure release and again pressurizing the system. During TA 2010 period there were considerable problems with forgotten blinds at AVD6 or FCC, see row 15 in Table 2. Particular attention should be paid to flanges during starting up the unit when temperatures of all equipments are rising to process parameters. Flanges can be tight in cold state but at higher temperature metal dilatation takes place of bolts, flanges and also pipelines. This can lead to leakage and such a flange must be tightened again, as it is written in previous chapter. Therefore it is necessary to check all equipments during startup to prevent fire occurrence and use only blinds with so called "ears" and/or painted with signal paint.

FITTINGS

Next sources of leakage are fittings. Large amount of fittings are dismantled and sent for maintenance during TA. Maintenance of fittings is made usually by external company. Therefore it is necessary to mark the fitting so it would be installed at a same place. Sometimes happens that after repair of fitting it is not tight. In some cases bolt tightening can help during operation but this depends on process conditions, material, pressure, temperature and tightening must be done very carefully. Fitting sealing (packing) is to be performed on a place, without dismantling, but fitting must be depressurized in closed position. During RHC startup after TA 2010 pressurizing of NG pipeline was carried out 4 times due to leakage on fittings of gas and liquid quench to 2nd and 3rd reactors. Altogether there were found 4 leaking fittings. After 1st depressurizing 2 of them were repaired, 3rd fitting was repaired at 2nd try and the last one finally after 3rd depressurizing. Problem was caused by fault metal sealing rings. This led to a 2-day delay in the startup of the unit. Learning point of this situation is that the metal sealing rings must be replaced for new ones during every fitting maintenance.

The wrong fitting cannot be always identified prior to startup of the unit. Sometimes leakage occurs when the equipment reached process parameters. Similar case happened at FCC unit. After the successful start of the unit a leakage occurred at feed inlet fitting to reactor. This fitting was repaired during TA. Next fitting started to leak at steam generator during standard unit operation which caused slowdown of the unit. See row 10 in Table 2.

Next problem with fitting is wrong seal material or damaged seal which is used again. This problem is connected with lower expertise of contractor employees. These employees are mostly for the first time in a refinery and they don't have any personal experience with such a work, see rows 7, 16 and 17 in Table 2.

Such a deficiency occurred at FCC unit where in local level indicators wrong seals were used. Also wrong seals were used in fittings at heat exchangers and some other equipment; similar problems were also identified at other units. Damaged seal was found at suction side of FCC circulation compressor which must be used in case of emergency shutdown. At RHC unit an ebullating pump seal leakage was found leading to emergency shutdown due to possible fire formation. Investigation identified that the seal was replaced at TA 2006 and in June 2009 it was reused without geometry and ring checks. This problem caused that TA 2010 was started 3 weeks earlier than planned. Based on this experience it is now prescribed that at every dismantling of the ebullating pump new seal ring must be used.

AUTHORITY APPROVAL

Less frequent but also significant problem is realization of investment projects which are connected with approval by state authorities. Investment projects in refinery are mostly long-term, wide nature and TA planning is mostly adjusted by them. Approval period prescribed by law is not possible to keep in the frame of TA period. Therefore this must be kept in mind prior to starting the investment projects and it is important to reach an agreement with state approval authority for a sooner approval term. An example can be taken from AVD6 unit where we replaced burners in heaters F1 and F2. TA was finished on 1 of June 2010. Approval from state authority for usage of these burners was obtained on 4 of June 2010. Prior to finishing the TA unit employees performed pressure tests by nitrogen and then were waiting for state approval. When approval was received crude oil was introduced to the unit and burners were started. Before the approval unit could not start the burners and performed steam-air decocking. This kind of situation can cause a problem in the future and leads to undesirable losses.

WET CLEANING

Water remaining in equipment after cleaning processes also causes frequent problem during startup of the unit. Problems occur while heating up equipment and water presence leads to pressure fluctuation, pump cavitation, material foam creation, wrong level measures, etc. Water presence is very dangerous in equipments where vacuum is created prior to startup, water from other equipment can be transferred to the vacuum part. Water can be removed by venting with air, perfect draining, etc; water remains are removed by heating the equipment or by circulation of material through material tank where water is separated. See row 5 in Table 2.

IMPURITIES

Clogged filters represent a very typical problem of startup. Filters are clogged with mechanical impurities mainly at pump suction side. This problem is connected with cleaning work quality but cannot be fully eliminated. Therefore during the startup a maintenance employee should be ready to dismantle and clean the clogged filter while unit employees start hot standby pump.

LIGHTS

In the frame of TA works on electricity are performed as well. Sometimes it is forgotten to plug some part of outside light to electric network. This can be solved very quickly by shift electrician.

FAILURE REPAIR AFTER TA

Handling of some small failures identified during startup means small problem mainly from organizational point of view. After TA the unit is submitted for startup and all failures found during startup must be removed or repaired according to a new requirement which has described some process of approval. This problem can occur also when removing some inspection reviews or supplementary works out of TA work list.

ORDER ON PLACE

Not so big but common problem is cleanness of the unit after TA. TA contractors in final phase of their works are mainly focused on finishing their works and often forget to clean the workplace. Not used or not needed material, forgotten scaffoldings, bags with material put close to hydrants, on roads, left on platform and obstructing operation staff leads to delay in unit startup from safety and fire protection point of view. See rows 3 and 13 in Table 2.

Specific unit problems

SULPHUR RECOVERY UNIT

During startup of Sulphur Recovery Unit (SRU) a problem has been realized at control valve of its Superclaus part. This valve was plugged with sulphur which solidified during shutdown of the unit. This was solved by several hours duration heating. During pre-startup activities high H_2S and NH_3 gas creation led to HV Turbo blower capacity problems.

After the startup second SRU unit had no flow of produced sulphur from 1st siphon due

to plugged outlet pipeline which led to higher pressure in equipment. It was necessary to release small amount of H_2S and NH_3 gases to flare but this has no impact on the other units startup procedures. Process was stabilized within 24 hours. Higher creation of H_2S and NH_3 gases led to several problems with capacity of HV Turbo blower together with unit capacity based on higher processing.

SULPHURIC ACID REGENERATION

Right after feed introduction to Sulphuric Acid Regeneration (SAR) unit problems with high voltage of 1st and 2nd section of electrostatic filter occurred. These problems have been eliminated after 3 days. Later equipment pressurizing problems occurred with indication of flame detach in burning chamber, frequent feed introduction problems, not sufficient air amount, its flow decrease and decrease of sulphuric acid production took place. Thus, SAR unit must be after 24 hours of operation shutdown. When opening the equipment it was found that tubes and tube surface in waste heat boiler were covered by impurities. After cleaning and startup sulphuric acid production was restored. Problems with pressurizing again took place and SAR unit must be shutdown again based on same reasons as previously. Analyses of impurities from heater and consultation with SAR and Alkylation unit licensors didn't result in any explanation of the unit status. Investigation team was nominated to solve this problem. Startup deadline of SAR unit was prolonged due to inspection findings. It was found that glass condensator refractory was damaged at the bottom part and must be repaired in presence of glass condensator licensor. When Alkylation unit has TA it is necessary to count with more complicated startup of SAR unit due to sediments from Alkylation unit cleaning, which caused fouling at SAR unit as it is written thereinbefore.

Conclusions

Finally, it must be mentioned that TA of such a complex of units cannot be realized without any problems. The main message of this article should be how to prevent or minimize all known problems even though they may occur. It must be mentioned that during TA 2010 there were not any injuries, any fire and any unexpected event from HSE point of view.

Keywords: problem, shutdown, turnaround, startup

Reviewed by Martin Bičan

Abbreviations of technology units

Technology description	Abbreviation
Residual Hydrocracker Unit	RHC
Vacuum Gasoil Hydrotreating	VGH
Atmospheric and Vacuum Distillation	AVD6
Fluid Catalytic Cracking	FCC
Alkylation	ALK
ETBE	ETBE
Sulphur Recovery Unit	SRU100
Sulphur Recovery Unit	SRU200
Amine Recovery	AAR
Sulphuric Acid Regeneration Unit	SAR
Sour Water Stripping	SWS
Field Flares	PH


RANGL

How to calculate Mechanical Availability (MA)

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Abstract

The efficiency of a refinery is demonstrated by its availabilities (mechanical, operational, on-stream). The availabilities are depended on magnitude and type of the shutdowns. The availability can be calculated for any unit. Three type of mechanical availability are calculated: monthly mechanical availability, cumulated mechanical availability, annual expected mechanical availability. The target MA can be planned for the next duration safely.

Összefoglalás

Hogyan számoljuk a mechanikai rendelkezésre állást
Egy finomító teljesítőképességét a rendelkezésre állás értékek (mechanikai, üzemeltetési, on-stream) mutatják. A rendelkezésre állások az üzemkiesések nagyságától és jellegétől függnek. A rendelkezésre állás bármilyen egységre kiszámítható. A mechanikai rendelkezésre állásnak három típusát számoljuk: havi mechanikai rendelkezésre állás, kumulált mechanikai rendelkezésre állás, valamint éves várható mechanikai rendelkezésre állás. A mechanikai rendelkezésre állás következő időszakra vonatkozó célértéke biztonsággal meghatározható.

Introduction

What is meant by availability of the Solomon? The availability of Solomon is a calculation method of such an international benchmark system, which from the point of view of the efficiency of a refinery can be measured.

The list of the required input data and exact calculation method are given by Solomon. Applying algorithm the availability as a conclusion is reached. The purpose of study is to submit the method of calculation and planning of mechanical availability.

Solomon ratio

By Solomon the availability of a refinery can be calculated in the following equation [1]:

$$A[\%] = 1 - \left[\frac{\sum_{i=1}^{units} \left[T_{shutdown,i} \cdot K_i \right]}{T_{duration} \cdot \sum_{i=1}^{units} K_i} \right] \quad (1)$$

where

- K_i – weighted kEDC of the units by Solomon. The kEDC™ (kilo Equivalent Distillation Capacity) gives the importance of an actual unit in the availability of a refinery,
- $T_{shutdown}$,i [hours] – aggregated shutdown time of an actual unit within investigate duration,
- $T_{duration}$ [hours] – investigate duration.

The availability can be given for any investigate duration (for example the monthly mechanical availability of a refinery can be calculated by its actual events). The investigate duration may be also more years.

Three type of availability are determined [1]:
- Mechanical Availability™ (MA[%]),
- Operational Availability™ (OA[%]),
- On-stream factor™ (On-stream[%]).

The mechanical availability attaches to the planned and unplanne d maintenance activities, till the operational availability applies to the technological and authority shutdowns. The on-stream factor can measure the functional continuity of the refinery.

In the following parts, let us sum what kind of shutdown time-periods belong to the availabilities:
- At the mechanical availability the shutdown time is the total maintenance activities of turnaround period, breakdown period and slowdown period (performance of the unit less than 75 % of its nominal process) of the investigate duration: (2)

$$T_{shutdown,MA} = T_{turnaround} + T_{slowdown} + T_{breakdown}$$

- At the operational availability the shutdown time is the aggregation of period belonging to MA, and period of technological activities (catalyst regeneration, catalyst replacement, furnace decoking, operator error, maintenance of utility system) and period of authority activities (environmental testing, pressure vessel inspection, other regulatory inspection) in the investigate duration: (3)

$$T_{shutdown,OA} = T_{shutdown,MA} + T_{technology} + T_{authority}$$

- At the on-stream factors the shutdown time is the summary of period belonging to MA and period belonging to OA, and period of the other external reasons (economic, process unit incident, off-site incidents, other external) in the investigate duration: (4)

$$T_{shutdown,on-stream} = T_{shutdown,MA} + T_{shutdown,OA} + T_{other}$$

All shutdowns are had to take into account at the calculation of availabilities independently of their planned or unplanned state.

Table 1 gives the relationship between shutdowns and availabilities [1].

Each availability shows the refinery efficiency from a given point of view, still the most important indexes are the mechanical and operational availability without slowdown.

Comparing the shutdown periods it can be seen, that the following fundamental is true for tree type of the availabilities: (5)

$$MA \geq OA \geq \text{on-stream}$$

It can be seen in the equation (1), that a refinery would be able to reach the biggest and the most characteristic availability, if the planned shutdowns were reduced to the necessary level and the unplanned shutdowns were cut to the smallest values with the appropriate maintenance strategies.

Type of shutdown (BD - breakdown SD – slowdown)	*Type of availability*		
	MA	*OA*	*On-stream factor*
Turnaround	x	x	x
Non-turnaround maintenance BD/SD	x	x	x
Technology / authority BD/SD		x	x
Other BD/SD			x

Table 1. Relationship between BD/SD and availabilities

Calculation of Mechanical Availability

To quantify the above, see the following 3 unit-groups and 10 units belong to an imaginary refinery. Let us note that the calculation method of the operational availability and on-stream factor is not described because calculation method of the mechanical availability is based on the same principles.

For the basic items of MA calculation method are given in Table 2 for years and in Table 3 for months of 2010. Items are the imaginary values; these are identical with the reality in order of magnitude.

EDC is the primary normalization basis for Solomon's competitive metrics. This is a key normalization value for benchmarking [1].

The weighted kEDC values are found in the tables, which show the complexity and capacity of the units. In percentage the relative weight kEDC shows the importance of unit in proportion to whole refinery.

Shutdowns of a unit can be caused by planned or unplanned events.

Turnaround is a planned shutdown. Usually, cycle of a turnaround is 4-5 years and duration

of a turnaround is 1-2 months. By Solomon, in the calculation of availabilities the extensive reduction effect of turnaround for the mechanical availability is not allowed to treat in as a concentrate item. Whereas the real turnaround values are had to divide in uniform distribution depending on the investigate duration into years (see Table 2 Column turnaround) or months (see Table 3 Column turnaround). So the data in these columns of the tables are shows that, as if in a given year (Table 2) or in a given month (Table 3) the units had got quasi-values of turnaround for yearly or monthly. Turnarounds always belong to the preventive maintenance strategies and activities. By Solomon, absolute past of turnaround values (cycles and durations) are taken into consideration for calculation of the availabilities. Before effective turnaround achievements, the cycle and duration of planned turnarounds are represented hesitancy.

Corrective maintenance activities are caused by unplanned breakdowns or slowdowns. In Tables 2 and 3 practical values of the unplanned events are specified. Refinery summaries can be found at the lower part of tables.

Using (1) and (2) equations for calculation of mechanical availability, the issues of Figures 1 and 2 can be represented.

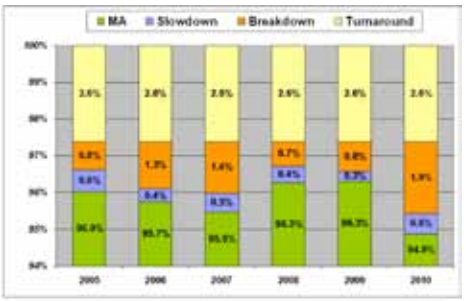

Fig. 1. Annual Mechanical Availability of a refinery (2005-2010)

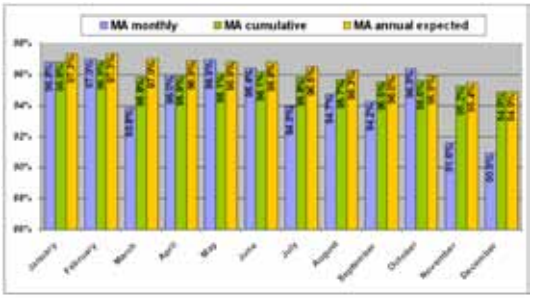

Fig. 2. Mechanical Availability of a refinery by the month (2010)

Figure 1 shows what kind of unplanned or planned shutdowns reduced mechanical availability from the perfect level (100%). The effects of turnarounds are the same in years. Only the unplanned events are changed together with mechanical availability.

Tree types of mechanical availabilities are given in Figure 2:

				Planned			Unplanned											
				2005-2010			2005		2006		2007		2008		2009		2010	
Group	Unit	kEDC	relative kEDC	turnaround cycle	turnaround duration	Turn-around	Break-down	Slow-down	Break-down	Slow-down	Break-down	Slow-down	Break-down	Slow-down	Break-down	Slow-down	Break-down	Slow-down
				[month]	[hours]	[hours/year]	[hours]	[hours]	[hours]	[hours]	[hours]	[hours]	[hours]	[hours]	[hours]	[hours]	[hours]	[hours]
Group01	Unit01	200	25.6%	48	960	240	50	100	225		223		45	48	52		100	74
Group01	Unit02	50	6.4%	48	1680	420	200		128	12	10	48	128	73	47	58	286	5
Group01	Unit03	20	2.6%	48	720	180	350	45	45	48	125	128	75	128	129	49	174	41
Group01	Unit04	10	1.3%	48	1056	264	12			73			362		230	159	23	15
Group02	Unit05	150	19.2%	48	480	120	36	78	169	57	63	73		79	25		247	4
Group02	Unit06	100	12.8%	48	1440	360		55			79	18	158	12	79	27	41	45
Group02	Unit07	25	3.2%	48	1200	300	89			6			36	28	258		54	139
Group03	Unit08	125	16.0%	48	576	144	112		67	105	12	83			146	78	258	75
Group03	Unit09	70	9.0%	48	1200	300	56	15	27		256	78	72		23		245	47
Group03	Unit10	30	3.8%	48	432	108		32		10	368	38	128	14			100	25
Summary		780	100.0%			2436	905	325	661	310	1136	466	1084	382	989	371	1528	470
BD+SD summary							1230		971		1602		1386		1360		1998	

Table 2. Annual planned and unplanned shutdown by sorting of unit in 2005-2010

				2010		2010		2010		2010		2010		2010		2010		2010		2010		2010		2010		2010	
				January		February		March		April		May		June		July		August		September		October		November		December	
Group	Unit	kEDC	Turn-around	BD	SD	BD	SD	BD	SD	BD	SD	BD	SD	BD	SD	BD	SD	BD	SD	BD	SD	BD	SD	BD	SD	BD	SD
			[hours/month]	[h]	[h]	[h]	[h]	[h]	[h]	[h]	[h]	[h]	[h]	[h]	[h]	[h]	[h]	[h]	[h]	[h]	[h]	[h]	[h]	[h]	[h]	[h]	[h]
Group01	Unit01	200	20													100			74								
Group01	Unit02	50	35					230				56									5						
Group01	Unit03	20	15	4		12				158					41												
Group01	Unit04	10	22											23											15		
Group02	Unit05	150	10				4																			247	
Group02	Unit06	100	30								45			41													
Group02	Unit07	25	25	13	128								7				4	41									
Group03	Unit08	125	12							75														258			
Group03	Unit09	70	25																	245			47				
Group03	Unit10	30	9																			100					25
Summary				17	128	12	4	230	25	158	45	56	7	64	41	100	4	41	74	245	5	100	47	258	15	247	25
BD+SD summary				145		16		305		203		63		105		104		115		250		147		273		272	

Table 3. Monthly planned and unplanned shutdown by sorting of unit in 2010

- Monthly MA: such a mechanical availability that is calculated from actual monthly shutdowns, and the given month is characterized.

Monthly MA can be changed from month to month. Investigate duration ($T_{duration}$) is the day number of the given month. The monthly shutdowns ($T_{shutdown}$) are aggregated from the monthly events (breakdown, slowdown and monthly turnaround).

- Cumulated MA: such a mechanical availability that is calculated from the aggregated shutdowns from the prime of the year until the given month.

In the investigate duration the cumulated MA can be decreased or increased depending on the actual monthly MA in proportion to previous month cumulated MA. In January the cumulated MA equals with monthly MA, if the January is the first month in investigate duration. Investigate duration ($T_{duration}$) is the day number of the cumulated months. The shutdowns ($T_{shutdown}$) are aggregated to base on events (breakdown, slowdown and monthly turnaround) from the prime of the year to the actual moth.

- Annual expected MA: such a forecasted yearly mechanical availability that is calculated from the aggregated shutdowns (for a whole year) in any given month.

In any given month, the annual expected MA shows that, if from the actual month the shutdowns were only planned shutdowns (turnarounds) and unplanned shutdowns (breakdown or slowdown) were not happened at all, than at the end of the year how much the yearly MA would be. In the investigate duration the annual expected MA can be decreased or fixed in proportion to previous month annual expected MA. In December the annual expected MA equals with cumulated MA. Investigate duration ($T_{duration}$) is day number of the year. The shutdowns ($T_{shutdown}$) are aggregated from the day of unplanned events (breakdown, slowdown) until the actual month, and the day of planned turnaround events for whole year.

The values of Figure 1 and Figure 2 can be calculated for unit-groups and units.

Planning of Mechanical Availability

The target MA such a yearly MA, that can be performed in given conditions to the end of the next investigate duration. The iteration method is demonstrated in the following flowsheet (see Figure 3).

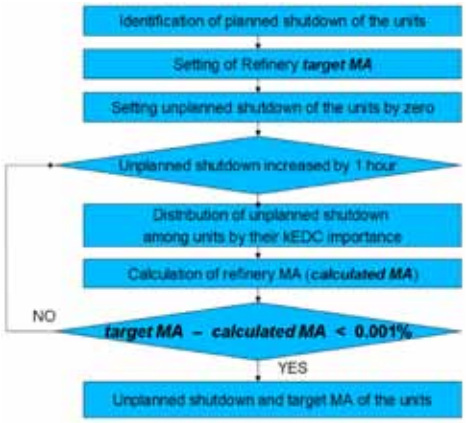

Fig. 3. Flowsheet of MA planning

Based on Table 2 the following steps are for planning of MA:

- For units the planned shutdowns correspond with annual turnarounds.
- The target MA of refinery is adjusted, which is based on the real data of the previous durations (years). According to duration of 2005-2010 (see Figure1) the mean value of mechanical availabilities is modelled: 95.78%. Let us assume that the refinery can achieve the 95.5% MA in the next year (2011) safely. It is important to note, that the target MA can be arbitrary. In determination of the target MA, it can be necessary the careful analysis of the actual historical data of the previous durations, with the purpose of, what the probability of the earlier shutdowns would be able to occur in the next duration. Farther it is practical to take business-prospects into account, otherwise it should be estimated that if the higher target value was achieved, would the profit-productive capability of the refinery be really increased?
- Unplanned shutdowns of all units are adjusted zero as an initial condition.
- Entering to the iteration cycle, the whole unplanned shutdown of the refinery is increased with 1 hour in each cycle. The refinery unplanned shutdown is distributed among the units according to their kEDC weighting. More spare time belongs to the more weighting unit (more importance), and less weighting unit has got less spare time (less importance). A well-known problem: what the unplanned shutdowns distribution (among the units) is based on. What would be the best principle of distribution? We

used the weighting kEDC, but the average of unplanned shutdowns of units can be taken as a basis.

- Calculated MAs of the refinery and the units are determined.
- The unplanned shutdown is to be increased and new iteration cycles are to be initiated, while the difference between target MA and calculated MA would be less than a specified error, which is very small (for example 0.001%).
- When the above condition is true, the target MA and unplanned shutdown of units are obtained for the next investigate duration at the calibrated refinery target MA. The solutions are given in Table 4.

Unit	kEDC	Turnaround cycle	Turnaround duration	Turnaround	Shutdown (spare time)	MA
		[month]	[hours]	[hours/year]	[hours/year]	[%]
Unit01	200	48	960	240	261.8	94.3%
Unit02	50	48	1680	420	65.4	94.5%
Unit03	20	48	720	180	26.2	97.6%
Unit04	10	48	1056	264	13.1	98.8%
Unit05	150	48	480	120	196.3	96.4%
Unit06	100	48	1440	360	130.9	94.4%
Unit07	25	48	1200	300	32.7	96.2%
Unit08	125	48	576	144	163.6	96.5%
Unit09	70	48	1200	300	91.6	95.5%
Unit10	30	48	432	108	39.3	98.3%
Refinery					**1021**	**95.50%**

Table 4. Target MA and spare time of the units in 2011

In the next points the resolutions of Table 4 can be explained:

- In 2011, the refinery can reach the estimated 95.5% MA with yearly 1021 hours unplanned shutdowns (spare time). Unplanned shutdown of the refinery is such a spare time, which is a maximum that the refinery can "use" for a year. More unplanned shutdown outputs the non-performance of target MA.
- If the units achieved the own target mechanical availabilities (did not exceed their spare times), for the refinery the 95.5% target MA would be true.

In the next step the above iteration is performed for the different refinery MA target, where the space is 0.5% (see Figure 4.). The unplanned shutdowns (spare time) are illustrated in percentage and hours.

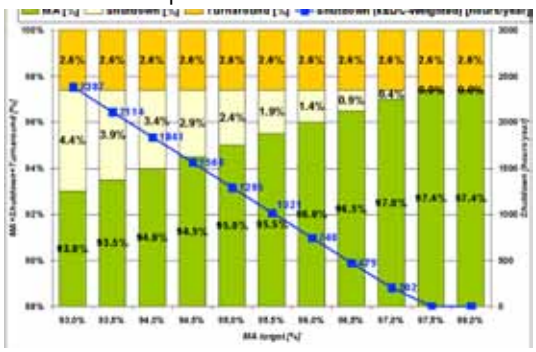

Fig. 4. Connection between refinery MA and spare time

Conclusions

1. Refinery efficiency is determined by its availabilities, that are depended on magnitude and type of the shutdowns (planned, unplanned breakdown and slowdown).
2. The following equation is always true for the availabilities of Solomon:

   MA ≥ OA ≥ on-stream
3. Refinery would be able to reach the biggest and the most characteristic availability, if the planned shutdowns were reduced to the necessary level and the unplanned shutdowns were cut to the smallest values with the appropriate maintenance strategies.
4. Tree types of mechanical availability can be identified: monthly mechanical availability shows the prompt monthly value, cumulated mechanical availability gives an aggregated value from the prime of the year to a concrete month, and annual expected mechanical availability defines the other aggregated value to the end of investigate duration (usually year-end).
5. For the next investigate duration such a target mechanical availability can be calculated and it can be achieved to the year-end of next duration, if the magnitude of its unplanned shutdowns is given by the experiences of previous years.

Reference

[1] Fuels Refinery Performance Analysis for Operating Year 2008 – Solomon Associates (including proprietary trademarked key metrics: Mechanical Availability, Operational Availability, On-Stream Factor and EDC). www.SolomonOnline.com

Acknowledgement

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Keywords: Mechanical Availability™ (MA), Operational Availability™ (OA), On-stream Factor™, Breakdown (BD), Slowdown (SD), Equivalent Distillation Capacity EDC™, monthly MA, cumulated MA, annual expected MA, target MA

Reviewed by János Németh (head of refinery maintenance)

Mrs. Dezső Hegedüs

(1948-2011)

On 3 January 2011 Mrs. Dezső Hegedüs, born Éva Varga, a former director of MOL Refining and Marketing Division, Logistics Organization, a former colleague respected and appreciated by many of us, died after a short, but very severe period of illness.

She was born in 1948 in Békéssámson, a tiny village in the south-eastern part of Hungary. She got her degree of chemistry at the Szeged University. In 1972 she started her career at Duna Refinery (Százhalombatta, Hungary), and it was her first job. Her first activity was in the field of labour and plant organization, then for almost seven years the research laboratory was her usual place of work. In this period she took part in start-up of new plants, which had been constructed in Százhalombatta. At the turn of the years of 1982/83 she became head of the Gasoline Blending and Storage Plant, which job she had for 10 years. That time she was the only woman in charge of plant manager at Duna Refinery. In the early 1990s she got commissioned to supervise the technical field of reconstructing the Hungarian fuel storage terminals. With an approval given to the project of investment she was transferred to the organization of Investments – with the aim to supervise the work. In 1995 and 1996 she was the project manager of a job made with the co-operation of an outside advising firm: its aim was to increase efficiency. This large-scale activity of screening and analysing was the basis for creating Logistics, and as of 1996 until 2004 Mrs. Dezső Hegedüs was its first director. This new organization, set up along the most up-to-date principles of the world, integrated the assets and experts of storage, loading/unloading and transportation required for feedstock supply and sales. Her tasks were to provide for the operative control of supplying the refineries of MOL with feedstock; the inventory management of Hungarian and imported hydrocarbons; the tasks of storage and transportation; organizing and supervising services given to customers in conformity with the requirements of commercial contracts; and operating the systems of logistics with optimal costs and capacities.

In 2001 she did her utmost to control the work of preparation, made in order to introduce SAP R3 within the Refining and Marketing Division. She considered it really important to start using the new system in mid 2002 without violating any interests of the company or the customers, either. "It was an almost superhuman effort to start using the system in earnest … we could correct the faults while the system was in use," once she said in an interview made with her.

After bidding farewell to the organization of Logistics she controlled the due diligence of the INA system of logistics, then – already

after her retirement – the construction of the bio-diesel plant in Komárom (Hungary) and its start-up. She also gave help in making the storage of motor fuels for strategic stockpiling optimal, as an adviser.

She was considered a strict and exceedingly firm leader. However, she was also consistent and always considered her colleagues' human characters. She had a special gift to find the most proper positions for people within the organization, so that they give the best performance, and motivate others to do their best, too.

In a former interview she said: "I like the work of building, because it is an exceptional feeling to see the results of creation. I am still proud of the scene of my former job, the terminals which even bear comparison on the international level."

Mrs. Dezső Hegedüs' professional career of four decades, commitment to the oil industry, activities as a manager, open an honest relationship with her colleagues, and correct co-operation with outside partners are exemplary for all of us.

We shall keep her in our memory.