Conceptual Design of Natural Gas Facilities

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INTRODUCTION

Malaysia is experiencing an increase in gas production, indicated by an increasing number of gas fields supplying fuel and raw products to the market, and the development of regional markets and infrastructure to cater for the demand, of which the Trans-ASEAN Gas Pipeline (TAGP) is a good example. This and the current volatility in crude prices has generated an interest in the public as to the nitty-gritty of natural gas production.

The production of natural gas (NG) is an excellent field where various engineering skills can be demonstrated. The engineering concepts and skills are typically categorised into two: upstream, where the gas is extracted from the ground and basic separation and conditioning is performed; and downstream where the gas is further processed to provide end users with the products that they demand. These two activities tend to happen remotely from one another, as upstream activities happen where the product is, and downstream happens near where the users are, or at least where it can be sold to users. The two are connected by pipelines.

HYDROCARBONS

Natural gas is mostly composed of hydrocarbons, that are molecules made up of a carbon backbone with hydrogen atoms surrounding it (Figure 1). Hydrocarbons are categorised into families to make descriptions easier. For our purposes, we are interested in alkanes (only single bonds between carbon atoms), and specifically in methane (one carbon atom) to butane (four carbon atoms), and lump together all the types of molecules that have more carbon atoms.

This grouping helps us identify the composition of some of the familiar (and not so familiar) products made from natural gas (Table 1). There are also trends that follow the increasing size of the hydrocarbon molecules, namely that the longer (or 'heavier') ones are more likely to form a liquid, have a higher boiling point, density and heating value, and other properties that can be used either to set commercial terms, or to use in designing gas processing facilities.

Table 1: Component of various commercial gas mixes

	LNG	CNG	NLG	LPG
Methane	•	•	.	.
Ethane	•	•	•	.
Propane	•	•	•	•
Butane	•	•	•	•
Heavier than Butane	•	•	•	.
Uses	Transport Gas			Cooking Gas

GAS PROPERTIES

Below are defined some physical properties that are taken into account when negotiating or setting a gas sales contract.

Heating Value

The most common use of natural gas is as a fuel. Therefore, the buyer has an interest in ensuring that the gas has combustion properties suitable for her needs. A typical metric used for this purpose is the gross heating value. It provides an indication of how much energy is released upon burning a given amount of the seller's gas, whether on a mass (per kg) or volume (per standard m^3) basis. An example of such a specification is 35 MJ/m^3.

Wobbe Number

In addition to using natural gas as a fuel, the seller might have a specific application in mind, for instance as furnace fuel or fuel for a fired heater. These equipment have burners which may respond differently to different mixes of gases, even though they have the same heating value. A parameter that determines the compatibility of natural gas with the burner, or more specifically the burner nozzle is the Wobbe number. It is defined as the gross heating value divided by square root of specific gravity.

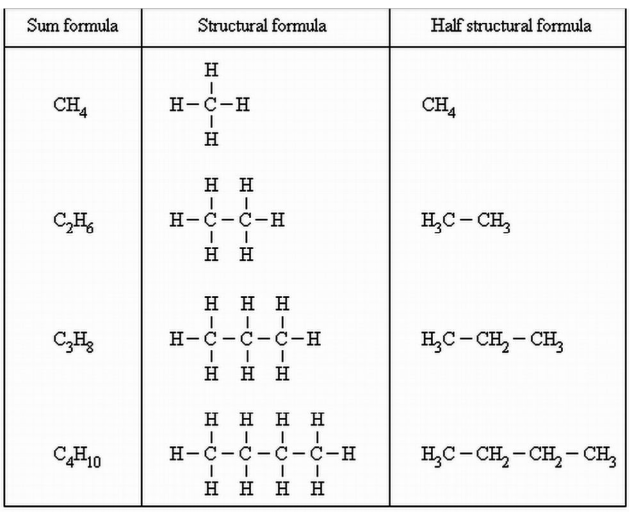

Figure 1: Hydrocarbon structure

Water Dew Point

Gas is transported from the production site to the processing facilities via a pipeline. As the pressure and temperature drop along the pipeline length, water vapour may condense out of the gas and form a free liquid. Liquid water and any condensed hydrocarbon may form hydrates, which resembles ice, but forms at a higher temperature (Figure 2). These hydrates form on the surface of piping, and can build up to physically block the process. The effect of hydrate formation ranges from limiting product throughput due to forming a constriction, worsen control by affecting the response of control valves, to causing damage and raise safety concerns due to a hydrate plug suddenly coming loose of the piping walls and colliding at high speed into other parts of the plant, damaging or failing equipment.

Hydrates form only when there is liquid water. Therefore, to eliminate the risk of hydrate formation, the amount of water vapour in the gas must be limited such that it does not condense out at the lowest transport (pipeline) operating temperature. An example of such a specification is 7lb/MMscf, which at 1000psi only starts to form liquid water droplets at 32°F.

Hydrocarbon Dew Point

The heavier components of natural gas (heavier than butane) may also condense from the gas as it travels along the pipeline. The buyer may not want to handle processing this liquid, and would request that the seller guarantee that above a given temperature, no liquids will form (drop out) from the gas.

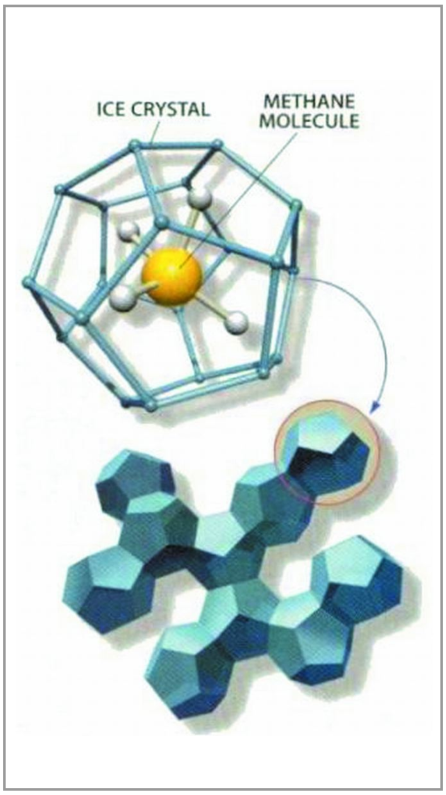

Figure 2: Schematic of hydrate

Contaminants

Natural gas produced from the ground has other components other than hydrocarbons. These gases do not burn (no heating value) and as such are not sellable. In addition, the most common gases (carbon dioxide and hydrogen sulphide) form acids when dissolved in liquid water, causing a corrosion concern in pipelines if there is free water drop out. To reduce the risk of pipeline corrosion, the seller has to limit the amount of carbon dioxide and hydrogen sulphide in the gas, typically 2% vol and 4ppm vol respectively. There are also health hazards to consider. Carbon dioxide is an asphyxiant, and hydrogen sulphide a poisonous gas in small quantities.

FACILITY DESIGN

Prior to designing individual unit operations, a conceptual plan of the facilities must be made. Following is a list of parameters that need to be considered.

- ***Design Conditions***: Upstream facilities have to be designed to cater for the life of the producing field. This tends to be different from downstream or petrochemical facilities, where there is a limited change in inlet condition. For upstream facilities, this may involve predicting changes in the well fluid temperature, pressure, gas composition and liquid to gas production ratios. Each of these changes needs to be considered, and the economical and practical considerations of producing these different states have to be evaluated. This might result in a design that will cater for the worst conditions that can be thrown at it, or a modular design where equipment will be installed and modified to handle the current phase of the production.

- ***Design standards***: The engineer tends to have a lot of tools in her toolbox, especially when it comes to doing detailed design of the facilities. She needs to be aware if certain methods are mandatory, and what the hierarchy is in case of a conflict. For example, it could be that the following standards are arranged in a decreasing order of precedence: government (Malaysia Law, PETRONAS guidelines), Company (PETRONAS Carigali), Design Company, International Organisations (ISO, API, IP). Other criteria that spices up the design challenge is to take exception to some standards, or agree that the most restrictive standards apply. If the design is for an overseas asset, then a foreign country's standard may need to be applied.

- ***Delivery conditions***: it goes without saying that the customer is always right. Hence, the engineer needs to ensure that the customer's delivery terms are met throughout the life of the asset, or at least put in milestones where the delivery conditions may be negotiated.

- ***Reliability***: one of the constraints imposed by either the engineer's management or the buyer is reliability and uptime, which is typically quoted as percentage of time the plant is able to meet the delivery conditions. Reliability can be improved by introducing a measure of redundancy, for example 2 compression trains, where each can cater for the full design flowrate, or extra fans in coolers, so that routine maintenance will not cause a bottleneck Another way is to purchase more reliable equipment. In case equipment does become available, it may be prudent to design or purchase equipment which can be locally supported rather than requiring jetting in expatriate expertise. This may reduce downtime should a failure occur, or at least reduce the cost of support.

- ***Operational cost***: The mantra of the design team is "in time, under cost." What can be forgotten in this mental state is that the facility does need to be operated by someone, and some items that may seem trivial are a major upset to the man in the field. For example, monitoring of individual vessel flowrates may be essential to troubleshoot problems, but it becomes an impossible task if the only flowmeter supplied is on a common header. Another example is insufficient capability to reroute or bypass flows in the case of one unit operation becoming unavailable.

- ***Operability***: Upstream gas production facilities tend to be located in offshore locations. What tends to be forgotten is that gas fields cover vast areas of acreage, and there may be an attempt to gather all associated production equipment in one location for ease of surveillance, control and maintenance of equipment, or have a cluster of discrete sites with only one producing well which may not be visited by staff for days at a time. This type of decision has to be made upfront, looking at the economics of the project, and designed accordingly. If the decision for many remote unmanned sites is determined, then the engineer has to design the site to be remotely operated and monitored. An example of an option that might be considered is more automation to select and open wells are to be produced. Site power options may need to be considered, either solar power or thermoelectric generators, which use production gas to produce electricity, or taking power of the national grid. Safety system configuration also needs to be considered, as standard practice is to restart a facility only after company staff are onsite to assess the cause of a safety-related shutdown. It may be that a risk analysis may determine that a remote reset for some situations is acceptable.

PROCESS MODELLING

After the high level design concepts are defined, they will need to be applied to raw data that can be manipulated and packaged into a form that discipline engineers can use for detailed design. One key step in this generation process is the construction of process models. This task falls on the process engineer, and happens very early in the design process. Note that a process engineer in the oil and gas industry is a different beast than that in say the manufacturing or electronics industry. 'Process' here means the thermodynamic processes, not assembly line or manufacturing processes.

Process models are models that contain the thermodynamic properties of the asset modelled. It may consist of inlet gas streams, unit operations, control schemes, extra calculation models and the ability to extract information from any part of the process of interest. Nowadays models tend to be constructed on computer and manipulated interactively, though for unit operations computer spreadsheets, or failing that pen and paper may be suitable for the work at hand. Models tend to be of varying levels of detail, depending on how much information needs to be extracted, or how much manipulation is required.

The process model can be used for the following:

- *Creation of mechanical data sheets* – the data extracted from the model is used to define the process conditions to which a unit operation is either exposed to (vessels) or a unit operation is required to perform (pump flowrate and discharge head). This data will be used to specify the equipment for purchasing, or further specification by other disciplines, for example material selection and design codes used.

- *Optimisation of process* – once data is available in an electronic form, it is easy to manipulate the data and determine how the process will perform at different operating conditions. For example, an increase in the amount of liquid produced might influence how separation vessels need to be designed. A projected decrease in inlet gas pressure might require replacement or restaging of compressor at some future time. The process model will allow all these changes to be explored, and catered for. Of course, if the process engineer is not given sufficient information, then these various cases might not sufficiently match actual process conditions, and more creative solutions might be required when the time comes.

- *Safety cases* – Safety is paramount in oil and gas operations. The engineer must do as much as she can to ensure that any potential unsafe events are catered for by the design. The process model assists in this task. For example, a fire may cause liquid and gas trapped in a vessel to heat up and either expand or boil off. The phase change results in increased pressure in the vessel, which if not relieved may eventually exceed the vessel's maximum allowable working pressure. To relief this excess pressure, pressure relief safety valves need to be designed to cater for the flows due to expansion and liquid boil off. This flowrate is calculated using thermodynamic properties generated by the process model. It is noted this example is not unique to the oil and gas industry, but whereas most other industries need to consider only one type of fluid (water, or a refined product), upstream facilities need to consider a mix of hydrocarbon components that may be different throughout the life of the plant.

The process model at some point has to have a connection with the real world. This happens during the process of fluid characterisation. A sample of the reservoir fluid that is to be produced is extracted and maintained at the original conditions in a sealed container. This is to ensure that the sample analysed is the same as that taken, and no component (especially the lighter hydrocarbons) do not evaporate from the sample. It is brought to a laboratory, and analysed. The properties generated are then input into a modelling program, and parameters are tweaked such that the fluid in the model behaves in a way similar to the sample. Properties that are looked at may include gas to liquid ratios at the sample temperature and compositions.

One question that arises is, even though most of the fluid is composed of butane or lighter hydrocarbons, how does one model the potential tens of components that may be present in the heavy (larger than butane) that are present in small quantities? These components will be important when

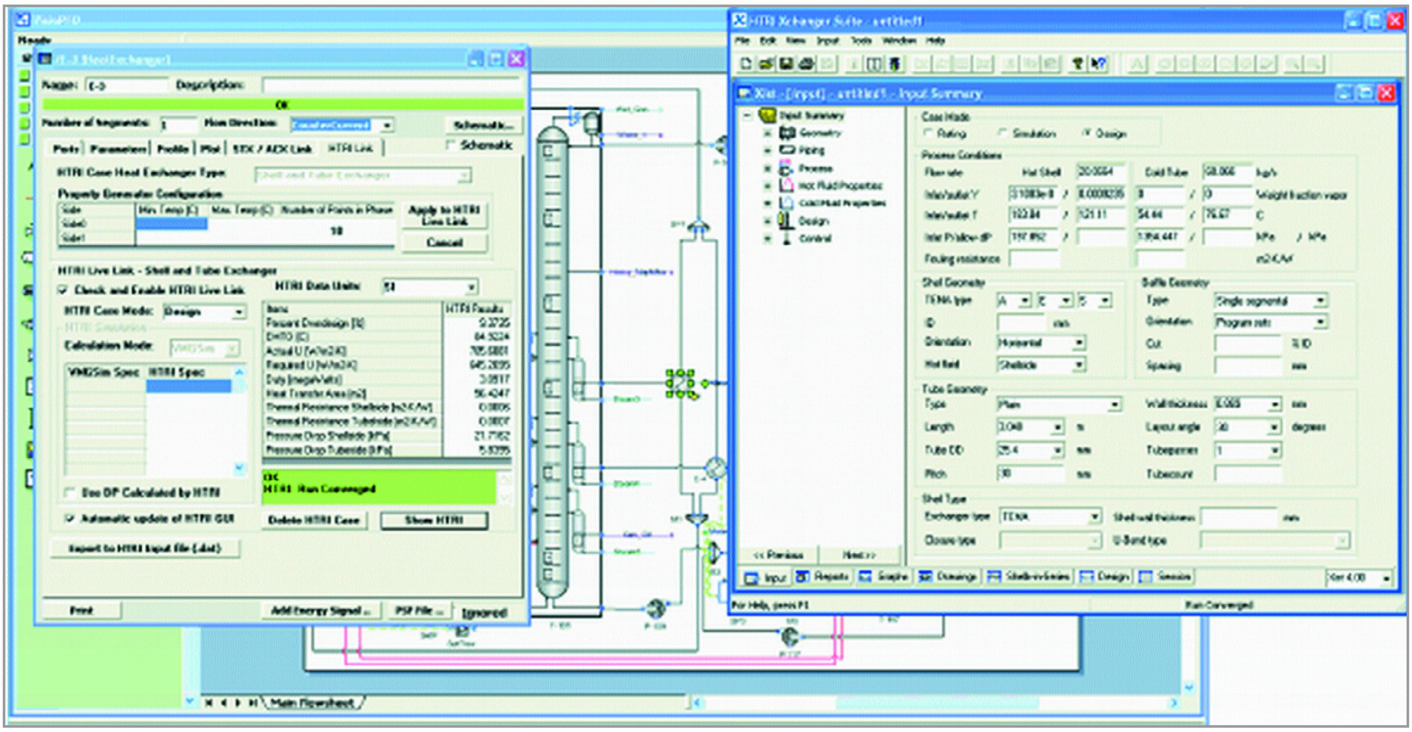

Figure 3: Screenshot VmGSim

the process model attempts to simulate liquid properties, for example during separation or fractionation. It is not practical to individually model each component. The answer is that the modeller creates pseudo-components that represents a group of actual hydrocarbons, and has the properties of that group.

Once the fluid composition is defined, the model then needs to consider how the different components will interact with each other, specifically how different state variables (temperature, pressure, volume) relate to each other at a given fluid composition. This is the job of equations of state (EOS). These equations vary in complexity, from SPM level (perfect gas equation, PV=nRT) through university level equations that can be analysed by the unfortunate undergraduate (van der Waals) up to equations that can only be practically manipulated by computing horsepower (Peng-Robinson, BWR) spiced up with proprietary equations (Shell, Esso) and in-house study data. It is the task of the engineer to select the most appropriate EOS for the task at hand.

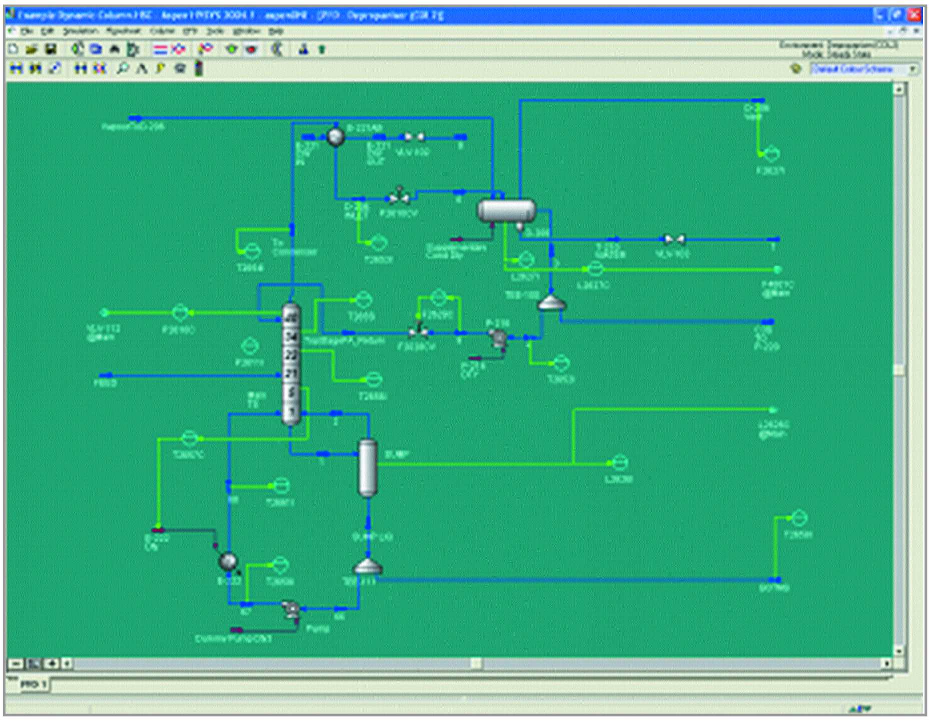

Figure 4: Screenshot HYSYS

Now, the above are input into the model. The model itself may be built inside a range of programs, each with its own advantages. Some packages are best suited for modelling a steady process, others are used to model dynamic processes. It is usual to select from a suit of packages as to what is best for the task at hand. Among the most well known process simulation packages are VMGSim (unit operations) (Figure 3), Pro II, HY SYS (Figure 4), Olga (dynamic pipeline simulation/flow assurance), Pipenet (piping networks), FlareSim (flare networks). ■