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Using underground gas storage to replace the swing capacity of the giant natural gas field of Groningen in the Netherlands. A reservoir performance feasibility study

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ABSTRACT

In this study we probe the ultimate potential Underground Gas Storage (UGS) capacity of the Netherlands by carrying out a detailed feasibility study on inflow performances of all onshore natural gas reservoirs. The Netherlands is one of the largest natural gas producers in Western Europe. The current decline of its national production and looming production restrictions on its largest field of Groningen -owing to its induced seismicity- have recently made necessary to upgrade the two largest UGS of Norg and Grijpskerk. The joined working volume of these two UGS is expected to replace the swing capacity of the Groningen field to continue guaranteeing the security of supply of low calorific natural gas. The question is whether this UGS configuration will provide the expected working storage capacity unrestricted by issues on reservoir performances and/or induced seismicity. This matter will be of paramount importance in the near future when production restrictions and/or the advance state of depletion of the Groningen field will turn the Netherlands into a net importer of high calorific natural gas. By then, the question will be whether the available UGSs will still be economically attractive to continue operating, or if additional or alternative UGSs will be needed?. Hence the characterization and ranking of the best potential reservoirs available today is of paramount importance for future UGS developments.

We built an in-house automated module based on the application of the traditional inflow performance relationship analysis to screen the performances of natural gas reservoirs in onshore Netherlands. Results enable identifying the 72 best candidates with an ultimate total working volume capacity of 122 ± 30 billion Sm^3. A detailed sensitivity analysis shows the impact of variations in the reservoir properties or wellbore/tubing configurations on withdrawal performances and storage capacity. We validate our predictions by comparing them to performances of the UGSs currently operating in the Netherlands. Our results show that although Norg and Grijpskerk stand midst the best candidates, their working:cushion gas volume (wv:cv) ratios appear amongst the lowest. We found many other reservoir candidates with higher wv:cv ratios (>1) and working volumes between 3 and 10 billion Sm^3 geographically distributed across the Netherlands. Any of the current and future UGSs will have to compete with economically more attractive means of gas import via pipelines and liquefied natural gas. We suggest that only the strategic development of a network of efficient underground gas storages with wv:cv ratios >1, could increase its economical attractiveness. This can reduce future dependence on foreign gas supply for cases of import disruption or shortages during peak demand in winter periods. Future political and economic decisions and societal acceptance will determine the role that UGS will play in the security of supply of natural gas in the Netherlands and Western Europe.

1. Introduction

The Netherlands is one of the top natural gas producers in Europe. It has produced an annual average of 70 billion Sm^3 of Groningen gas equivalent (Geq) for over the last 40 years (MEA, 2015) (Fig. 1). The dawn of the Dutch natural gas E&P industry goes back to the discovery of the giant Groningen field in 1959

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Nomenclature

Latin

a	Reservoir"s geometrical flow coefficient
A	Surface drainage area, m^2
A_t	Cross-sectional flow area tubing, m^2
b	Non-Darcy flow coefficient
c	Inertial factor constant, $4.1 \cdot 10^{11}$ m^{-1}
C_A	Dietz shape factor, dimensionless
D	Non-Darcy flow factor, s/m^3
d_i	Internal tubing diameter, m
f_{av}	Average Fanning friction factor, dimensionless
G	Acceleration of gravity, m/s^2
G_p	Plateau cumulative production, Sm^3
GIIP	Gas Initial In place, m^3
h	Thickness reservoir, m
h_p	Thickness of the reservoir perforated, m
k	Reservoir permeability, m^2
L	Tubing length, m
M	Gas molecular mass, kg/mole
$\bar{m}_R$	Average reservoir pseudo-pressure, Pa/s
m_{bh}	Well bottomhole pseudo-pressure, Pa/s
$m(p)$	Reservoir or bottomhole pseudo-pressure, Pa/s
P	Average reservoir or bottomhole pressure, Pa
P_f	Average reservoir pressure at initial withdrawal rate, Pa
P_i	Average reservoir pressure at cut-off withdrawal rate, Pa
p_r	Reference pressure for pseudo-pressure, Pa
P_{bh}	Bottomhole pressure, Pa
P_{wh}	Wellhead pressure, Pa
Q_{ini}	Initial rate of production, Sm^3/s
q_{sc}	Volumetric gas production rate at standard conditions, Sm^3/s
Q_p	Plateau production rate, Sm^3/s
R	Gas constant, Joules/kmole Kelvin
r_w	Wellbore radius, m
Re	Reynolds number, dimensionless
S	Mechanical-skin factor, dimensionless
T	Reservoir temperature, Kelvin
T_{av}	Average absolute temperature, Kelvin
T_p	time of contracted production, s
w_g	Mass flow rate of hydrocarbon gas, kg/day
z	Z-factor at reservoir temperature and pressure, dimensionless
Z_{av}	Average z-factor, dimensionless
Z_f	Z-factor at cut-off withdrawal rate, dimensionless
Z_i	Z-factor at initial withdrawal rate, dimensionless

Greek

α	Angle of tubing with vertical, degrees
β	Inertial factor, m^{-1}
δ	Tubing absolute wall roughness, m
μ	Gas viscosity, Pa s
μ_w	Gas viscosity at wellbore, Pa s
ρ	Gas density, kg/m^3.
ρ_{sc}	Density of dry gas at standard conditions, kg/Sm^3

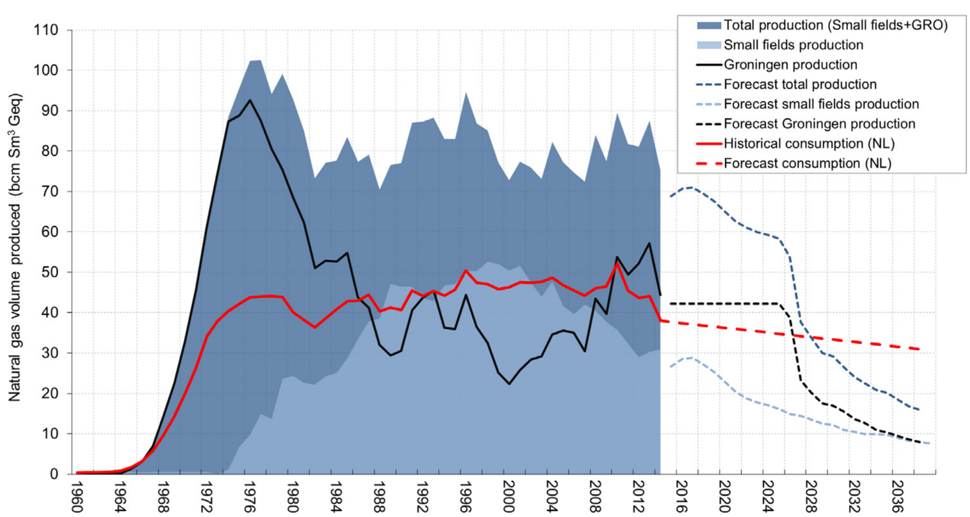

Fig. 1. Historical production of natural gas in the Netherlands between 1960 and 2014 depicted as total and as from the Groningen field and small fields (onshore + offshore) in billion standard m^3 of Groningen gas equivalent (bcm Sm^3 Geq) (MEA, 2015). Historical national consumption is also shown by the red continuous line. Dashed lines depict the natural gas production forecast for the small fields (reserves + contingent + prospects) and Groningen (MEA, 2014a) and the Netherlands national consumption of natural gas (ECN, 2014). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

(Breunese and Rispens, 1996; Correljé et al., 2003; De Jager and Geluk, 2007). This giant field, the largest found in western Europe, initially contained 3028 billion Sm^3, which is about 2/3 of the total natural gas reserves discovered in the Netherlands until today. In the first seventeen years, production from Groningen took place at an accelerated pace and was drastically reduced only after the oil crisis of 1973–74 (Correljé and Odell, 2000) (Fig. 1). In order to compensate for the reduction in production, the Dutch government implemented a set of measures to stimulate the discovery and production of other "smaller" natural gas fields (Mulder and Zwart, 2006; De Vaan, 2012). These measures led to the discovery of more than 450 onshore/offshore small fields (Breunese et al., 2005; MEA, 2015). These small fields have being produced at optimal rates, while the Groningen field is used as a swing producer to help balancing the gap between supply and demand, especially in winter time.

In early 2000s the production from the small fields started a slow decline, and continuous until today. Annual production is expected to fall below 20 and 10 billion Sm^3 by 2022 and 2033 (MEA, 2015) (Fig. 1). So far this decline has been compensated by a