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RESEARCH PAPER

Development journey and outlook of Chinese giant oilfields

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Abstract: Over 70% of China's domestic oil production is obtained from 9 giant oilfields. Understanding the behaviour of these fields is essential to both domestic oil production and future Chinese oil imports. This study utilizes decline curves and depletion rate analysis to create some future production outlooks for the Chinese giant oilfields. We can conclude that China's future domestic oil production faces a significant challenge caused by maturing and declining giant fields. Evidence also indicates that the extensive use of water flooding and enhanced oil recovery methods may be masking increasing scarcity and may result in even steeper future decline rates than the ones currently being seen. The Chinese petroleum industry has managed to keep many of their giants on a production plateau for many decades. However, nothing can change the eventual onset of decline in oilfields and many of the Chinese giants have already passed their peak production levels. Our results suggest that a considerable drop in oil production from the Chinese giant oilfields can be expected over the next decades.

Key words: giant oilfields; future Chinese oil production; decline curve analysis; production modelling; oil production strategy

Introduction

Only the largest of oilfields may be called giants, a common definition is that they must have ultimately recoverable resources (URR) of at least 7 950×10^4 m^3 according to the American Association of Petroleum Geologists (AAPG)[1–5], while others use the production rate to define giant oilfields and require them to deliver flows of more than 15 900 m^3/d for at least a year[6]. This study will use both definitions of a giant oilfield. Several studies have focused on the immense importance of giant oilfields for world oil supply[7–10]. In fact, giant oilfields have even been called "*the highway to oil*" as they represent roughly 65% of the global conventional oil recoverable resources[11]. Conventional oilfields refer to reservoirs that predominantly allow oil to be recovered as a free-flowing dark to light-coloured liquid[12]. Consequently, heavier crude oils that require special production methods are excluded.

The revised Geological and Mineral Industry Standard of People's Republic of China[13] states that Chinese field reserves should be calculated from recoverable reserves and gives 5 different field classifications: *super giant*, *large*, *medium*, *small*, and *extra small*[14]. The large class includes fields with ultimate reserves ranging from 2 862×10^4 m^3 to 28 620×10^4 m^3. Accordingly, our giant classification will include all Chinese fields denoted as super giant as well as some of China's large fields.

The dominance of giant oilfields can be seen on both a global and a national level. The 20 largest giants account for 25% of world oil production[10]. Similarly, one can see how the Norwegian or the Danish production has been governed by the behaviour of their giant oilfields[15,16]. Robelius[11] even states that global and national peak production will be chiefly determined by the giants and their behaviour.

As the world's second largest oil importer, China is of significant interest. China's future domestic oil production will determine its future oil import requirements. Currently, the Chinese demand for oil is growing and is likely to increase even more with continued development and modernization.

In this analysis we consider China's 9 giant oilfields (Table 1, Fig. 1). In addition to these fields, China contains a number of smaller fields, such as Jilin, Tuha, and Henan, that will be briefly discussed in relation to the giants.

This study will utilize decline curve analysis to project possible production scenarios for the Chinese giant oilfields. This methodology is chosen because of a strong theoretical background from natural science as well as a strong agreement with numerous empirical studies. In addition, decline curves are also one of the oldest and most used production forecasting techniques employed by petroleum engineers[17,18]. Furthermore, they have been used to provide reasonable produc-

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Table 1 Chinese giant oilfields

Field	URR/ 10^4 m^3	Discovery year	First oil	Peak year	Peak production / ($m^3 \cdot d^{-1}$)
Changqing	34 980	1971	1975		
Dagang	23 850	1965	1965		
Daqing	383 190	1959	1959	1999	174 900
Huabei	34 980	1975	1975	1979	55 650
Liaohe	79 500	1958	1970	1995	49 608
Shengli	251 220	1961	1961	1992	106 848
Tarim	17 490	1989	1989		
Xinjiang	89 040	1951	1951		
Zhongyuan	20 670	1975	1976	1988	23 055

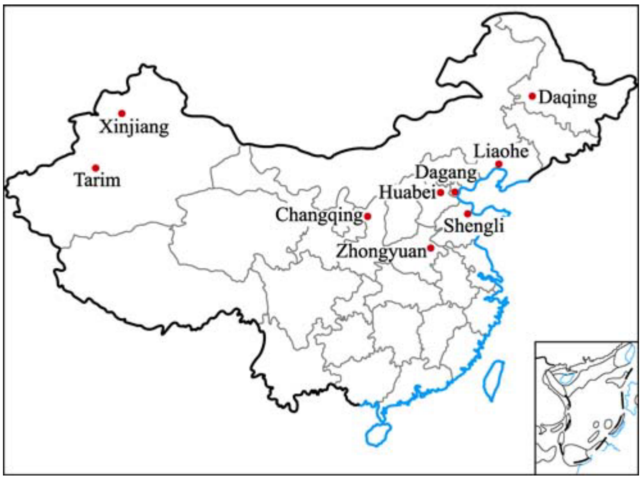

Fig. 1 Sketch of Chinese giant field distribution

tion outlooks in numerous cases without requiring extensively detailed data[9–10,19].

Understanding how the core of China's domestic oil production might behave in the future is essential. It is important for Chinese planners and policymakers in order to plan for the future and to anticipate problems before they occur. Proper understanding of the future behaviour of Chinese oil production is also helpful for other countries that will be competing with China for future oil imports.

Historical production data for the Chinese giant oilfields were taken from the statistics compiled by mainly Robelius[11], but complemented with sources such as Kang Zhulin et al.[20] and Xin Yan[21–23]. In addition, some 2008 figures were taken from press releases from various oil companies. The production data were found to be in good agreement with each other and aggregated production agreed well with national data figures, such as BP[24]. URR estimates were compiled from various sources, mainly from the compiled estimates of Robelius[11], Laherrere[25], and various other sources. Alternatively, decline curve analysis could be used to create our own URR estimations based on methodology described by Höök et al[16]. Generally, the URR figures were found to be in reasonable agreement.

1 Overview of China's petroleum sector

Chinese oil production prior to 1960 was practically non-existent. Xinjiang, Liaohe were discovered in late 1950s, but only a few sites produced petroleum and there was a widespread shortage of petroleum products. Exploitation of the vast reserves in the wide Daqing region, NE China, was almost completely done without any foreign expertise or equipment.

Experience from Daqing, new knowledge, and increased efforts quickly lead to additional discoveries of new oil areas. Shengli and Dagang were discovered in 1960s and Changqing, Huabei and Zhongyuan were discovered in the next decade. The giant discovery peak occurred in the 1960s and most reserve additions have been from non-giant fields. Wang Haijiang et al.[26] states that the Chinese oil reserve growth has reached a plateau and that discovery of new giants are unlikely.

During 1971–1978, China's oil output soared and saw an average annual growth rate of 16.5%[27]. Much of this spectacular growth can be connected to giant oilfields as the Daqing, Shengli and Huabei fields alone accounted to over 80% of the total Chinese oil production in 1980. However, in early 1980s production stagnated due to geological, technological, and institutional factors[27]. After 1984, new production methods, increased investments, changes in the institutions and management and increased exploration managed to make production increase again, although at less rapid pace than before. Tarim was discovered in 1989 and was the last and smallest of the Chinese giants.

Chinese oil production has still managed to increase since the 1980s, but this is becoming more and more challenging to sustain as more and more of the giants are reaching the onset of decline. Total giant contribution has been kept virtually constant since 1985, despite limited new field additions (Fig. 2). Most of the production increases has been derived from non-giants and this resembles the behaviour of Norway prior to their peak production, where giants reached a plateau for some years before the onset of decline[15].

The giant fields have dominated production, although their share is dwindling. Daqing has been the single most important contributor since its discovery and remains an integral part of Chinese domestic oil supply.

1.1 Geological overview

China's sedimentary basins developed and took shape

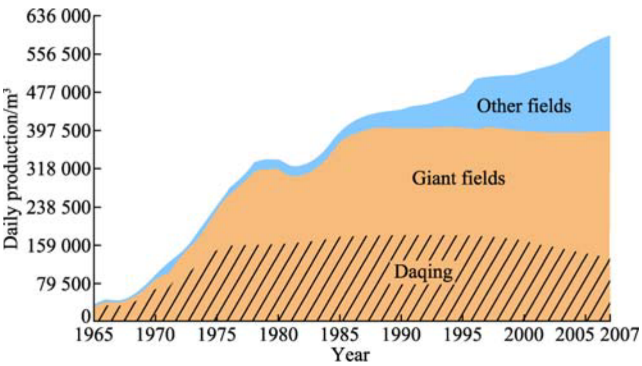

Fig. 2 Chinese oil production from 1965 to 2007

mainly during the Himalayan Movement period (about 65 Ma ago), which involves strong continent-to-continent collision and continuous compression between the India Plate and the Eurasia Plate[28]. A basic overview of the petroleum geology has been done by Li Desheng[29]. Reservoir rocks are commonly made of sandstone or the mixture of sandstone and conglomerate rock composed of mostly clastic detritus[30]. Most of the oilfields belong to river-deltaic sedimentary systems with apparent multicyclicity, resulting in multiplayer folding traps with sharp discrepancies. Consequently, permeability varies widely in different directions for many oil sediments[30].

An interesting property of many important Chinese fields is that they are associated with non-marine basins, in particular the Songliao Basin where Daqing was found[31]. The sedimentary basins in east China, where most of the giants are located, are characterized by a large number of highly fractured traps of mainly stratigraphic type[27]. This gives the oilfields great variability in reservoir distribution, porosity and permeability, creating generally complex conditions[32].

Daqing, Shengli, Huabei, Liaohe and Dagang may be seen as the most important giants and all of them are located in the north-east of China. Daqing is located in the Songliao Basin, while the others are found in the Bohai Bay Basin.

1.2 Production overview

Chinese oil production is chiefly done by large state-owned oil companies. The largest is China National Petroleum Company (CNPC), which is the largest reserve holder and domestic oil producer. Sinopec, the public arm of the state-owned China Petrochemical Company, is the second largest petroleum company in China and is involved in everything from refining and petrochemicals to pipelines and oil/gas production and exploration. China National Offshore Oil Company (CNOOC) is another state-owned company and the third largest player in the petroleum sector.

A brief historical overview of oil production technology in China has been made by Liu Xiangou[33]. Chow[27] explained how China adopted a short-sighted policy of forcing oil production at the expense of exploration and development in the 1970s. This resulted in extensive use of water injection. Daqing, for instance, was subjected to water injection directly from the start and excessive flooding lead to increase water cut and premature abandonment of many wells as well as reduction of soil temperature[27]. This overuse of water injection helped to enhance production but has been estimated to reduce ultimate recovery[27]. The water cut is over 80% for most fields and studies on additional enhancement of oil recovery have been carried out for more than 10 years now[30].

A rapid development in the study of the enhanced oil recovery (EOR) technology has occurred since the late 1970s[32], and will likely be vital for future domestic oil production. Generally complicated geological conditions, resulting in water channelling, fingering oil migration, and complicated pore structure of the rocks, limits the power of natural water flooding and have forced widespread reliance on water injection and EOR methods[30]. For example, microorganisms are employed for obtaining oil-releasing substances in the Daqing Oilfield[34], while surfactants and polymer flooding are extensively used at the Shengli Oilfield[35,36] along with special structure drilling techniques[37]. The use of horizontal drilling has also been chiefly applied to Chinese giant fields[38], as well as high frequency vibration recovery enhancement and thermal recovery technologies[39].

2 Modelling and analysis

Decline curves were originally introduced by Arps[40] and strived to obtain expressions with mathematical tractability that could be utilized in a simple and straightforward manner. Additionally, decline curve analysis is independent of the size and shape of the reservoir or the actual drive-mechanism[41], thus circumventing requirements on detailed reservoir data. Furthermore, decline curves are more than just an empirical model of field behaviour since they also represent physical solutions to reservoir flow equations in various cases[9]. A more comprehensive overview of decline curves and the methodology used in this analysis can be found in Höök et al[16].

The exponential and hyperbolic decline curves, mathematical expressions capable of describing the change in production rate over time according to Arps[40], will be utilized here to analyze and make a number of outlooks for the Chinese giants. It should be explicitly noted that the exponential decline curve is a special case of the general hyperbolic decline. This is the explanation why the 2 curves look virtually the same in some situations. Some of the Chinese giants (Daqing, Huabei, Liaohe, Shengli and Zhongyuan) are already in decline. The historical production data after the peak year is fitted with decline curves and used for projecting future production. The resulting outlooks should be regarded as optimistic, as production collapses caused by sudden events, economic or geological, cannot be included.

In total, we believe that 4 fields, Changqing, Dagang, Tarim and Xinjiang, have not peaked. The future production of these fields cannot be forecast by decline curves directly, so we chose to use a depletion rate analysis approach instead. This means that the depletion rate behaviour and its future trajectory are studied. Anticipated ultimate reserves are needed for these fields in order to calculate the depletion rate of the remaining reserves (URR estimates have been taken from Robelius[11] and others). The plateau phase is assumed to end when the typical depletion rate at peak value for giant oilfields on land is reached, that is, a forecasting-by-analogy approach based on typical behaviour obtained from a large statistical population of giant oilfields[9]. Once the plateau phase is over, the decline is assumed to be approximately as fast as the other giant oilfields of comparable size and character, whose typical decline rates are known from historical data.

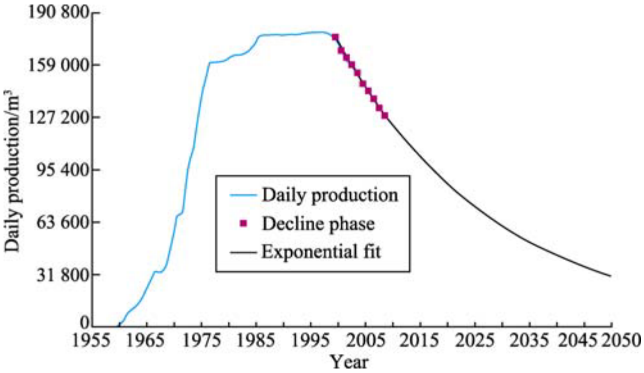

Fig. 3 Production outlook for the Daqing Oilfield. The hyperbolic case is the same as the exponential case and is omitted. Daqing will remain an important oil producer for many decades, but expected to be delivering around 31 800 m^3/d in 40 a.

2.1 Post-peak Chinese giants

Most of the Chinese giant fields are generally in the post-peak stage. The most important giant field, Daqing, has been in a steady decline since 1999, despite attempts to mitigate and stabilize production. The decline of Daqing has followed an exponential curve with 3.4% annual decline ever since the onset of decline and this is expected to continue in the future (Fig. 3).

Daqing has been sequentially developed since 1960s. By 1981, 23.5% of the original oil in place (OOIP) had been extracted and water cut had reached over 60%, due to the dominance of water flooding as the production method[42]. In 2004, the water cut reached 88.9% and 36.8% of the OOIP (or 75.6% of the recoverable reserves) had been recovered[43]. Daqing is essentially in the late stage of the high water-cut development phase and tertiary recovery methods must be applied. The challenge to sustain production is becoming increasingly more difficult. In addition to extensive water flooding, Daqing has also been subjected to various EOR projects and trials, including microbial techniques[34,44], and polymer/surfactant injection[45].

Huabei is also one of the world's important giants and played a vital part in the rise of Chinese oil production in 1970s[27]. However, the output peaked at 55 650 m^3/d in 1979 and began to decline (Fig. 4). In 1990s, the descent was halted and seems to have stabilized at slightly below 15 900 m^3/d. The Renqiu reservoir, belonging to the Huabei complex, has shown a dramatic production crash in 1986–2000 according to Laherrere[25], but this seems to have been offset by new additions. Huabei has also shown signs of land subsidence[46], possibly assisting recovery because of reservoir compaction. Huabei is probably also a good example of how a single decline curve cannot fully depict the historical behaviour and how a concerto of curves should be used for better agreement. The decline curve fit yields an average decline rate of roughly 8%, which reasonably may be seen again as soon as the temporary production increases cease to offset the underlying depletion-driven decline.

Liaohe ranks among the largest of the Chinese giants and saw a massive increase in production from the early 1970s to the 1990s. However, the field peaked in 1995 and has been in decline ever since (Fig. 5). It has also been subjected to combined alkaline/surfactant/ polymer (ASP) flooding after the Chinese government put emphasis on such measures in the 7th, 8th and 9th Five-Year Plans ranging from 1985 to 2000[47]. Trial tests with CO_2 injection are also being pursued at this field[48]. This far, none of the measures seems to have had much impact and their future effects remain to be seen. If the historical trend continues, production from Liaohe would be only 15 900 m^3/d by 2050.

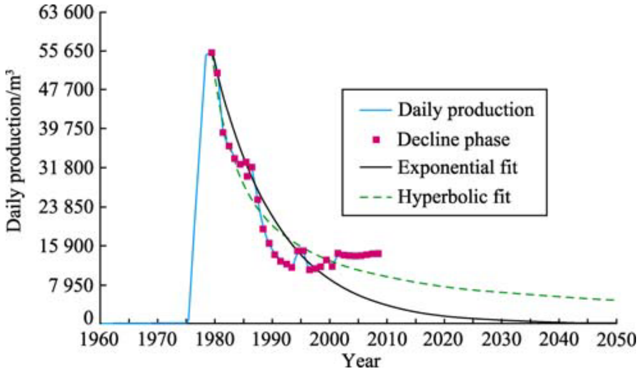

Fig. 4 Production outlook for the Huabei Oilfield. The field seems to have flattened out at slightly below 15 900 m^3/d due to redevelopment and new production enhancement methods.

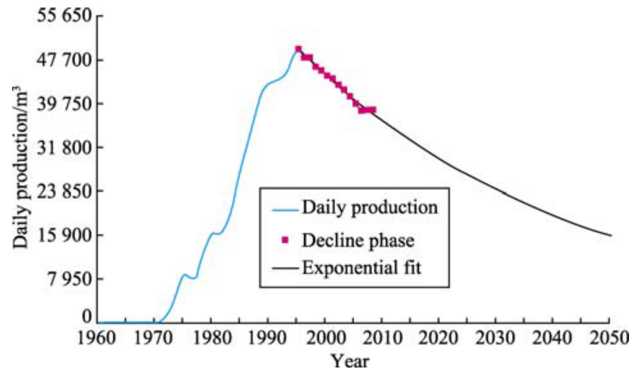

Fig. 5 Production outlook for the Liaohe Oilfield. The hyperbolic case equals the exponential case and is omitted. Provided that nothing unexpected happens, this field will follow a steady 2% decline in the future.

Shengli is a giant with recoverable reserves of around 159 000×10^4 m^3. A short period of stagnation was seen in 1975–1985, before production started to increase again (Fig. 6). The field peaked in 1993 at a production of 103 350 m^3/d, and now the formation is characterized by high water cut, massive water channelling, and inefficient oil recovery due to complex geology and serious heterogeneities[49]. For the moment, significant redevelopment and EOR measures are being pursued and have temporarily halted the decline. The measures include nitrogen foam[49], surfactant/polymer injection[50,51], and microbial activation[52]. How long the declining trend can be reversed remains an open question.

Zhongyuan is a relatively small giant that peaked in early 1990s with a daily production of 23 055 m^3/d. It has followed

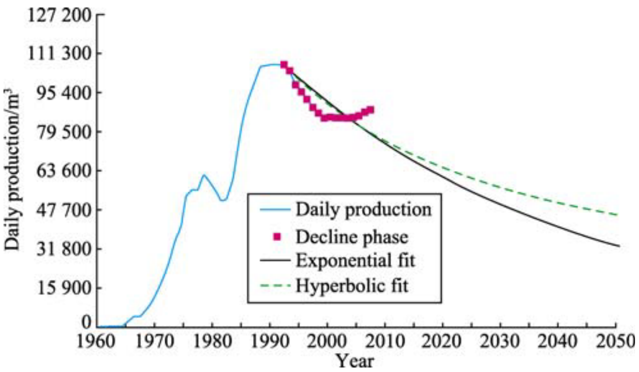

Fig. 6 Production outlook for the Shengli Oilfield. In recent years, redevelopment and EOR measures have been able to offset the decline and even cause a slight increase, but this is likely just temporary and a significant decrease in output can be expected over the next decades.

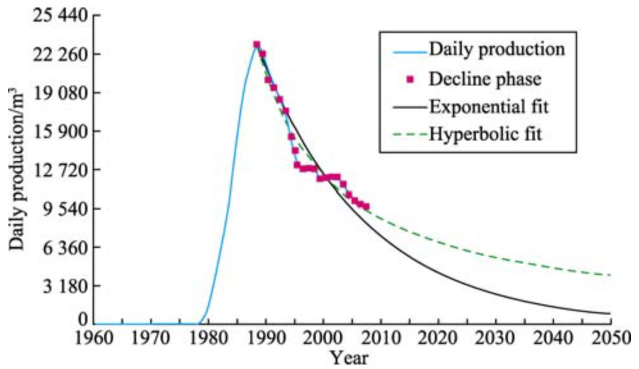

Fig. 7 Production outlook for the Zhongyuan Oilfield. This field agrees well with both exponential and hyperbolic decline curves, even though the hyperbolic fit is better.

both exponential or hyperbolic decline curves reasonably well ever since. The Zhongyuan field, its marginal oil areas and how those can be brought into production are discussed by Dai Shengquan et al[53]. Any major revival of the field seems unlikely and additional measures will largely be able to dampen decline to some extent.

2.2 Pre-peak Chinese giants

Changqing, Dagang, Tarim, and Xinjiang have all seen increasing production since they came on stream. In fact, increased production from the pre-peak giants has offset the decline from the post-peak giants (Fig. 8). Most of the production increase has been from Changqing, followed by Xinjiang and Tarim, while Dagang has seen relatively steady production since the mid-1970s. Consequently, the onset of decline in the pre-peak giant fields will have a major influence on the future domestic oil production in China.

The future behaviour of the pre-peak giants might be estimated by studying the depletion rate of the remaining reserves, provided that our URR estimates are reasonable. Previous studies of giant oilfields have investigated the typical values of the depletion rate at the onset of decline and found it to be occurring in a narrow band[9]. The importance of depletion rate of remaining reserves and its influence on reservoir flows and overall production has been discussed by Höök[54].

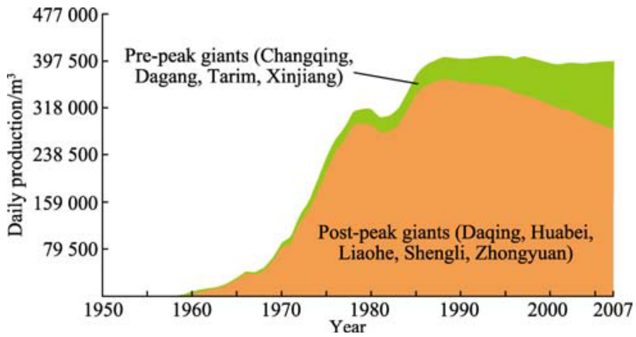

Fig. 8 Historical production of the Chinese giant oilfields. The pre-peak fields have been able to offset decline in the post-peak fields since 1990s, but this cannot continue forever and will cease as soon as the production increase in the pre-peak giants halts.

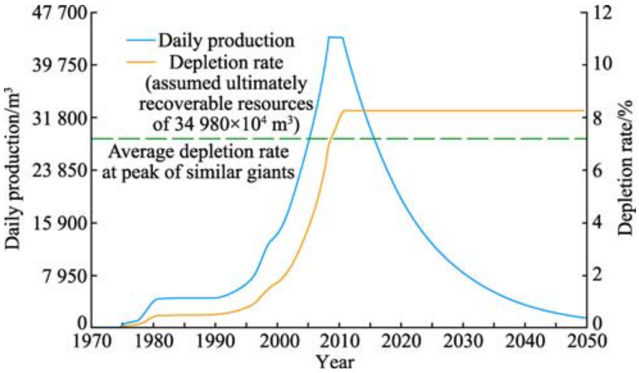

Fig. 9 Production profile and depletion rate behaviour of Changqing. The rapid production increase has resulted in a steep increase in the depletion rate of remaining reserves.

Jakobsson et al.[19] named this methodology "*maximum depletion rate modelling*" and did a broad overview. In practice, this means that the depletion rate of remaining reserves is allowed to reach a maximum value, found from empirical studies of other fields. Once that maximum value is reached, the depletion rate remains constant which corresponds to an exponential decline curve as shown by Jakobsson et al[19]. In contrast, the general hyperbolic case has a decreasing depletion rate with time[54].

Changqing, classified as a low-permeability reservoir[33], has seen a massive ramp-up of production from roughly 4 770 m^3/d in 1990 to over 39 750 m^3/d in 2008 (Fig. 9). Much of this rise can be attributed to advanced water flooding measures[55]. At some point, the increase must cease and this is indicated by the behaviour of the depletion rate of remaining reserves.

Current depletion rate of remaining reserves at the Changqing field is 7.1%, based on an URR of $34\ 980\times10^4$ m^3. This is around the typical depletion rate at peak value (7.2%) for 58 other giant fields of approximately equal size, all taken from our giant oilfield database. This implies that Changqing's production increase will stop soon and be turned into decline. The depletion rate also indicates that a reasonable average future decline rate would be around 8%[9].

Similar reasoning can be applied to Dagang (Fig. 10) and this implies that the plateau phase is about to end relatively soon, followed by a decline phase with an average annual

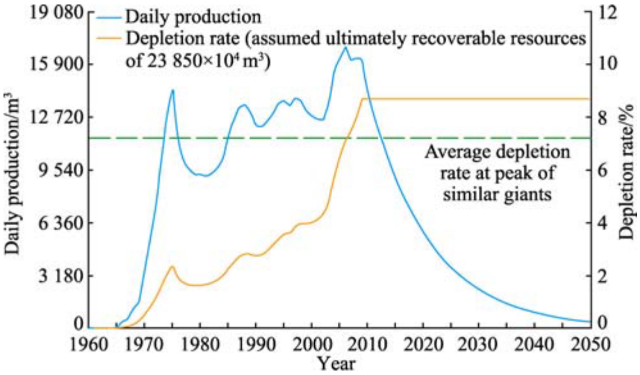

Fig. 10 Production profile and depletion rate behaviour of Dagang. A steep increase in depletion rate has occurred in 2000s.

decrease of roughly 10%. Possibly, Dagang reached its peak in 2006 although it is too early to determine with significant certainty.

Tarim (Fig. 11) is estimated to have ultimate reserves of 14 310×10^4 m^3, can also be modelled in the same way from its depletion rate behaviour. This indicates that the field is about to quit the build-up phase and soon enter the decline phase. The probability of increasing production is becoming smaller, given the relatively narrow distribution of reasonably depletion rates for giant oilfields[9].

Xinjiang (Fig. 12) is enormous compared to the other pre-peak giants and has been steadily increasing production since 1970s. Its URR has been estimated to 89 040×10^4 m^3[11].

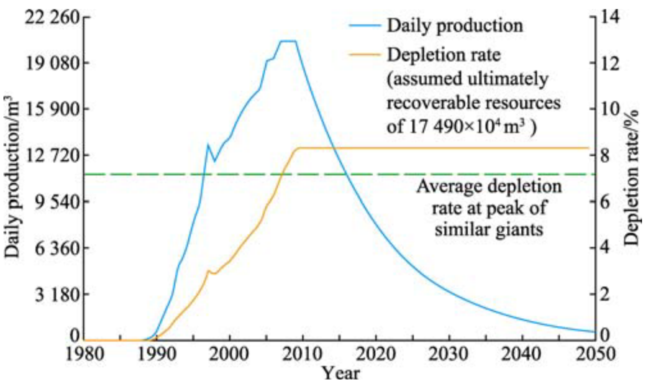

Fig. 11 Production profile and depletion rate behaviour of Tarim. The rapid production increase is followed by the steep increase in depletion rate.

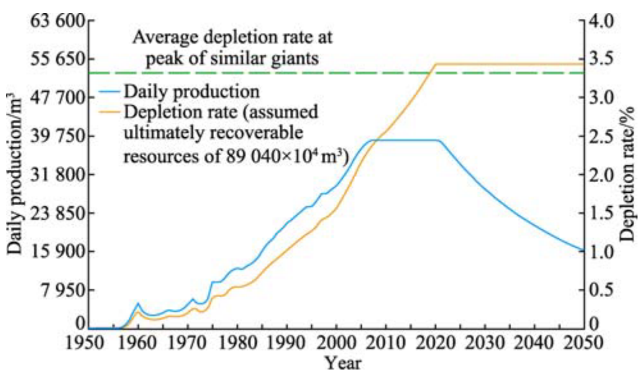

Fig. 12 Production profile and depletion rate behaviour of Xinjiang. The rapid production increase is followed by the steep increase in depletion rate.

The future production of this field and its onset of decline can be estimated by using analogies with similar fields worldwide, using our world giant oilfield database and the narrow distribution of typical depletion rate values at the onset of decline[9,54].

Sarir, Karanj, Minas, East Texas and Liaohe are giant fields of comparable size in terms of recoverable reserves and they all reached a production peak or left the plateau phase at depletion rates of around 3%. It is not reasonable to expect that Xinjiang will differ widely from this typical behaviour and this leads us to the conclusion that Xinjiang is about to reach a peak somewhere in the following decade, or possibly decades, provided that our URR estimate is reasonably accurate. A realistic future decline rate would be around 3.5%, also based on similarities with other fields and the strong correlation between depletion rate at peak and future average decline rate[9].

In summary, we believe that each of the pre-peak giants is close to reaching the onset of decline if they exhibit behaviour similar to the many hundreds of other giant oilfields worldwide. An exact peak year is hard to estimate, but from the narrow distribution of reasonable depletion rates for giant oilfields, we can conclude that the onset of decline can be expected to occur relatively soon, likely within a few years, for the pre-peak Chinese giant fields.

2.3 Technology and future decline rates

Secondary and tertiary production techniques can boost extraction rates by creating better drainage of the oil in place, maintaining reservoir pressure, or even reducing the viscosity[56]. Such measures have been used extensively throughout history and are being aggressively pursued at present. This brings about another problem for the future, namely how extraction technology masks increasing scarcity. Compelling evidence shows that such measures only increase or maintain production levels temporarily at the expense of steeper subsequent decline rates in a general case.

Both the Forties field in the UK North Sea and the Yates field in the US have been studied in detail by Gowdy and Julia[57]. Their finding was that investment in technology only temporarily raised or maintained production and that the result was steeper future decline rates. The analysis also showed that actual details on field level are important and that the common belief that technology always will mitigate shortage is untrue. EOR may just accelerate depletion of existing reserves *or* it may improve depletion rate and capture significant additional reserves.

The conclusions of Gowdy and Julia[57] were later extended and generalized for the world's giant oilfields by Höök et al.[9]. Studies of how typical giant field behaviour had evolved over time indicate that prolonged plateau phases and increased depletion, made possible by new technologies and secondary and tertiary measures, resulted in generally higher decline rates. The spectacular collapse of the giant Cantarell field, which had been subject to extensive nitrogen injection, may be seen as an extreme example of what can happen when decline finally sets in. Additional discussions on average decline rates and comparisons with other studies have been made by Höök et al[10]. In essence, the strong correlation between depletion rate and decline rate[9], verifies the well-known but seemingly ironic nature of oil extraction: "*the better you do the job; the sooner it ends*".

Based on this reasoning, we state that the analysis of the Chinese post-peak giant fields may be optimistic and that significantly steeper decline rates are likely to occur once the temporary gains from EOR measures wears off. A definite and certain estimate of how much higher decline rates is impossible to give at this time, but the mere possibility calls for further investigations, preparation, and responsible planning from the affected parties.

2.4 Future outlook

This analysis assumes that China's post-peak giants will continue to develop according to the decline curve fits (Figs. 3–7). The Huabei field (Fig. 4) is an inherently bad fit, but we expect it to be compensated by overestimations for other fields. This methodology is identical to the approach used in previous studies[10,15–16].

Based on the depletion rate modelling, we estimate that the most pre-peak fields will peak in the imminent future (Changqing in 2010, Dagang and Tarim in 2009) while Xinjiang can increase its output to 47 700 m^3/d before reaching the onset of decline in 2020 (Figs. 9–12). In other words, the decline from post-peak giants will not be offset as an increasing number of the non-peaked giants enter the onset of decline. Assumed future decline rates are 9% for Changqing and Tarim, 8% for Dagang, and 4% for Xinjiang.

The integral picture for all Chinese giants can be seen in Fig. 13, and shows how a massive decrease in domestic oil production can be expected in the near future. Some characteristic parameters are compiled in Table 2. As soon as the production increases from the pre-peak fields ceases, the real decline will set in and become apparent. After 2010, almost 318 000 m^3/d of production capacity will be lost due to maturing fields and inherent decline. The lost production capacity will have to be replaced with new capacity or additional oil imports, or both.

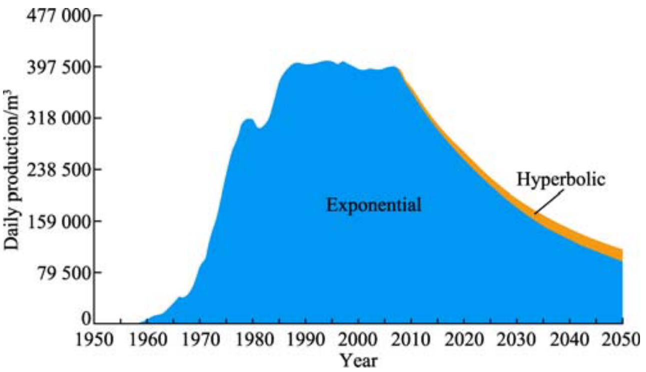

Fig. 13 Possible outlook for the domestic oil production from Chinese giant oilfields in both the exponential and hyperbolic case. The average annual decrease is around 3% and will be a major challenge to offset with new production, given the sheer production dominance of the giant fields.

Table 2 Characteristic parameters of the Chinese giant fields

Fields		URR/10^4 m^3	Peak year	Decline rate*/%	Cum. Prod. by 2050/10^4 m^3
Post-peak giants	Daqing	383 190	1999	3.2	338 670
	Huabei	34 980	1979	8.9	34 980
	Liaohe	79 500	1995	2.1	81 090
	Shengli	251 220	1992	2.0	198 750
	Zhongyuan	20 670	1988	7.6	23 850
Pre-peak giants	Changqing	34 980	2010	8.3	33 390
	Dagang	23 850	2009	8.7	25 440
	Tarim	17 490	2009	8.3	17 490
	Xinjiang	89 040	2020	3.4	81 090

*The decline rates for the post-peak giants are given for the best fit of the exponential or hyperbolic decline curves, and the decline rates for the pre-peak giants are assumed values.

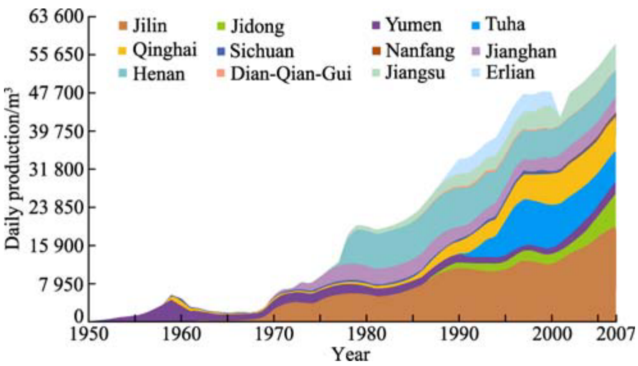

Fig. 14 Historical production of some Chinese non-giant fields

2.5 Other fields

China also has a number of smaller oilfields and petroleum provinces. In total, these account for around 159 000 m^3/d or 30% of the domestic production capacity. Most of them are located on land, even though there are some offshore fields in the Bohai Bay and other coastal areas around China. Many of these fields are very small, but some of them produce significant amounts of oil (Fig. 14). Even among these fields, the dominance of just a few fields can be seen. Jilin can be classified as giant, but due to poor data we have chosen to exclude it from the giant group and keep it among the other fields.

With better data and a more detailed study of each field, we suspect that many of the non-giant fields are also near the onset of decline or show to have significant challenges associated with production increase, due to maturity or limited remaining undeveloped reserves. Needless to say, none of these other fields can realistically increase their future production to offset the decline in the giant fields. The number of smaller fields needed to just offset a single giant is huge[11] and we do not foresee how China can maintain its domestic oil production without bringing new giants on stream.

The number of additional new fields required to offset the expected decline from the giants (Fig. 14) would be enormous and not achievable in any realistic case as we see. The solution to the problem imposed by the declining giants cannot be found in other domestic fields.

3 Implications for future Chinese oil supply

Based on our study of the giant fields, we conclude that future domestic oil production in China faces a significant challenge. The enormous dependence on giants for domestic production (Fig. 2), as well as the magnitude of a giant compared to a smaller field, will make it very problematic to offset the decreasing production in the giant fields with new domestic sources. There seems to be limited opportunities of uncovering additional new giants in mainland China[26], and this will make it even harder to compensate for the declining giants.

It appears likely that the giant fields will remain the largest and most dominant part of the domestic oil production in China; however, it is questionable whether other petroleum sources can offset the declining giants. If not, the peak of Chinese oil production will arrive around 2010 with some uncertainty related to the peaking of the pre-peak giants. For this reason, our general expectation of the future production trajectory is largely similar to that of Campbell and Heapes[58], even though they are using a widely different forecasting methodology not based on a bottom-up approach from field level.

The reserve-to-production rate, i.e. the inverse of the depletion rate of remaining reserves, is low for China[59], indicating a rapid depletion of China's oil reserves. Given the strong correlation between depletion rate and decline[9], it is necessary to ask whether this rapid depletion is desirable as it leads to rapid decline.

The expected decrease in production from the giants is significant (Fig. 13), and will inherently alter picture of future Chinese oil supply. Over the next decade and into the foreseeable future, a major shortfall of domestic oil production will occur, caused primarily by the maturing and declining giants. This predicament calls for wisdom in both planning and policymaking, along with responsible countermeasures in order to ensure continued growth and well-being of China and its people.

Additional discussions on peak oil in China have been provided by Pang Xiongqi et al.[59] and Feng Lianyong et al[60]. It is important to remember that peak oil do not mean the end of growth and development, rather it is a development theory that dictates that the growth of any finite resource cannot be sustained indefinitely[61]. Continued petroleum-driven growth will naturally not last longer than the availability of petroleum. Therefore, responsible planning and proper handling of the energy issue are essential for ensuring continued Chinese development.

4 Possible countermeasures

First, continued exploration and development of domestic oilfields are essential for maintaining production and to dampen the decline of the giant fields in the future. Dreams of continued increase in domestic oil production are seemingly unfounded in the longer perspective, even though a few years of slight increase or maintained production levels can be expected to occur. Managing decline and alleviating the reduced output of the Chinese giant fields as much as possible must be an integral part of any reasonable plan for Chinese oil supply. These types of countermeasures include additional exploration, improved recovery as well as utilizing new technologies and unconventional oil formations. The importance of technology is also mentioned briefly by Feng Lianyong et al[60].

Secondly, it was proposed that alternative energy sources or replacements should be developed. These include synthetic liquid fuels, wind turbines, nuclear energy, electric vehicles and other measures of similar type. China is already forcefully pursuing new energy sources, but the present plans might have to be revised in the light of changed situations and peak oil. For example, the immense tonnage of coal required for coal liquefaction makes it questionable whether coal-derived synthetic fuels can be a viable alternative for providing the necessary volumes of liquid fuels[62]. Alternative energy pursuits should also be undertaken to reduce the environmental impact, which is an important goal in itself apart from improving the Chinese energy security.

Thirdly, increased oil import and strategic alliances with future suppliers is a reasonable mitigation method too. Oil import requires that someone is able to export. Therefore, the potential countries that can supply China in the future will become quite limited. Selecting suitable suppliers and engaging in reasonable long-term cooperation and contracts can prove to be an imperative way of ensuring access to the necessary oil imports in a future world where oil becomes increasingly scarce and the number of oil exporters diminishes. Feng Lianyong et al[60] also points to the importance of forging new relationships.

Lastly, energy consumption and demand reduction were identified as a possible countermeasure with significant energy saving potential. Improvement of energy efficiency in the heavy industry as well as other sectors is targeted in the 11th Five-Year Plan, spanning from 2006–2010, but future plans should pursue energy efficiency even more forcefully given the huge potential for energy consumption reductions. Rebound effects must also be considered and properly handled. This category also includes lifestyle changes and the need to adopt a more sustainable existence than a Western consumption-based way of life.

5 Conclusions

The Chinese petroleum industry has managed to keep many of their giants on a production plateau for many decades. The achievements in Daqing are impressive, resulting in stable and sustained production over many decades. However, nothing can change the eventual onset of decline in oilfields and many of the Chinese giants have already passed their peak production levels (Figs. 3–7). In addition, the other giants seem to be near their maximum production levels and about to enter the decline phase in the foreseeable time. The result is that a considerable drop in the oil production from the Chinese giants can be expected over the next decades (Fig. 13).

There is also a possibility that our projection is optimistic, as prolonged plateau phases and utilization of secondary/tertiary recovery methods have been shown to come at the expense of a steeper future decline[9–10,57]. Whether the production collapses or deviates significantly from the historical trend in Daqing and other fields remains to be seen, but should it do so, the consequences would be dramatic. In essence, this can be seen as a policy question of whether a prolonged plateau with a rapid decline is preferable compared to a shorter plateau with a gentler decline.

There is an increasing demand for oil in China with the continuous and steady growth of its economy, in the latest decade the average economic growth rate is 9.5% and oil consumption growth rate is 6.5%. However, the average oil production growth rate was only 1.5% during the latest decade. For Chinese policymakers, it is worth paying attention to the problem of whether oil production in new oilfields or small oilfields can effectively make up for the decline in oil production of the giant oilfields. With more and more Chinese giant oilfields passing their peak of production, the conflict between demand and production will become more apparent. With stagnant or decreasing domestic production and increasing demand, the call on imported crude would be significant. Continued reliance on oil will force China into greater import dependence, and even further once domestic oil production begins to falter. Rising trends for imported crude oil and oil products should be a warning sign for policy makers that want to avoid becoming too dependent on foreign oil supplies.

Finally, it is welcome news that China's National Energy Administration issued its "*Development Plan of New Energy Industry*" in 2009. The plan calls for an investment of more than 3×10^{12} Yuan in new energy industries between 2009 and 2020. China should lessen the dependence on conventional fossil energy, although it is difficult. Long-term energy supply and energy security must ultimately be sought from other non-fossil energy sources and in new, more efficient ways of utilizing energy[61].

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