Smart Technology for Marginal Field- Radial Jet Drilling & its Hydraulic Optimization

College of Engineering Studies

University of Petroleum & Energy Studies

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By:

Abhijeet Narang (R870212001)

Prashant Chaubey (R870212025)

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Smart Technology for Marginal Field- Radial Jet Drilling & its Hydraulic Optimization

(Final Project Report)

Submitted by

Abhijeet Narang

Prashant Chaubey

In partial fulfilment for the award of the degree of

Bachelors of Technology in Applied Petroleum Engineering with specialization in Upstream

Under the guidance of

Dr. Pushpa Sharma

(Mentor)

Approved

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Dean

College of Engineering Studies

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April, 2016.

CERTIFICATE

This is to certify that Abhijeet Narang and Prashant Chaubey, students of B.Tech Applied Petroleum Engineering (Upstream) have written their thesis on "Smart Technology for Marginal Field- Radial Jet Drilling & its hydraulic Optimization" under my supervision and have successfully completed their project within stipulated time.

Dr. Pushpa Sharma

(Mentor)

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Finally, yet importantly, we would like to express our heartfelt thanks to our families for their blessings and for their encouragement for the successful completion of this project.

DECLARATION

This is to certify that we, Abhijeet Narang and Prashant Chaubey, did our major project under Dr. Pushpa Sharma on the topic "Smart Technology for Marginal Field- Radial Jet Drilling & its hydraulic Optimization"

Abhijeet Narang | Prashant Chaubey

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1. ABSTARCT

Marginal field refers to a prospect which at a given point of time may not be economically viable to develop due to constraints which maybe- economical, technological, geographic or geologic in nature, at that given point of time. In recent times the development of Marginal fields is being viewed with increased interest as the world's mature fields undergo a steady decline and the discovery of large fields becomes more and more occasional. However, the development of such "small" fields cannot be done on same pattern as for the conventional fields, as they may not prove economical and profitable for a company.

Moreover, there are certain problems that occurs in a field even once it is put to production which may lead to a lower productivity than expected. Formation damage, wax deposition etc. can be some of the causes for this lower productivity. Well stimulation to attain better productivity is quite an expensive and human resource intensive process and can be undertaken only when economics from the field is justified. Marginal fields does not have a higher rate of return, so such well stimulation techniques can prove to be very expensive and uneconomic. Newer technologies are hence needed to be implemented to marginal fields to increase productivity keeping in mind the economics.

Radial Jet Drilling (RJD) is one of such technique which we have undertaken under this project to be applied in a marginal field to improve productivity with better economics, since it is a comparatively cheaper process. Under this project we have done a brief literature review of the marginal fields, Indian scenario of marginal fields, challenges in a marginal field etc. which is then followed by a review of RJD technique and hydraulics optimization of RJD technique on MS Excel based on various force and pressure loss equations.

Deliverables:-

Under this project work, our aim was to develop a hydraulic optimization of RJD technique for marginal fields on MS Excel which may prove to be economical and environment friendly at the same time. We have considered all the aspects of RJD technique and based on that we have presented a new model for hydraulics optimization of RJD technique for marginal fields which will be completely based on MS Excel software, further, user may enter their data on our model to get optimum flow rate for efficient drilling.

Keywords: - Marginal Field, Radial Jet Drilling, hydraulics, formation damage

2. OBJECTIVES

- To do a brief literature survey of marginal fields in order to understand the basic concepts.
- To understand the challenges faced in monetizing a marginal field and pinpoint various approaches to increase productivity from a marginal field economically.
- To do a literature survey on the chosen technique i.e. Radial Jet Drilling (RJD) to understand the basic concepts and the hydraulics involved in the above process.
- To devise a model based on MS Excel to optimize the overall system of RJD process.
- To validate the above model using a case study.

3. CHALLENGES

- Limitation of data
- Vastness of the subject and available literature.
- Time constraint
- Involvement of complex mathematical function and solving methods
- No such previous model to analyze the hydraulics was present so it was new and we tried to incorporate all the associated formulae into excel, developing graphs, which was an arduous task.

4. INTRODUCTION

Marginal field refers to a prospect which at a given point of time may not be economically viable to develop due to constraints which maybe- economical, technological, geographic or geologic in nature, at that given point of time.

The term 'marginal field' in some cases may refer, for various reasons (geologic, geographic, technological, pricing or taxation) and under given economic conditions, the development has been unviable by conventional methods and for standalone conditions. This calls for integration of fields and facilities. This 'marginality' depends on the projected profiles/ volumes, price and the development cost. In other words, the exploitation of hydrocarbon from such fields gives profit margin below a benchmark level, thus referred 'marginal'.

Nearly half of the world's proven reserves of oil lie offshore and it is estimated that over two-thirds of all future oil discoveries will also be located offshore. But in any oil exploration area it is the larger fields which tend to be found first and even when small discoveries are made the oil tends to be left in the ground as the oil companies rush to develop the larger and more commercial fields. Classification of a discovery as 'commercial', 'uncommercial' or 'marginal' depends on a combination of many factors, economic, technical and political, and is not necessarily indicative of the size of the field. A useful definition of the three terms would be:-

- <u>Commercial</u> — the prospect yields an economically attractive rate of return to the oil company when conventional technology is applied to its exploitation.
- <u>Uncommercial</u> — the prospect is unlikely to yield an economic return to the oil company under any foreseeable technical or fiscal scenarios.
- <u>Marginal</u> — the prospect may be capable of yielding an economic return to the oil company.

As noted above, the 'marginal' field as generally understood is primarily an economic concept rather than a technical one. An offshore field is considered marginal if it cannot be developed at a reasonable profit using tried and tested, or conventional technology.

While there is no general rule constituting what is an acceptable return, it appears that most companies regard a 7% to 15% real rate of return as being 'marginal'. If the projected return is less than this level the development is usually postponed, while at higher rates the project could be expected to proceed. Oil companies share a characteristic which is common to most economic entities— they are not charities. It is quite natural that they should develop their more commercial discoveries first. However, offshore exploration and oil production has now been underway in the harsh northern latitudes for more than a decade. During that period a considerable number of marginal fields have been discovered. Indeed many fields which were quite uncommercial when they were found are now considered marginal as a result of the dramatic oil price increases since 1973 and recent technological advances

S. NO.	Country	Definition
1	Egypt	Fields that have recoverable reserves near the range of 5 million barrels of oil.
2	Netherlands	Defines for gas field, if it has gas reserves of less than 4 thousand million cubic meters.
3	United Kingdom	Termed marginal if it has equivalent of 20 million barrels of oil.
4	Malaysia	If the field can produce less than 30 million barrels of oil equivalent.
5	USA	Oil wells that produce less than ten barrels per day or less for a 12 month period.
6	Nigeria	As decided by President or non-producing after 10 years since discovery.

Table 1 - Different definitions of a marginal fields in various countries (ref. source: SPE 178347)

In recent times the development of Marginal fields is being viewed with increased interest as the world's mature fields undergo a steady decline and the discovery of large fields becomes more and more occasional. However, the development of such "small" fields cannot be done on same pattern as for the conventional fields, as they may not prove economical and profitable for a company.

Marginal fields can be produced either by tie-back to existing facilities. Or in a stand- alone scheme in which case joint development of several marginal fields could be considered. There are many challenges in both the options which we have to face while development and production stages which need to be taken care of.

As stated above, the marginal fields cannot be developed in the same way a mammoth field is developed hence the alternative approach to the use of fixed platforms is to consider the use of what we call 'Marginal field technology', i.e. technology which aims to have the following characteristics:

—Low capital cost—this generally involves a trade-off with higher operating costs and decreased reliability.

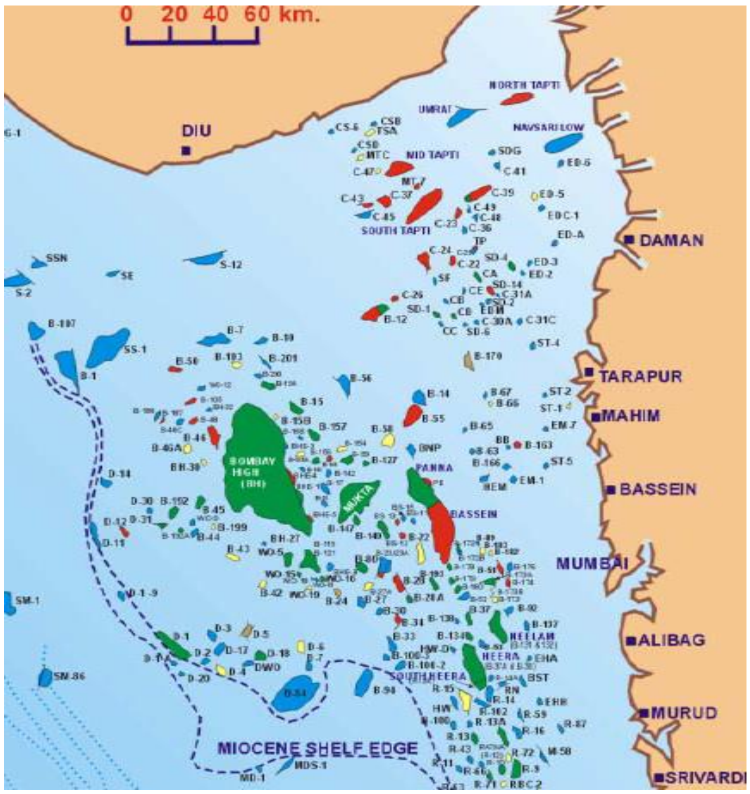
—Rapid development period—thus reducing the time from start of expenditure to first oil.

—Suitability for short-term use—thus promoting mobility and reuse of the system on other fields.

—Amenable to innovative financing.

5. INDIAN SCENARIO OF MARGINAL FIELDS

Currently ONGC has more than 165 fields which comes under small and marginal field category which have a total reserves of more than 297 MMT. The concerted efforts in term of human resources, newer technologies and better economic policies has led to monetization of 62 fields till date while 60 fields are in various stages of development and monetization, 30 fields are at exploration stage and 13 fields are proposed for cluster development. Western offshore fields account for majority of reserves which are scattered over a very large area as show in figure below:-



(ref. source SPE 155145)

Till year 2000, development of these fields was uneconomical mainly due to their isolated location, low in-place volumes (distributed in multiple pays) and huge cost required for offshore facilities coupled with the 'economically viable window' that needed to fit into the given hurdle rate. Now these fields are being developed by ONGC using two types of development strategies:-

(A) <u>In house Development</u>: - which includes clustering, utilization of nearby in house facility, sharing the infrastructure of JV, converting old rigs to MOPU, CAPEX and OPEX optimization, hiring of FPSO, batch drilling and concurrent exploration.

(B) Development through Service contract: - Here ONGC gives the field on lease to other companies which develop it and share products or profit. Generally smaller companies prefer marginal fields as economics can be justified in their case.

Following tables gives the detailed status of marginal fields in India:-

Total marginal fields: - 165
Western offshore: - 58
Eastern offshore: - 21
Onshore: - 86

S. No	Category	No. Of Fields	% in place reserves	% ultimate reserves
1.	Fields on production	62	40.09	45.51
2.	FR approved	23	19.51	24.96
3.	FR under preparation	2	0.25	0.46
4.	Under service contracts	9	0.30	0.60
5.	Under monetization	8	0.78	1.40
6.	Identified for outsourcing	26	5.93	4.36
7.	Under exploration	21	17.51	4.10
8.	Hub Development	13	15.62	18.94
9.	Surrendered	1		
	TOTAL	165	100.00	100.00

(ref source One petro -SPE 155145)

5.1 <u>Status of offshore marginal fields in India</u>:-

(a) Western Offshore-
Total fields= 58
Scheme made= 37
On production = 15
84.01% of in place is accounted for monetization.

(b) Eastern Offshore-
Total fields= 21
Scheme made= 2
On production= 3
10.84% of in place is accounted for monetization.

5.2 <u>Status of onshore marginal fields in India</u>:-

Total fields= 86

(a) Western on land –
Total fields= 23
On production=12
94.03% of in place is accounted for monetization.

(b) Eastern on land-
Total fields= 63
On production= 32
90.38% of in place is accounted for monetization.

5.3 Resolution- Marginal field Policy of India (15-Oct-2015)

Many of the Marginal oil and gas fields of Oil & Natural Gas Corporation Ltd (ONGC) and Oil India Ltd (OIL) could not be monetized for years due to various reasons such as isolated locations, small size, prohibitive development costs, technological constraints, unfavorable fiscal regime, etc. On 2nd September, 2015, the Cabinet has approved the Marginal Field Policy (MFP) with the objective to bring marginal fields to the production at the earliest so as to augment the domestic production of oil and gas. Government has attempted to include certain reforms in the hydrocarbon exploration and production management through this policy with sole intention to increase the production at the earliest. The salient features of this policy are given below:

1. Single license for conventional and nonconventional hydrocarbons: - A single license will be provided to enable E&P operators to explore and extract all hydrocarbon resources covered under the Oilfields Regulation and Development (ORD) Act, 1948, and Petroleum and Natural Gas (PNG) Rules, 1959 under one PEL/PML. This will enable the contractor to explore conventional and unconventional oil and gas resources including CBM, shale gas/oil, tight gas, gas hydrates and any other resource to be identified in future which fall within the definition of "Petroleum" and "Natural Gas" under PNG rules, 1959.

2. No restriction on exploration activity during Contract Period: - The contractor will be allowed to carry out exploration activity during entire contract duration. Exploration will be at the sole risk and cost of the contractors.

3. Model for inviting the bids: - Bids will be invited for the Marginal Fields on a Revenue Sharing Contract (RSC) Model. To ensure viability of operations, it is proposed to cluster fields / discoveries, as may be required at the time of Notice Inviting Offer (NIO). This revenue sharing model will be based on a revenue based linear scale. The contractor shall be required to pay biddable Government share of revenue (net of royalty or post royalty).
A simple and easy to administer contractual model in line with Government's efforts to promote 'Ease of Doing Business' requiring minimum regulatory burden for monetizing these fields has been developed.

4. Crude Oil Pricing and Sale: - The contractor will be free to sell the crude oil exclusively in domestic market through a transparent bidding process on arm’s length basis. However, for the sake of calculation of Government revenue, the minimum price will be the price of Indian Basket of Crude Oil (currently comprising of Sour Grade (Oman & Dubai Average) and Sweet Grade (Brent Dated) of Crude Oil processed in Indian refineries) as calculated by Petroleum Planning and Analysis Cell (PPAC) on a monthly basis. If the price arrived through bidding is more than the price of Indian Basket of Crude Oil then the Government's take will be calculated based on the actual price realized.

5. Natural Gas Pricing: - The contractor will have freedom for pricing and allocation of gas produced from a cluster / field / discovery on arm's length basis. The Government share of revenue shall be calculated as per the Domestic Natural Gas Pricing Guidelines in vogue at relevant point of time. However, if the discovered price is more than the calculation based on the Domestic Natural Gas Price Guidelines issued by the Government from time to time, then the Government's take will be calculated based on actual price realized.

6. Royalty: -Royalty rates applicable under New Exploration Licensing Policy (NELP) regime will be adopted in the Policy for Marginal Field of ONGC and OIL.

7. Oil Cess: -No oil cess shall be applicable on crude oil production from marginal fields.

8. Customs Duty: -Exemption from custom duty will be provided on all machinery, plants, equipment, materials and supplies related to petroleum operations as applicable in NELP.

9. Mining Lease: -Current Mining Lease holder will be required to transfer/assign the Mining Lease (ML) or Petroleum Exploration License (PEL) along with all available clearances to the awardee of the area/ Contractor, to the extent legally possible, or else the Contractor has to obtain the same. Lease / License rent / fees will be governed as per ORD Act 1948 and P&NG Rules 1959 as amended from time to time.

10. Contract Duration: -The contract duration for development and production from the offered Marginal Fields would be a maximum of twenty years from the effective date (effective date is the date of PEL/ML grant/ transfer /signing of deed) or till the economic life of the field as submitted by bidder along with development plan in the bid, whichever is earlier, unless the Contract is terminated earlier in accordance with its terms, but may be extended upon mutual agreement between the Parties for a further period not exceeding ten years. If the production of Crude Oil or Natural Gas is expected to continue beyond the end of the relevant period referred above, the Parties may agree to extend this Contract for a further period upon such terms as may be mutually agreed. The contract can be extended based on the provisions of the contract and extant GOI guidelines, if any. Contract can be terminated earlier by GOI if the production from the offered Marginal Fields ceases for a period of over one year at any instance.

11. Management Committee: - A Management Committee (MC) will be constituted with representatives from Government/DGH and contractor.

12. Eligibility for participation in bids: - National oil Companies, Indian Private Companies and foreign companies either alone or in joint venture can bid for the offered marginal fields. Up to 100% participation by foreign companies, joint ventures will be allowed.

13. Site Restoration: -The site restoration fund shall be maintained by the contractor, as per the notified "Site Restoration Fund Scheme1999", as amended from time to time. The activity of site restoration will be done as per applicable rules / standards /notifications.

6. CHALLENGES FACED IN MARGINAL FIELD DEVELOPMENT

On a broader basis there are three main enemies in developing a marginal fields:-

1. The uncertainty of DATA
2. The uncertainty of TIME
3. The uncertainty of PROFIT

Out of the above, the data acquisition problem refers to the exploration problems which includes:-

- Heavy data acquisition is an impossible choice in marginal fields
- One or two discovery wells is only possible economically and 3D seismic is must
- Appraisal drilling, long duration tests, are not applicable
- Further, the number of wells required cannot be freely played with, as economy cannot bear MULTIPLYING the number of wells
- Limited to use of horizontal wells, multi branched wells and hydraulic fracturing.

As in the case of uncertainty in TIME, we have certain constraints as:-

- We have to go fast with the development to cope up with the short production period.
- Formation damage is not at all bearable and must be avoided at all cost.
- Hence production must be optimized to reduce the velocity to insure a good recovery and have as high a rate as possible to insure profitability.

Challenges related to production operations life includes:-

- The uncertainty in total expenditure and profit generated from such fields, require transferring costs from CAPEX to OPEX.

1. Talking of the platform required to develop an offshore field, generally jackets are preferred for various reasons but when a field is depleted a fixed structure becomes a major liability. However, this is not a problem if the field is in production for the 15 or 20 years typical of large offshore developments. However, when one considers a marginal field which may only produce for three to seven years, the non-revisability of a fixed platform which cannot be redeployed has to be amortized over the brief life of the field.

2. Apart from the development scheme to be followed, the ever fluctuating oil prices pose a major challenge to the development of marginal offshore fields. Currently, the oil prices are fluctuating around $40 a barrel, which has converted many marginal fields into uncommercial prospects and developing them will not yield any profit.

3. It must also be borne in mind that every offshore development involves the State as a partner, either indirectly through the various combinations of taxes and royalties, or directly by reason of

state participation agreements. Any change in the fiscal environment can affect the economics of an offshore prospect much more rapidly and effectively than developments in technology. This is clearly evidenced by the boost given to marginal field developments by recent favourable changes in the tax code. Similarly, a drop in interest rates or increase in oil prices can dramatically improve marginal field economics and vice versa. However, it is worth remembering that changes in technology, capital costs, the oil price, tax rates, interest rates etc. *will not eliminate marginal offshore oilfields.* These changes will merely shift the margin to put even less attractive accumulations into the 'marginal' category.

4. Production facilities are a major economic constraint for exploring and developing marginal offshore fields. If you consider the subsea tree, production lines to the FPSO, injection capabilities, and flow assurance the economics are poor for developing a small field of 20 to 50 million bbls of recoverable oil with three to six wells. There needs to be an innovative solution that provides a production system that is very modular and adaptable to production rates of 10k to 25k BOPD, able to provide early injection of water and gas, provide some oil storage. And all of this needs be very cost effective.

5. Productivity uncertainty is another constraint. Sand production at the time of testing may indicate a lower production from these fields, formation damage due to various reasons can also lower the productivity. Such condition will require well stimulation techniques which are not economically feasible generally, especially for a marginal field where the profitability is not too high. Hence some technique to increase productivity is required. Moreover, such a technique must be economically viable.

6. Flow assurance is another constraint, especially in subsea production systems which are generally used nowadays in marginal fields.

So, we can say that the major challenges we face in developing a marginal field are:-

- Oil and Gas price (Future Predictions are almost impossible)
- Small Recoverable Reserves are dealt with.
- Characteristics of the reservoir like sand production, wax formation etc.
- Remote Location
- Legislation, especially fiscal regime.
- Hurdle Rate i.e. internal rate of return.
- Expensive well stimulation and other processes which are not viable in marginal fields.

Major exploration and production players across the world have taken up various strategies to exploit these marginal fields. Some of the approaches are listed below:-

- Focusing on newer technologies to improve the economies.
- Integrated Development- combining economically viable field with marginal fields
- Leasing out such fields to smaller operators to have a lower overhead cost.
- Emphasize on accurate estimation of reserves, RF and development cost.
- Improve the productivity of such reservoirs by adopting new and economically viable techniques.

As discussed above. It is very essential to increase the productivity of such marginal fields by applying various new technologies that are both efficient and economically viable. We have pinpointed certain technologies which are being used in this respect:-

1. Multiphase Flow System with proper designing
2. Cable Deployed ESP
3. Dual ESP System
4. Extreme Overbalance Perforation
5. Gas lift using coiled tubing
6. Vapor Extraction
7. Formation Damage Control Strategies
8. Multilateral technology
9. Slim-hole technology
10. Radial drilling
11. Heavy oil steam system (radial drilling + steam injection + dual completion)

Out of the above technologies, radial drilling technique has been efficiently used to increase productivity in various fields. It can be applied to a marginal field as it is very economical and covers the aspect of formation damage control strategy, slim-hole technology, and to certain extent the concept of multilateral drilling technology. Radial drilling technology can also be used to optimize the economics in a marginal field, hence, under this project we have considered this technology as a means to improve productivity of a marginal field. We have taken the hydraulics optimization of a radial drilling operation under this project.

7. Formation Damage and its mitigation

As discussed in the previous section, reduction in the productivity of the field is one of the main challenge in any type of field whether commercial or marginal. The reduction is productivity is mainly due to the formation damage that may occur during the lifetime of a field. Formation damage can be defined as any reduction in near wellbore permeability which is the results of any stuff we are do like drilling, completion, production, injection, attempted stimulation or any other well intervention. This reduction in permeability can be defined by a dimensionless entity called skin effect. A positive skin is associated with reduction in permeability while negative skin has the reverse effect.

A positive skin or can be due to many reasons like mechanical causes such as partial completion and inadequate number of perforations, by phase changes and by natural reservoir permeability. Modern well perforation are done using a perforation gun that is attached to a wire line or coiled tubing which allows a good perforation density with small phasing , however a positive skin effect is associated with this type of perforation technique. On a similar pattern there is a damage skin effect associated with horizontal wells.

Formation damage can be caused by plugging of pore spaces by solid particles, by mechanical crushing or disaggregation of the porous media, or by fluid effects such as creation of emulsions or changes in relative permeability. Plugging of pores by solid particles is the most pervasive of these mechanism and can result from many sources, including injection of solids into the formation, dispersion of clays present in the rock, precipitation and growth of bacteria etc.

Impact of damage to the economics can be understood by the fact that Shell estimated that at oil price of less than $20/barrel a total of $1billion/year will be the total cost of damage. Further at price of $70/barrel, estimate for cost of damage due to deferred production and dealing with damage rose to $100,000,000,000/year.

In case of a mammoth field where more recoverable reserves are present and a greater rate of return is expected, the above cost of damage is accountable. However, in marginal fields, formation damage can be a very serious issue as the cost for mitigating the damage is quite high and generally uneconomical. Various techniques can be used in order to mitigate the formation damage like Acid Stimulation or matrix acidization, hydraulic fracturing , acid fracturing , bypassing the damage zone etc. However all these techniques are quite complex and require careful designing and simulation before they can produce effective results.

Newer technologies of well stimulation to increase the productivity have been devised now a days which are cheaper and more environment friendly. Some of them are already highlighted in previous section. The conventional simulation techniques are expensive and labor intensive and require a multi-disciplinary expertise to carry out and hence these cannot be implemented in a marginal field.

Technologies like multilateral drilling, slim-hole technology and radial drilling can be suitable and economically viable in a marginal field and hence we will focus on radial drilling under this project work.

8. Radial Drilling Technology

With a world context of low oil prices and a rate of increase in reserves from new discoveries, that is not enough to compensate the rate of extraction, in addition to the high maturity of oilfields currently being developed worldwide, companies have been working to improve the recovery factor of reserves, as a strategy to extend the useful life of the existing assets. Working in this direction, radial drilling technology seems to be an alternative, which, in spite of the fact that it currently raises uncertainty since it has never been tested in the past in or country, can be adapted to the existing wells thus becoming a low investment alternative.

With growing global energy demand and depleting reserves, oil well stimulation has become more important. In all of these reservoirs, formation damage is a headache problem which needs to be treated. One of the proposed techniques is to bypass the damaged zone. Radial drilling can provide a solution with lowest costs than the others. Increasing production and rising usable reserves from known horizon now a days has been a very good motivation for development of a new technologies. One of these new technologies is radial drilling technique. *“Radial drilling technique utilizes hydraulic energy to create several lateral holes in different directions and levels with several lengths. These lateral holes are made by milling the casing with small bit then by extending these holes laterally using high pressure hydraulic jetting.”*

The technology involves drilling lateral horizontal bores of small diameter and up to one hundred meters long, with the possibility of placing several within the each productive layer. Radial drilling is a technique that can create several small diameter drains from the well in a relatively short time, fast method to rehabilitate and optimize oil and gas wells, perforates 25-50 mm diameter holes in the casing, using high pressure fluid at selected depths, a hole of about 100 Mt long is created perpendicular to the mother well.

Radial drilling process consist mainly of three stages, first stage is milling casing with a bit size ranging from 3/4" to 2", second stage is using hydraulic jetting to create holes with a certain length and the last stage is washing out the formation while pull out of hole this technique has a various benefits than other combatants such as low environmental risk, low cost and applicable when other stimulation techniques not applicable “in layers closed to OWC”. For this evaluation, pilot tests were performed in different oilfields, with the intention of covering a wide range of possible scenarios and being able to evaluate the best applications for this new alternative.

This technique was applied first time in Egypt in 2010; the main objectives were to find an appropriate and/or alternative for conventional completion and stimulation technology. Theoretically creating a small diameter holes with long depth of penetration (aims to or should achieve an increase in productivity index, increasing apparent pay thickness, eliminating permeability barriers in the reservoir and increasing the recovery factor.

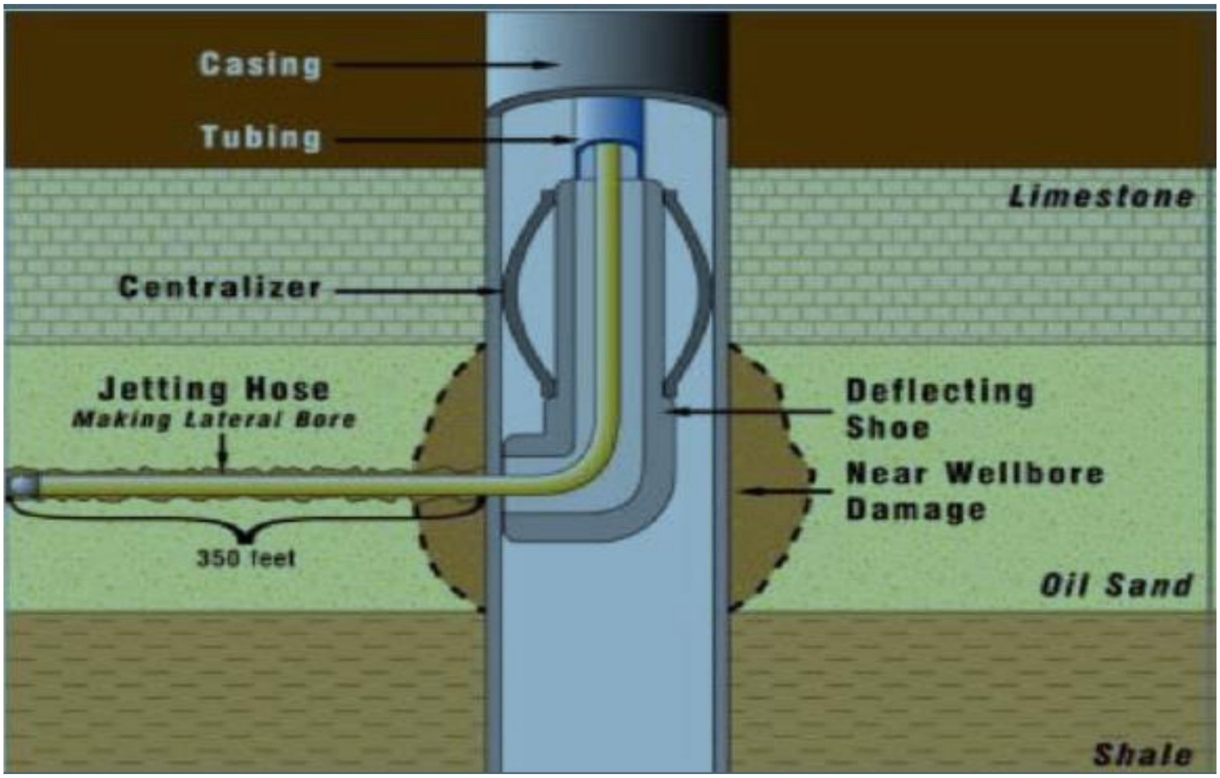


Image 2- Radial Drilling Down hole Equipment (ref source petrowiki)

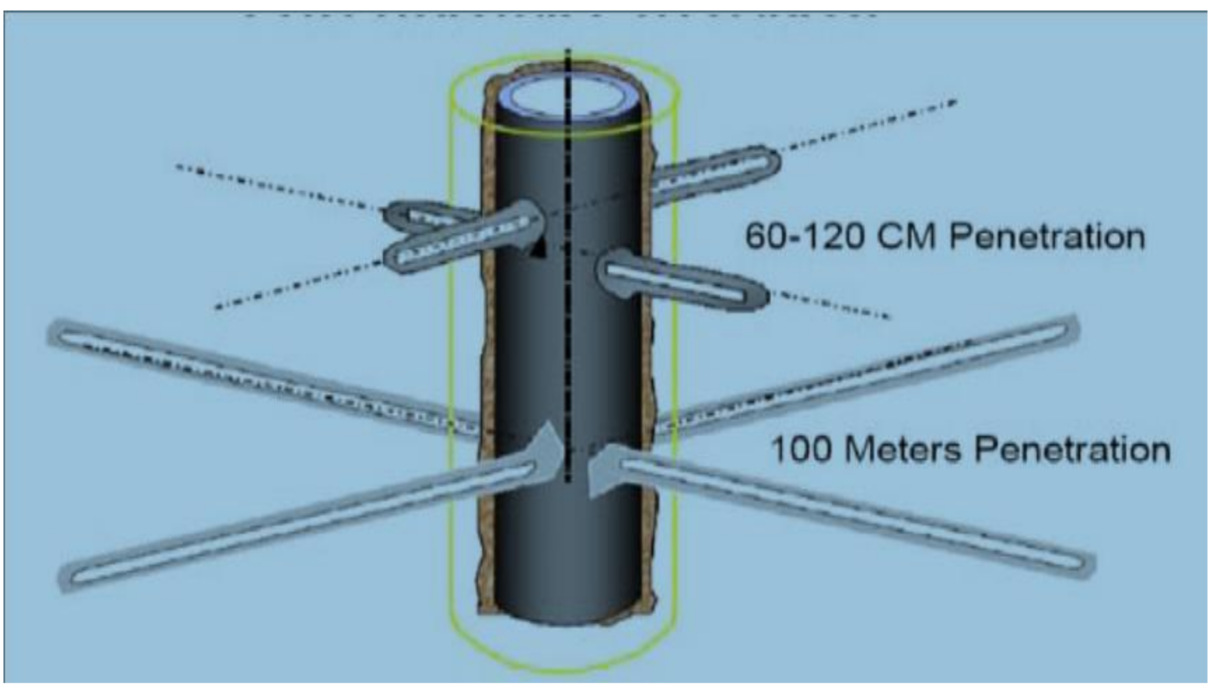


Image 3- RD holes compared to normal perforations (ref source petrowiki)

This application combines the following important factors:

- Low cost, it is applied to existing wells (new wells are not required).
- Low geological uncertainty.
- Low environmental risk.

Among various reasons for this technique to increase production, the following could be highlighted:

- Improves the conductivity of an important area around the well (improving drain efficiency).
- Possibility to define direction of the perforations.
- Helps the mobilization of viscous oils.
- Connects to areas of better petro physical conditions
- Allows intervention of oil reservoirs limited by close by aquifers.

The most expected advantage of RJD is to increase the productivity index through horizontal perforations increasing the apparent pay thickness and eliminating permeability barriers in the reservoir; as well as increasing the recovery factor through the improvement of drain efficiency. In addition, this technique could replace or complement other conventional stimulation techniques that are used to increment production such as hydraulic fractures and matrix stimulations especially in fields where the rate of return is not too promising or where conventional techniques are not economically viable like in the case of a marginal field.

Greater horizontal penetration in the reservoir increasing the apparent pay thickness, low vertical development (Intervene in oil reservoirs limited by close-by aquifers) and option to define direction of the perforation are some of the added advantages of this process.

8.1 Selection of wells: -

In order to evaluate and define the representative group of wells for the pilot Project, a multidiscipline team of Workover Engineers, Reservoir Engineers, Geologists and technical personnel and operational personnel from the radial drilling company was gathered taking into account the following considerations for the selection of the wells:

- Electrical open-hole logs to define the petro physical characteristics of the reservoir and select the best section to intervene.
- Observation of lateral cores, evaluation of amount of sand in tests, wells close to failures, etc.: to evaluate the consolidation of the formation, avoiding those that have unconsolidated or friable sands.
- Data from TST, RFT, etc., considering that the pressure reading not be inferior to 45% of the original.

- Well spacing, petro physical data (permeability, porosity, water saturation, etc.), thickness of the productive formation and production data.
- Water-oil and gas-oil contacts so as not to connect with undesired fluids.
- Type of well, vertical or directional
- CBL-VDL-CCL electrical logs as they are necessary to have good cement between the casing and the formation to back up the Jetting outlet.
- Casing mechanical status to avoid collapse, as up to four bores at the same level will be made.

8.2 Description of Radial Drilling Equipment: -

It basically has a Coiled Tubing special unit and fittings.

1. <u>Unit</u>:

Similar equipment to a Coiled Tubing with the following characteristics:

- ½ inch pipe, up to 13500 ft. long and 10000 psi working pressure.
- Monitoring and command cab.
- Source of hydraulic power.
- Triplex pump (2 - 5 gpm) of low flow rate and high pressure (10000 psi)
- Injection head with hydraulic drive (pull = 10000 lbs) optional, only for units operating more than 6500 ft.

2. <u>Fittings</u>:

Anchor: lowered with the work string of the Workover unit and has three functions:

- Maintain the tool outlet hole on the side of the casing; the positioning is just with a simple pressure generated by a band located on the opposite side.
- Guide the tool to go from vertical to horizontal in 1 ft. through a forged duct in the interior.
- Prevent reactive torque of the down-hole motor while the casing is perforated, through longitudinal guides where a groove is located on the body of the motor.

BHA for the perforation of the casing, formed by the following elements:

- Mill
- Elbow or articulated joint
- Nipple with lock
- Down-hole motor

Drilling BHA

- Jet with three bores oriented forward and three towards the back.
- Kevlar flexible hose, deflector sub and gyro tool.

Image 4- Coiled Tubing Surface Unit (ref source petrowiki)

Image 5- RJD BHA showing centralizer, gyro tool and deflector sub (ref source petrowiki)

8.3 Radial Drilling Process and Field Operation: -

Before starting the three steps of radial drilling, we first run in hole with deflector sub, one side centralizer to fit and guide the tool form vertical to horizontal and gyro tool for orientation on drill pipes.

The three steps are performed as follow.

1. First Step (Milling the Casing): - Is consisting mainly of a milling bit with a specific size the used size was 1 ¾" bit connected with flexible shaft both are rotated by conventional mud motor connected to coiled tubing up to surface connected to coiled tubing unit with its monitoring system.

2. Second Step (Jetting Formation): - Jetting the formation with nozzle has three opening oriented forward and three oriented from backward connected to a 0.5” hose. The jetting is performed with a pressure greater than fracture pressure of the formation, the pressure range from 7000 psi to 10000 psi.

3. Third Step (Washing out the Formation): - out the formation accomplished by pulling out the hose and while Pull out of hole we keep pumping through the operation.

8.4 Mechanism of Penetration

Bruni.et.al, reported that four main penetration mechanisms were identified in RD operation; surface erosion, hydraulic fracturing, poroelastic tensile failure and cavitation.

- Surface Erosion: - is the process where the rock fragments are removed from the surface of the rock due to the shear and compression forces exerted on the rock surface due to jetting force.
- Hydraulic Fracturing: - The same theory of hydraulic fracturing stimulation, as the pressure increase at the stagnation point diffuses in to formation, the formation may fail or crack if this pressure is higher than the stresses set by formation stresses.
- Poroelastic Tensile Failure: - A rapid fluid pressure decrease at the rock surface will induce effective tensile stresses in the formation equal to the decrease. If this induced tension is higher than the sum of the smallest effective stress in the formation and the tensile strength, the rock will fail in tension. This induced tension occurs as the compressibility of the rock grains and pore fluid is not equal, and any deviation from equilibrium between the rock grains and pore fluid has to be restored by fluid flowing through the pore space. This flow takes time due to the finite permeability of the rock, and gives rise to this transient poroelastic effect. However, for high permeability sandstones the time scale is around 1 µs, which may be unrealistically fast. However, the time scales inversely with the permeability and for chalk (1 md) or shale (1 mDarcy) this effect may be important
- Cavitation: -When the water accelerates to pass through comers of the nozzle, the pressure may drop below the vapor pressure. This may cause vapor bubbles to form as the flow moves into a larger area, the pressure recovers to a certain degree. This

increases the pressure above the vapor pressure, causing the vapor bubbles to collapse or implode. The shock waves may be extremely high and cause additional erosion and tension effect.

The net forces that affect to drive jetting nozzle forward can be derived from three main mechanisms; under pressure force, jetting force and ejector force. The main mechanism is jetting force mechanism.

Image 6- Mill Bit

Image 7- Jetting Nozzle for RD

(ref source petrowiki)

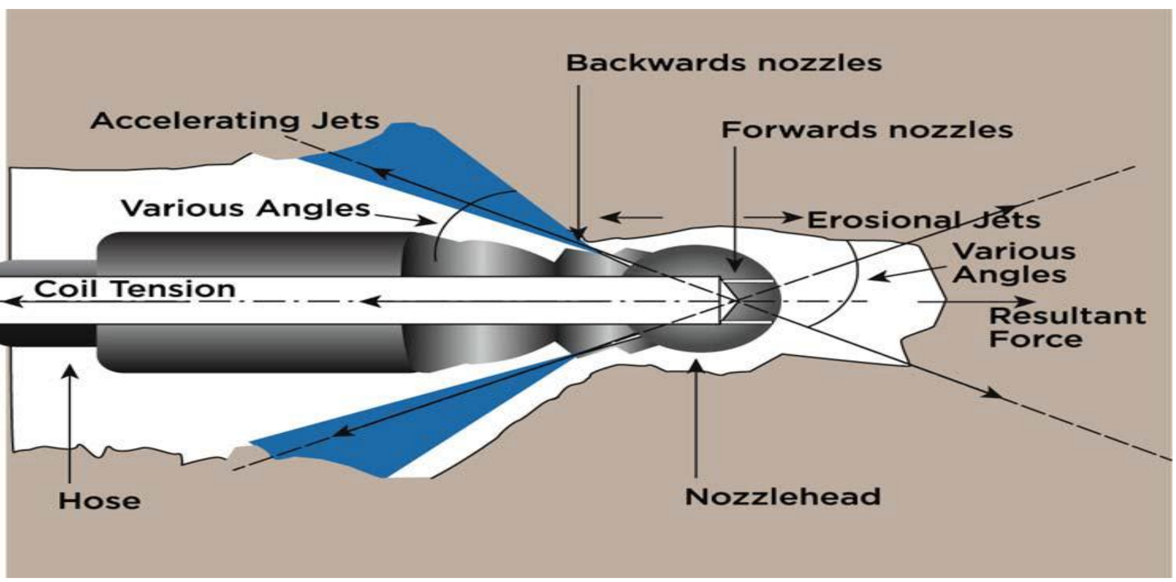


Image 8- Mechanism of Penetration (ref source petrowiki)

8.5 Hydraulics Optimization:

In the present project we have undertaken the optimization work of a Radial Jet Drilling (RJD). Before this we need to understand the RJD system and its components and for ease in understanding of the calculation and optimization process done here, we have already detailed description of the system in above text.

As the fluid flows, pressure keeps on dropping through the various components of system. The pressure losses are governed by the flow rate of the fluid inside the system. Higher the flow rate, higher is the pressure drop against bit which eases the drilling process. But at the same time the flow rate are limited by the yield pressure of coiled tubing and high pressure hose.

In the optimization process, we have established an optimum flow rate that is high enough to provide best possible ROP and also manages the pressure within ranges. In order to satisfy the objective, programming has been done on **MS-Excel.** One set of calculations have been performed by taking a case exampled data-set. The optimized results have been shown below, supported by graphs, plots and numerical figures. For future work, with the help of excel files programmed, one can perform for any and different applicable cases just by substituting the values in required fields.

The pump pressure for RJD can be calculated as follows:

$$\Delta PL = \Delta P_{CT} + \Delta P_{ST} + \Delta P_h + \Delta P_b \quad \text{(1)}$$

Where, ΔP_L is the pump pressure (MPa), ΔP_{CT} is the pressure loss in spiral section of CT (Pa), ΔP_{ST} is the pressure loss in the straight section of the coiled tubing (Pa), ΔP_h is the pressure loss in the high-pressure hose (Pa), and ΔP_b is the pressure drop at the jet bit (MPa).

<u>Pressure Loss in CT</u>. According to a steady-state mechanical energy balance, the general CT pressure-loss formula can be written as follows:

$$\Delta P_i = \frac{2fLv^2}{d_i} \quad \text{(2)}$$

Where, f is the Fanning friction factor (dimensionless), q is the fluid density (kg/m3), v is the fluid mean velocity (m/s), di is the pipe inner diameter (m), and L is the pipe length (m).
The fanning friction factor for Newtonian turbulent flow in CT has been proposed.
Substituting the coefficients f_{CT} and f_{ST}, the CT pressure loss of coiled ΔP_{CT} and straight ΔP_{ST} sections can be expressed as follows:

$$\Delta P_{CT} = \frac{0.218\,\rho^{1.05}\,L_{CT}\,Q^{2.058}}{d^{4.95}\mu^{.05}D^{0.1}\left\{\log\left[\frac{\Delta}{3.7065\,d} - \frac{3.9625\mu d}{\rho Q}\log\left(\frac{1}{2.8570}\left(\frac{\Delta}{d}\right)^{1.1098} + 4.7096\left(\frac{\mu d}{\rho Q}\right)^{.8981}\right)\right]\right\}^{2}} \quad \text{(3)}$$

$$\Delta P_{ST} = \frac{0.2025\ \rho^{1} L_{ST}\ Q^{2}}{d^{5}\left\{\log\left[\frac{\Delta}{3.7065\ d} - \frac{3.9625\mu d}{\rho Q}\log\left(\frac{1}{2.8570}\left(\frac{\Delta}{d}\right)^{1.1098} + 4.7096\left(\frac{\mu d}{\rho Q}\right)^{.8981}\right)\right]\right\}^{2}} \quad ……(4)$$

where LST is the length of the CT straight section (m); LCT is the length of the CT spiral section (m); d is the CT inner diameter (m); D is the diameter of CT reel drums (m); D is the CT wall roughness (m); l is the drilling-fluid dynamic viscosity (Pa_s); Q is the pump-flow rate (m3/s); and Lh is the length of the high-pressure hose (m).

Pressure Loss in the High-Pressure Hose. The high-pressure hose is made from a composite material and consisted of polyurethane outer layer, braided-steel-wire middle layer, and polyamide inner layer. Polyamide is a plastic used in engineering applications.

The absolute roughness of plastic is much lower than that of commercial steel. The Blasius friction factor is a simple, commonly used equation for smooth pipes. We assumed that a high-pressure hose is a smooth pipe. To simplify the calculation, we derived our model from the Blasius correlation by introducing a frictional-correction factor a.

Blasius developed the Fanning friction factor in turbulent smooth-pipe flow:

$$f = \frac{.0179}{{N_{Re}}^{0.25}}, \quad ……(5)$$

Where, N_{Re} is the Reynolds number of the fluid, defined as

$$N_{Re} = \frac{\rho v d}{\mu} \quad ……(6)$$

Substituting Eqs. 5 and 6 into Eq. 2 yields the following pressure-loss model in the smooth pipe (ΔP_{ss}):

$$\Delta P_{SS} = 0.2399 \rho^{0.75} \mu^{0.25} \frac{L}{dhi^{4.75}} Q^{1.75} \quad ……(7)$$

On the basis of Eq. 7, we can introduce a frictional-correction coefficient, a, such that the pressure-loss model of the high-pressure hose can be written as follows

$$\Delta P_{h} = \alpha \rho^{0.75} \mu^{0.25} \frac{L_h}{dhi^{4.75}} Q^{1.75} \quad ……(8)$$

Where, d_{hi} is the inner diameter of the high-pressure hose (m).

Jet-Bit-Pressure Loss. The following pressure-loss model for a multi-nozzle jet bit:

$$\Delta P_{h} = \frac{0.5136 \rho Q^{2}}{C^{2} A^{2}} \quad ……(9)$$

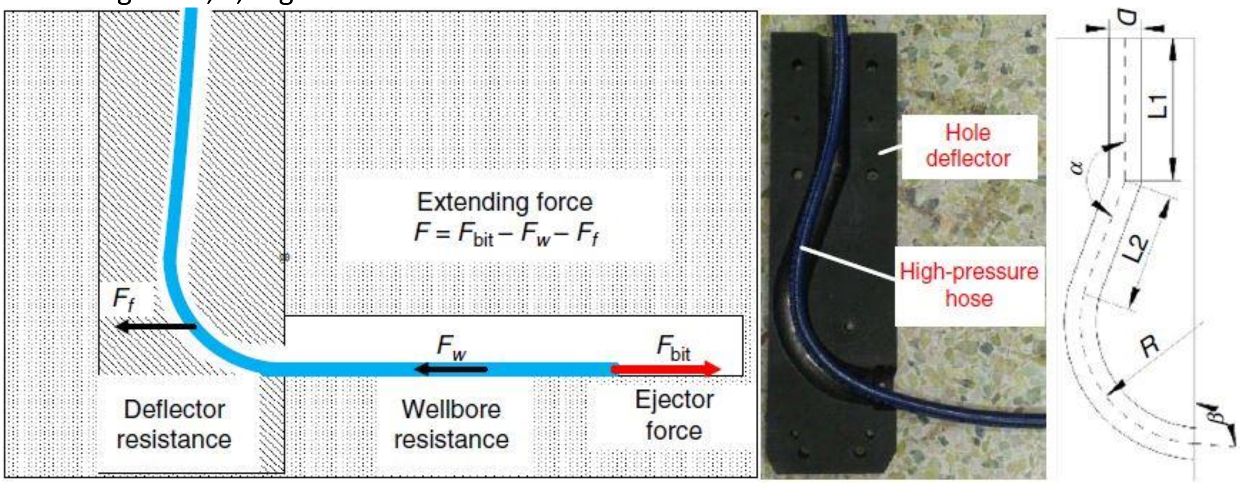
Where, C is the jet-bit-discharge coefficient (dimensionless), A is the total area of nozzles (mm2), and Q is the pump-flow rate (L/s).

For a specific type of jet bit and a known test fluid, the coefficient C is the only unknown term in Eq. 9. This coefficient can be determined by substituting the experimental data for the pressure loss and pump-flow rate into Eq. 9.

8.5.1 Lateral-Extending-Force Model: Under actual drilling conditions, the high-pressure hose is in contact with the wellbore and deflector. According to the force analysis in Fig below, the lateral extending force includes the jet-bit-ejector force F_{bit}, the wellbore resistance F_w, and the deflector resistance Ff. Thus, the lateral horizontal- extending force can be calculated as

$$F = F_{bit} – F_r = F_{bit} – F_w - F_f \text{ ....(10)}$$

Where, F_r is the lateral-extending resistance (N). The lateral can extend when the lateral-extending force, F, is greater than zero.



(ref source petrowiki 'RJD- Radial Jet Bit Drilling')

Ejector Force of the Jet Bit. The ejector force of the jet bit is mainly generated by the momentum difference between the forward and backward jets. Li et al. proposed a theoretical ejector-force model for a multi-nozzle jet bit (Fig. 8). The model was correlated and validated by both experimental data and numerical- simulation results. The ejector force can be calculated as

$$F_{bit} = \frac{\rho}{A_o} mQ^2 \text{ ....(11)}$$

Where, A_0 is the cross-sectional area of the jet-bit inlet (mm2), Q is the pump-flow rate (L/s), and the coefficient m is defined as the self-propelled-ability coefficient:

$$m = \frac{0.081{A_o}^2 S}{C^2 {d_{ne}}^4} + 0.5(1+S) - \left(\frac{k}{(n_f+1)(k+1)}\right)^2 {D_c}^4 S + n_b\left(\frac{1}{(n_b)(1+k)}\right)^2 {D_b}^2 \cos\theta_b$$

....(12)

Where, D_c and D_b are the diameter ratio of the jet bit and nozzle (dimensionless), which were defined as follows:

$$D_c = \frac{d_o}{d_c} \qquad D_b = \frac{d_o}{d_b}$$

A_o = cross sectional area of jet bit inlet (mm^2)

$$A_o = \frac{\pi r^2}{4}$$

d_{ne} = equivalent area of jet bit nozzle (mm)

$$d_{ne} = \sqrt{n_f {d_f}^2 + n_c {d_c}^2 + n_b {d_b}^2}$$

S = area coefficient for front face

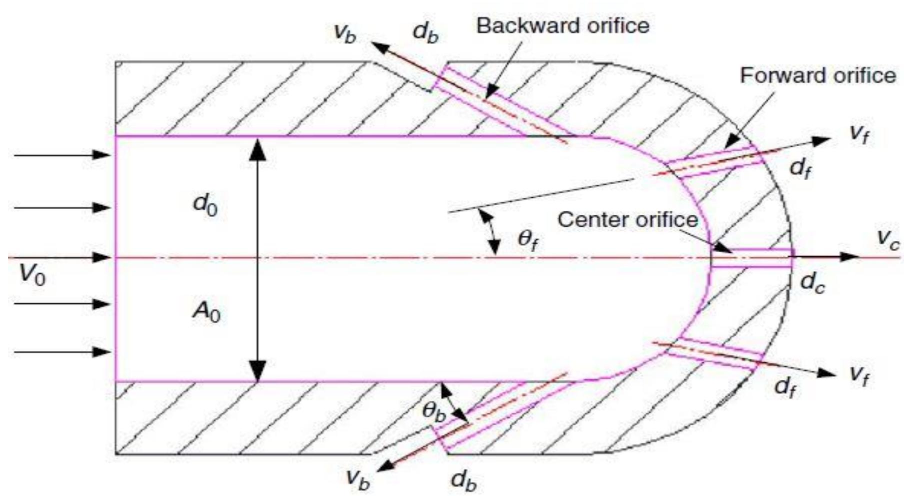
$$s = \left(\frac{1}{{D_c}^2} + \frac{n_f}{2\cos\theta_f {D_c}^2}\right)$$

Where, k is the flow ratio of the forward and backward nozzles (dimensionless) and C is the jet-bit-discharge coefficient. k and C are related to the nozzle structure and material roughness, which can be determined by means of a jet-bit. According to the experimental results, the discharge coefficient of the multi-nozzle jet bit, C, varies from 0.5 to 0.8.

The flow ratio of the forward and backward nozzles, k, is mainly related to the nozzle-area ratio, which can be estimated as follows:

$$k = \frac{n_f {d_f}^2 + {d_c}^2}{\gamma\, n_b {d_b}^2}$$

Where, γ is the backward-flow-rate factor (dimensionless). On the basis of our experimental observation, the backward-nozzle-flow rate is lower than the forward-nozzle-flow rate when their nozzle total areas are equal. Therefore, we introduce γ as the backward flow- rate factor. The flow ratio k can be estimated accurately when the value of γ is 0.9.
Ejector force is mainly determined by pump-flow rate and jet-bit structure.



According to computational-fluid-dynamics simulation, the surrounding flow field of jet bit is complex, and it is difficult to develop a theoretical model to describe those surrounding factors.

Therefore, the model has been simplified by neglecting those surrounding effects. The influence of these surrounding effects on ejector force needs further research.

8.5.2 Extending Resistance: The extending resistance is the sum of the wellbore resistance and deflector resistance.

The extending-resistance model can be expressed as follows:

$F_r = F_w + F_f$

$= \mu_s q_{bh} L_h + a\{\Delta P_h + \Delta P_b\} + b$ ……………………………………………………….(13)

Here, a =0.88 b=6.06

q_{bh} is the submerged weight of hose = 0.96 N/m

μ_s = 0.35 (sliding friction coefficient)

8.5.3 Assumptions:

1. On the basis of our calculations, the effect of water compressibility on pressure-loss calculation was minimal. To simplify the calculation, we assumed that the drilling fluid was incompressible, the fluid density was 1000 kg/m3, and the fluid viscosity was 1.005 mPa_s.
2. For RJD, we often use $1^{1/2}$- or 1-in. CT to satisfy the high-pressure condition in the field run. On the basis of our calculations, the fluid flow of the RJD system is always turbulent in the field run. To simplify the calculation, we assumed that the fluid flow in the hose and CT was always turbulent flow.
3. For RJD, the pump-flow rate is lower than that used for conventional drilling. On the basis of our calculations for Well A, the pressure loss in the annulus is only 0.087 MPa. To simplify the calculation, we assumed that the annular-pressure loss was negligible.

8.5.4 Procedure:

With flow rate dependence of pressure, a range of flow rate was required. Range necessitates the knowledge of maximum and minimum values. Both, maximum and minimum have their own specific conditions which need to be satisfied.

Minimum flow rate:

This values should further satisfy the following two conditions;

1. The ejector force should be greater than the drilling resistance for the required length.

   $\mathbf{F_{bit} > F_r}$
2. Pressure drop at the bit should exceed minimum threshold rock bearing pressure.

   $\mathbf{\Delta P_b > P_{min}}$

Maximum flow rate:

The maximum flow rate that can be accommodated in the system is limited by the pressure that various pressure components, primarily being high pressure hose and coiled tubing can withstand.

Thus, **equipment working pressure < yield pressure.**

8.5.5 Calculations:

For a cased example study, we consider a **Well A,** in which a lateral is to be drilled for a length of 100m.

DATA SECTION	
General	
Total Coiled Tubing length	4000 m
Formation Depth	2215 m
Straight Section tubing	2215 m
Coiled Section of Tubing	1785 m
Ρ	1000 Kg/m^3
μ	1.005 m-Pa_sec
Outer diameter of hose	14 mm
Inner diameter of hose	9 mm
Jet Bit Diameter	14 mm
Jet Bit Data	
n_f	5
n_b	9
n_c	1
d_f	0.7 mm
d_b	0.9 mm
d_c	0.7 mm
θ_f	12
θ_b	30
Coiled Tubing	
Outer Diameter	38 mm
Inner Diameter	31 mm
Reel Drum Diameter	1.828 m
Deflector	
Length	118 mm
Width	400 mm
Turning Radius	90 mm

8.5.6 Calculation of minimum flow rate:

Though we have taken the lateral length as 100m but for the first case of calculation we have shown for lengths of 20m, 40m, 60m, 80m and 100m.
The ejector force and drilling resistance different lengths, have been plotted on one single graph (graph 01). The flow rate corresponding, point where the black line (ejector force) cuts other specific line drilling specific line gives minimum flow rate required to drill that length.
In the required case of 100m, this minimum flow rate comes out to be nearly 54 lpm.

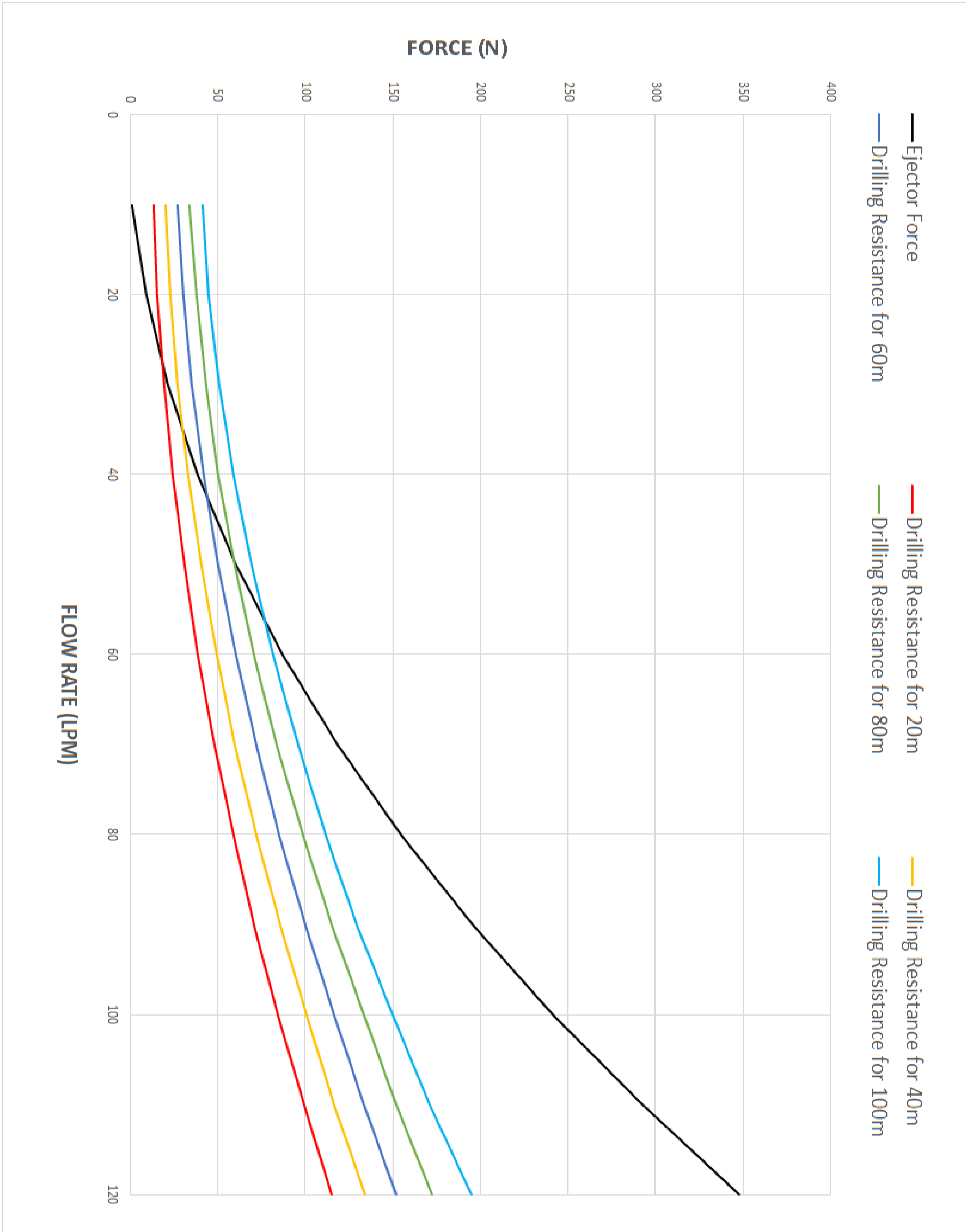
The second cut off which the minimum flow rate must exceed is one that causes pressure drop at bit to exceed above minimum threshold rock bearing pressure. Different rocks have different values of this threshold value and data is available in literature to obtain these values.

Rock Type	Threshold Pressure (MPa)
Soft Sandstone-1	9.00
Soft Sandstone-2	13.50
Soft Sandstone-3	15.50
Coal-1	11.50
Coal-2	13.00
Coal-3 (Chang-2006)	15.00
Coal-4 (Li-2008)	5.00

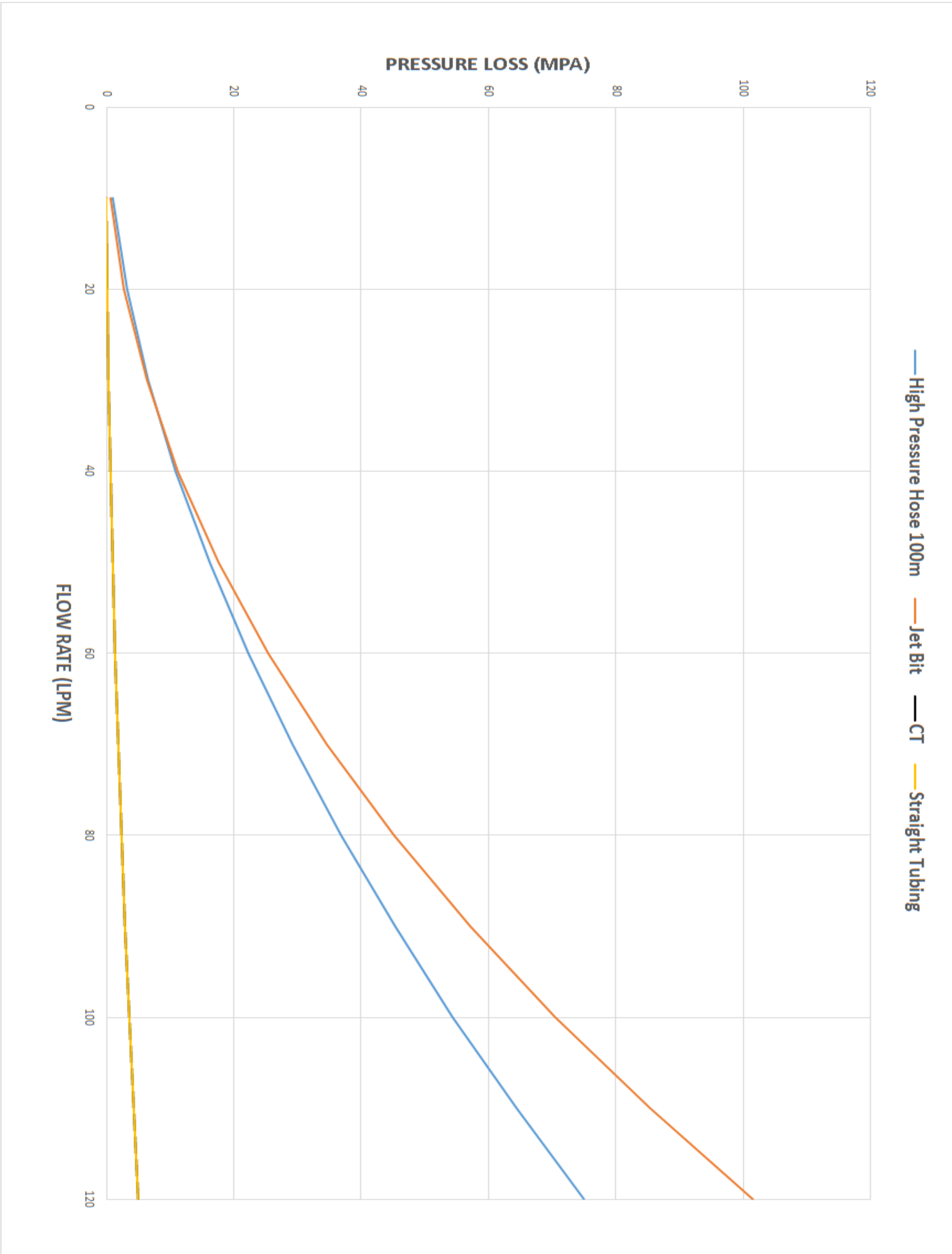
(ref source ONGC oil field manual)

Though the sandstones values are less but limestone values can be high and keeping this in mind we have taken the threshold value as 15 MPa.
Now the various pressure drops including coiled tubing, straight tubing, jet bit and high pressure hose for 100 m were plotted on one graph (graph 02). Since the minimum pressure drop against bit should exceed 15 MPa, we found the corresponding flow rate which came out to be 48 lpm.

Upon merging the above two conditions, the minimum flow rate that satisfies both required conditions is 54 lpm.


FORCE (N)
FLOW RATE (LPM)
Ejector Force
Drilling Resistance for 20m
Drilling Resistance for 40m
Drilling Resistance for 60m
Drilling Resistance for 80m
Drilling Resistance for 100m
0
50
100
150
200
250
300
350
400
0
20
40
60
80
100
120

Graph 01

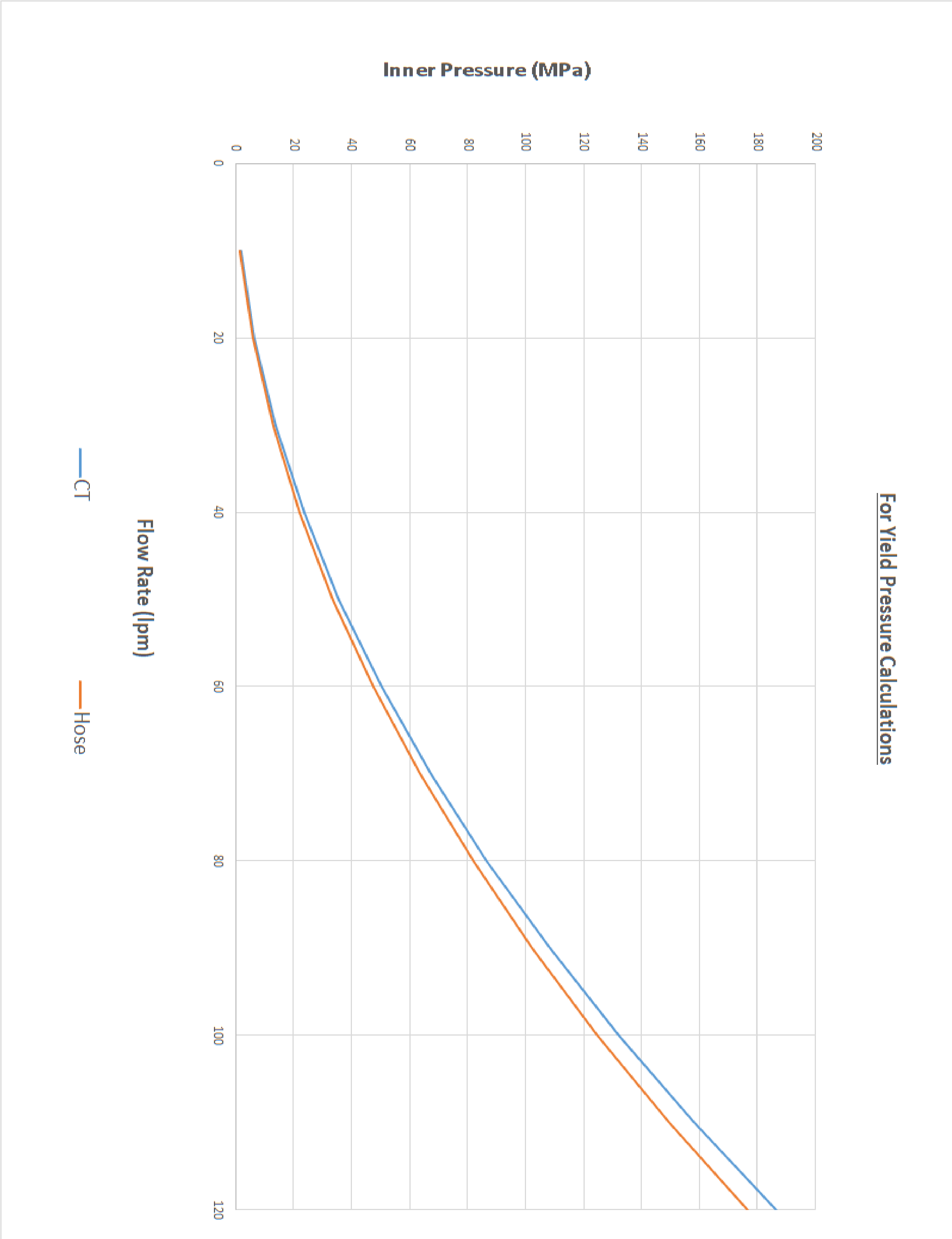

PRESSURE LOSS (MPA)
0
20
40
60
80
100
120
FLOW RATE (LPM)
0
20
40
60
80
100
120
High Pressure Hose 100m
Jet Bit
CT
Straight Tubing

Graph 02

8.5.7 Calculation of maximum flow rate:

Higher flow rates higher pressure inside the components. Various components are rated for their specific yield pressures. At any point of operation, this pressure should never be exceeded.
Our purpose could be solved if we could find the flow rate corresponding to the component with least yield pressure. In RJD system, the major components associated with high pressure are coiled tubing and high pressure hose. The yield pressures of both components were obtained from the literature taking the high pressure hose's internal pressure to be 40 MPa and coiled tubing's yield pressure to be 82 MPa.
In the next step the flow rates were obtained for both pressure from the graph 03, which is plotted internal pressure vs. flow rate. From the graph, the flow rate for 40 MPa is nearly 56 lpm and for 82 MPa is around 80 lpm.
But the overall figure will be decided by the lowest pressure rating which is 40 MPa and thus maximum flow rate that system can accommodate is 56 lpm.

With both maximum and minimum flow rate values known as **56** and **54 lpm** respectively, which can choose the final flow rate in this range. Since higher flow rate gives higher ROP (Rate of Penetration), the optimized flow rate figure come out to be **56 lpm**.


For Yield Pressure Calculations
Inner Pressure (MPa)
0
20
40
60
80
100
120
140
160
180
200
Flow Rate (lpm)
0
20
40
60
80
100
120
CT
Hose

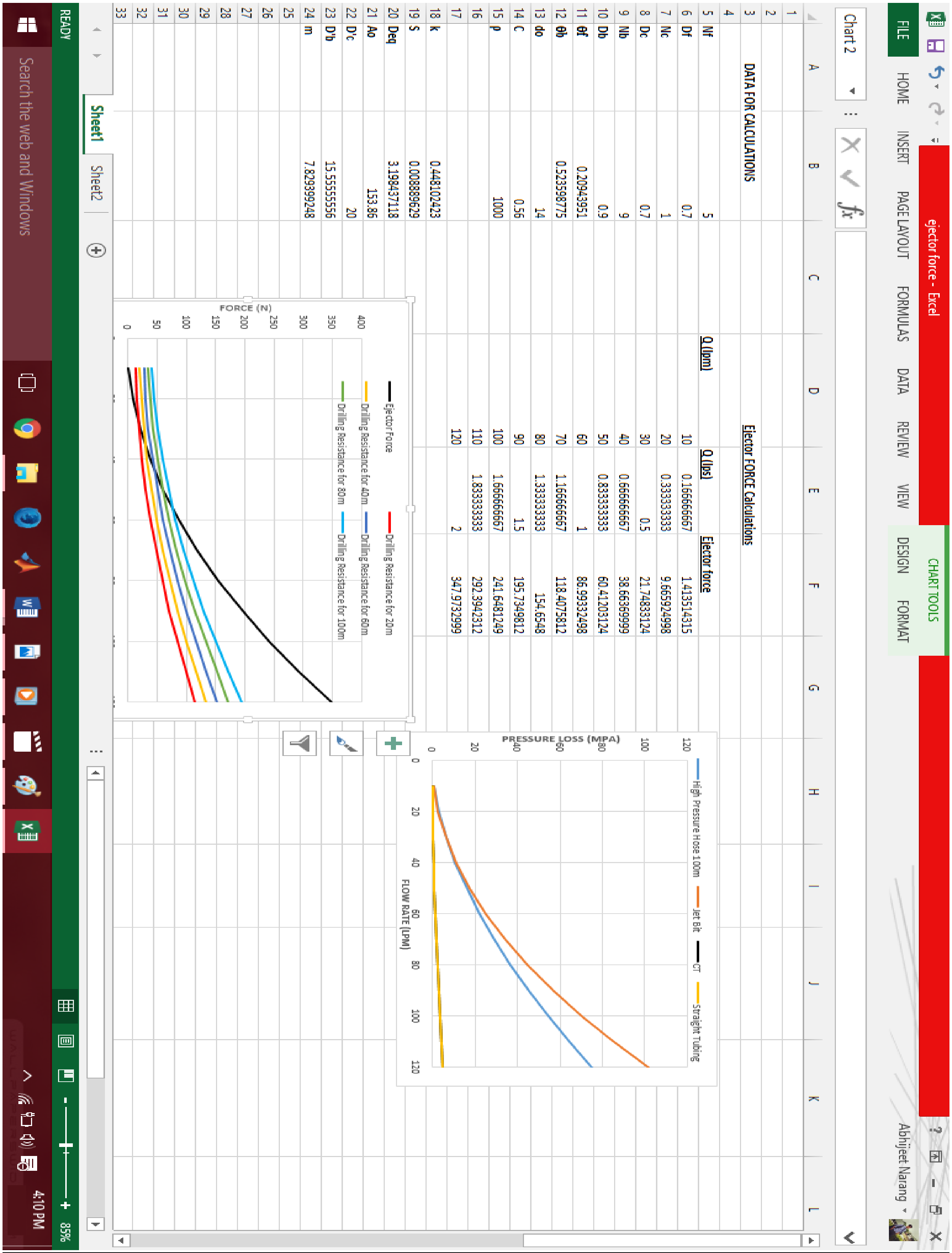
Graph 03

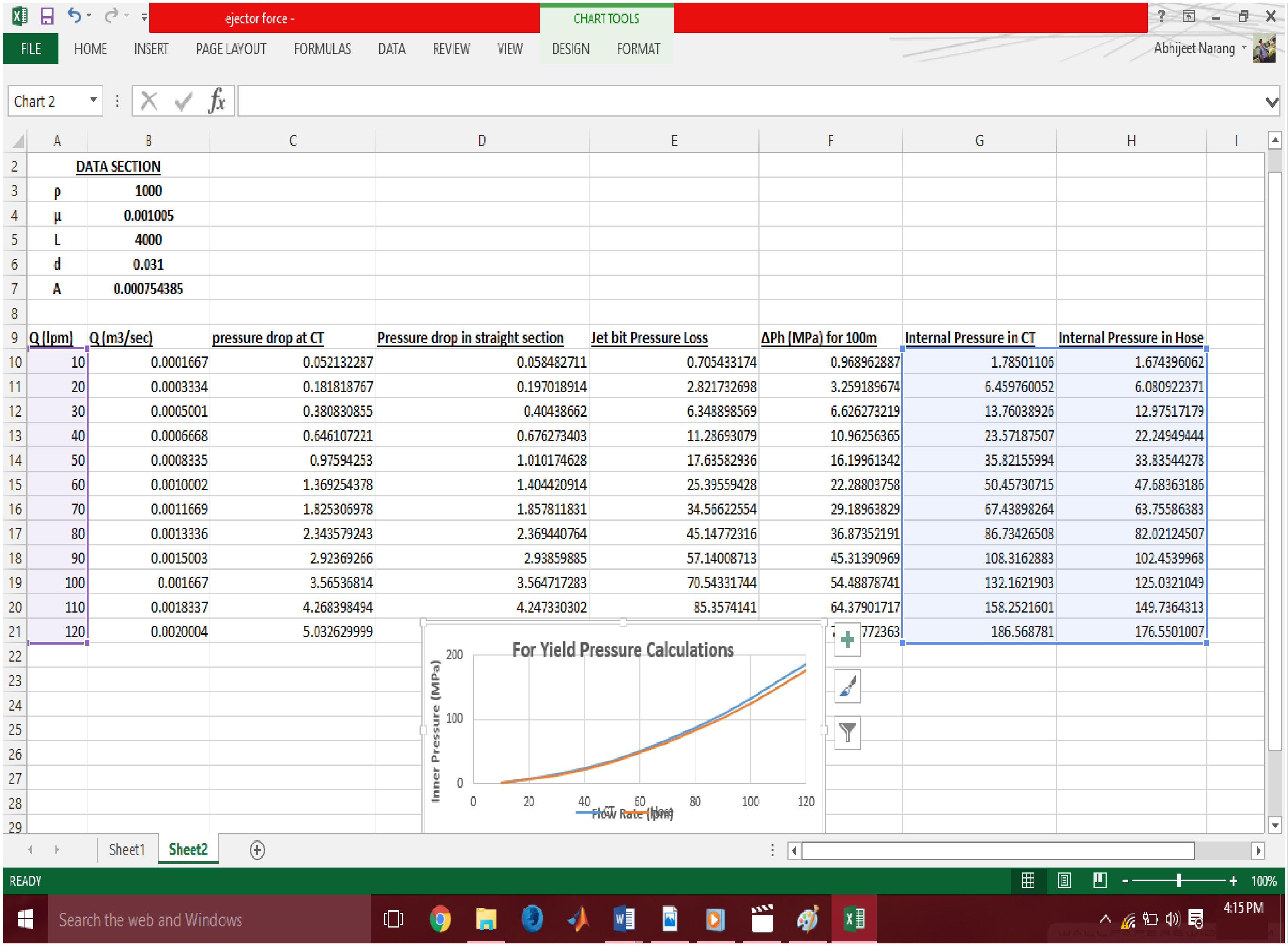
Given below are the screenshots of the data sheets from which data for above graphs has been obtained:

ΔPh (MPa) for 60m	ΔPh (MPa) for 80m	ΔPh (MPa) for 100m
0.583209942	0.777613255	0.968962887
1.951409894	2.601879859	3.259189674
3.974372796	5.299163729	6.626273219
6.580991098	8.774654797	10.96256365
9.729974063	12.97329875	16.19961342
13.36814335	17.82419113	22.28803758
17.5164096	23.3552128	29.18963829
22.13572729	29.51430305	36.87352191
27.17883251	36.23844335	45.31390969
31.93941271	43.59102993	54.48878741
36.77062417	50.0326452	64.37901717
41.60183562	56.77580437	74.96772363

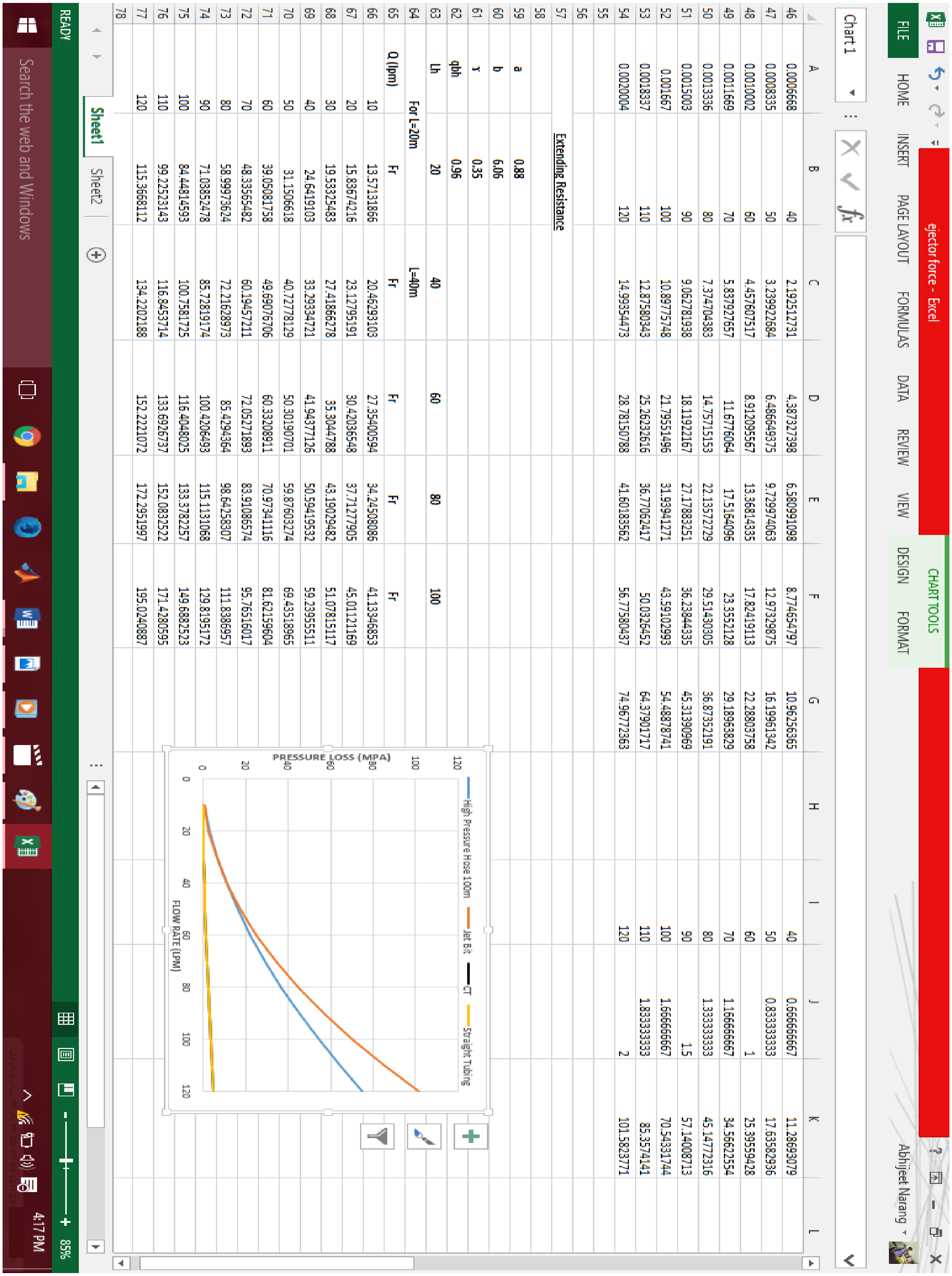
flow rate l/min	Flow Rate (Q) L/sec	Jet bit Pressure Loss
10	0.166666667	0.705433174
20	0.333333333	2.821732698
30	0.5	6.348898569
40	0.666666667	11.28693079
50	0.833333333	17.63582936
60	1	25.39559428
70	1.166666667	34.56622554
80	1.333333333	45.14772316
90	1.5	57.14008713
100	1.666666667	70.54331744
110	1.833333333	85.3574141
120	2	101.5823771

flow rate l/min	Flow Rate	Pressure drop in CT	Pressure drop in straight secti
10	0.000167	0.052132287	0.058482711
20	0.000333	0.181818767	0.197018914
30	0.0005	0.380830855	0.40438662
40	0.000667	0.646107221	0.676273403
50	0.000834	0.97594253	1.010174628
60	0.001	1.369254378	1.404420914
70	0.001167	1.825306978	1.857811831
80	0.001334	2.343579243	2.369440764
90	0.0015	2.92369266	2.93859885
100	0.001667	3.56536814	3.564717283
110	0.001834	4.268398494	4.247330302
120	0.002	5.032629999	4.986050261


ejector force - Excel
CHART TOOLS
FILE HOME INSERT PAGE LAYOUT FORMULAS DATA REVIEW VIEW DESIGN FORMAT
Abhijeet Narang
Chart 2
DATA FOR CALCULATIONS
Ejector FORCE Calculations
Nf 5
Df 0.7
Nc 1
Dc 0.7
Nb 9
Db 0.9
θf 0.20943951
θb 0.523598775
do 14
C 0.56
ρ 1000
k 0.448102423
S 0.008889629
Deq 3.198437118
Ao 153.86
D'c 20
D'b 15.55555556
m 7.829399248
Q (lpm) Q (lps) Ejector force
10 0.166666667 1.413514315
20 0.333333333 9.665924998
30 0.5 21.74833124
40 0.666666667 38.66369999
50 0.833333333 60.41203124
60 1 86.99332498
70 1.166666667 118.4075812
80 1.333333333 154.6548
90 1.5 195.7349812
100 1.666666667 241.6481249
110 1.833333333 292.3942312
120 2 347.9732999
High Pressure Hose 100m
Jet Bit
CT
Straight Tubing
PRESSURE LOSS (MPA)
FLOW RATE (LPM)
Ejector Force
Drilling Resistance for 20m
Drilling Resistance for 40m
Drilling Resistance for 60m
Drilling Resistance for 80m
Drilling Resistance for 100m
FORCE (N)
Sheet1 Sheet2
READY
85%
Search the web and Windows
4:10 PM



	A	B	C	D	E	F	G	H
2	DATA SECTION							
3	ρ	1000						
4	μ	0.001005						
5	L	4000						
6	d	0.031						
7	A	0.000754385						
8								
9	Q (lpm)	Q (m3/sec)	pressure drop at CT	Pressure drop in straight section	Jet bit Pressure Loss	ΔPh (MPa) for 100m	Internal Pressure in CT	Internal Pressure in Hose
10	10	0.0001667	0.052132287	0.058482711	0.705433174	0.968962887	1.78501106	1.674396062
11	20	0.0003334	0.181818767	0.197018914	2.821732698	3.259189674	6.459760052	6.080922371
12	30	0.0005001	0.380830855	0.40438662	6.348898569	6.626273219	13.76038926	12.97517179
13	40	0.0006668	0.646107221	0.676273403	11.28693079	10.96256365	23.57187507	22.24949444
14	50	0.0008335	0.97594253	1.010174628	17.63582936	16.19961342	35.82155994	33.83544278
15	60	0.0010002	1.369254378	1.404420914	25.39559428	22.28803758	50.45730715	47.68363186
16	70	0.0011669	1.825306978	1.857811831	34.56622554	29.18963829	67.43898264	63.75586383
17	80	0.0013336	2.343579243	2.369440764	45.14772316	36.87352191	86.73426508	82.02124507
18	90	0.0015003	2.92369266	2.93859885	57.14008713	45.31390969	108.3162883	102.4539968
19	100	0.001667	3.56536814	3.564717283	70.54331744	54.48878741	132.1621903	125.0321049
20	110	0.0018337	4.268398494	4.247330302	85.3574141	64.37901717	158.2521601	149.7364313
21	120	0.0020004	5.032629999	[illegible]	[illegible]	[illegible]772363	186.568781	176.5501007



	A	B	C	D	E	F	G	H	I	J	K
46	0.0006668	40	2.192512731	4.387327398	6.580991098	8.774654797	10.96256365		40	0.666666667	11.28693079
47	0.0008335	50	3.239922684	6.486649375	9.729974063	12.97329875	16.19961342		50	0.833333333	17.63582936
48	0.0010002	60	4.457607517	8.912095567	13.36814335	17.82419113	22.28803758		60	1	25.39559428
49	0.0011669	70	5.837927657	11.6776064	17.5164096	23.3552128	29.18963829		70	1.166666667	34.56622554
50	0.0013336	80	7.374704383	14.75715153	22.13572729	29.51430305	36.87352191		80	1.333333333	45.14772316
51	0.0015003	90	9.062781938	18.11922167	27.17883251	36.23844335	45.31390969		90	1.5	57.14008713
52	0.001667	100	10.89775748	21.79551496	31.93941271	43.59102993	54.48878741		100	1.666666667	70.54331744
53	0.0018337	110	12.87580343	25.26232616	36.77062417	50.0326452	64.37901717		110	1.833333333	85.3574141
54	0.0020004	120	14.99354473	28.78150788	41.60183562	56.77580437	74.96772363		120	2	101.5823771
55											
56											
57		Extending Resistance									
58											
59	a	0.88									
60	b	6.06									
61	ɣ	0.35									
62	qbh	0.96									
63	Lh	20	40	60	80	100					
64	For L=20m		L=40m								
65	Q (lpm)	Fr	Fr	Fr	Fr	Fr					
66	10	13.57131866	20.46293103	27.35400594	34.24508086	41.13346853					
67	20	15.83674216	23.12795191	30.42036548	37.71277905	45.01121169					
68	30	19.53325483	27.41866278	35.3044788	43.19029482	51.07815117					
69	40	24.6419103	33.29334721	41.94377126	50.59419532	59.23955511					
70	50	31.1506618	40.72778129	50.30190701	59.87603274	69.43518965					
71	60	39.05081758	49.69076706	60.33208911	70.97341116	81.62159604					
72	70	48.33565482	60.19457211	72.05271893	83.91086574	95.76516017					
73	80	58.99973624	72.21628973	85.4294364	98.64258307	111.8386957					
74	90	71.03852478	85.72819174	100.4206493	115.1131068	129.8195172					
75	100	84.44814593	100.7581725	116.4048025	133.3782257	149.6882523					
76	110	99.22523143	116.8453714	133.6926737	152.0832522	171.4280595					
77	120	115.3668112	134.2202188	152.2221072	172.2951997	195.0240887					
78											

9. RESULTS

Our project aimed at hydraulic optimization of the radial drilling technology which included the calculation of various forces along the RJD system comprising of ejector force, pressure losses along high pressure hose, coiled tubing, jet bit pressure loss and extending resistance.

Taking into consideration all these forces, an optimized flow rate was obtained keeping in mind the yield pressure of RJD and tubular components. All the calculations were done on MS Excel and the final optimized flow rate was calculated on basis of generated graphs (on MS Excel)

1. Flow rate for high pressure hose (YP=40Mpa) = 56lpm
2. Flow rate for coiled tubing (YP= 82Mpa) = 80lpm
3. Maximum flow rate= 56lpm
4. Minimum flow rate= 54lpm
5. Optimized flow rate range for RJD process (with considered sample data) = 54-56lpm

Note: - the above results are for sample data we have considered for our calculation, the results will change with the data entered by user in our MS Excel software. Excel file can be obtained from the e-copy of this report (in CD).

10. CONCLUSIONS

There is a lot of conclusions have been drawn from this work such as:

- Form the actual results, as the length of lateral hole increases, the net oil production rate increases.
- Consolidated formation is preferred for performing radial drilling as stimulation technique to bypass the damaged zone than the unconsolidated one.
- The higher hole numbers, the higher production rate can be obtained than less ones.
- The enhancement of net oil production ranges from 12.5 % to 47% but the key issues is the duration after that increasing.
- Radial drilling is a little bit easy to be apply and less expensive compare to the other stimulation techniques.
- The real challenge is keeping the increase in production is constant as long as possible after Radial Drilling where it is noticed that most of the increase not extended for long time.
- Radial Drilling can be successfully applied in fields with low amount of reserves that promise lower profit, where conventional simulation techniques cannot be applied due to high amount of expenses in terms of money and time.
- Simulation for RJD job is easier and no complex machinery is required.
- Hydraulic optimization software for RJD was not available in market yet and hence our MS Excel based software can help in the optimization.
- Formation damage is quite a headache in every type of field whether marginal or giant, hence well stimulation is necessary and RJD is an economical and fast technology in this regard.
- Moreover, RJD is generally applicable to thin and shallow reservoirs and mostly all of the marginal fields (especially offshore) are thin and shallow.
- Also, RJD covers most of the aspects of all the technologies we have discussed in regard with increasing the productivity of the field.

At the end we can say that RJD technology is a newer and promising technology with quite a wide variety of applications, especially in the case of marginal fields.

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