Journal of Petroleum Technology and Alternative Fuels Vol. 4(2), pp. 12-23, February 2013
Available online at http://www.academicjournals.org/JPTAF
DOI:10.5897/JPTAF12.015
©2013 Academic Journals

Case Study

Case study in deducing pump discharge pressures with applied methods for maximizing throughput of a strategic crude oil pipeline

Hesham A. M. Abdou

Agiba Petroleum Company, Cairo, Egypt. E-mail: heshamaabdou@gmail.com.

Accepted 18 December, 2012

The aged crude oil pipeline; 16" x 166 km since November 1984, extends from Meleiha field at Western desert to El-Hamra terminal at coast of the Mediterranean Sea. Its original capacity was 100,000 BOPD using two pumping stations; one at Meleiha and the other is a boosting station, 83 km far from Meleiha. Planned pumped flow rate increased to 177,000 BOPD at the time that maximum allowable working pressure (MAWP) reduced from 1463 psi to 950 psi. Here is shown how could pump higher flow rates without reaching MAWP, where two solutions to accommodate such increase in production were applied; firstly by looping the existing pipeline with a (16" x 56 km), secondly by using a drag reducing agent (DRA), that could reduce hydraulic friction losses and total dynamic pressure (TDP) in the system and could pumped more with reduced initial pumping pressure at Meleiha. So, the intermediate station was temporarily abandoned. Mathematical models are designed to simulate pumping operation through the whole system, where TDP is predicted for the three pipeline cases: 1- Normal case without both looping and DRA. 2- Case without DRA and with looping. 3- Case with both looping and DRA.

Key words: Crude oil pipeline, drag reducing agent (DRA), Meleiha, maximum allowable working pressure (MAWP).

INTRODUCTION

This paper discusses the upgrading of the existing pipeline of Meleiha / El-Hamra, that could increase transportation capacity of this pipeline up to 177,000 BOPD (Figure 1). Crude oil is 42 °API, its sp.gr. (60 °F/60 °F) is 0.8156, from which pressure gradient is 1.1595 psi/m (used to express pressure in psi or bar as terms of oil pressure head in meter). Kinematic viscosity is 2.5 c.st. at 40°C. Upgrading stages passed the following two phases.

Pipeline upgrading phases

Phase-1

Crude oil is pumped from Meleiha, in addition to the crude oil pumped into three access points at the pipeline, without loops and without Drag Reducing Agent (DRA), pumping process is achieved using pumping station at Meleiha and another pumping station at mid point.

Phase-2

DRA is used to reduce hydraulic friction losses in piping system, so that increase in pipeline throughput was realized. Also, to increase pipeline flow rate, each of the two halves of the pipeline was looped with a pipeline of 28 km x 16".

Specifications of Meleiha / El-Hamra pipeline The pipeline extends from Meleiha to El-Hamra terminal, elevation of initial point is higher than end terminal by 232 m, relative to main sea level (Figure 2). Its specifi-cations are seen in Table 1.

Analyzing upgraded Phase 1

Total dynamic head of a system, m (TDH) of a system curve (for every selective Qs) in all figures are plotted practically.

For the operating point (pump flow rate (Qp) and pump

Figure 1. Western desert Map, A.R.E.

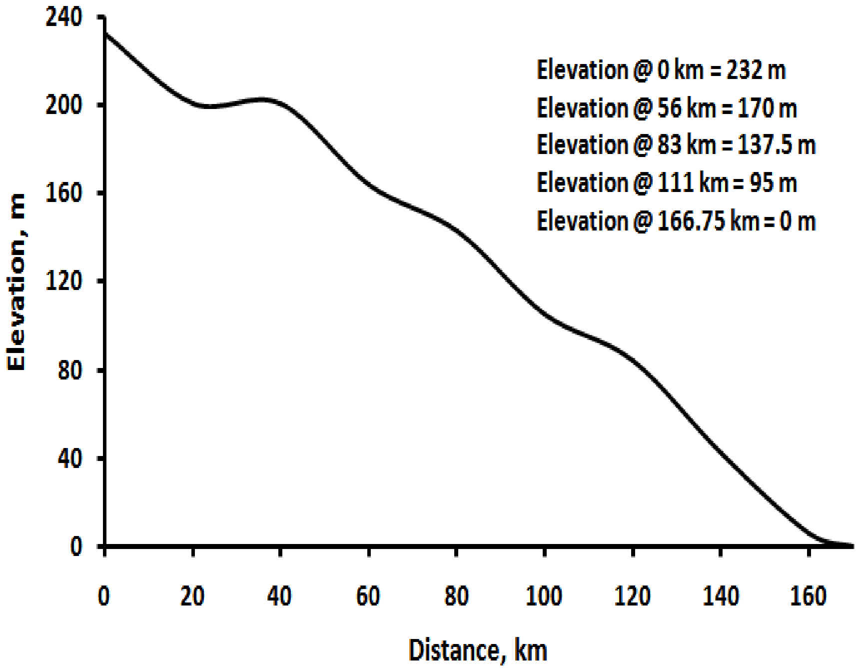

Figure 2. Pipeline profile.

Table 1. Specifications of the Meleiha / El-Hamra Pipeline (Specification (American Petroleum Institute, 2004; Mohinder, 2000).

Item	Specification
Nominal diameter, inch	16
Wall thickness, inch	0.375
Length, km	166.75
Material grade	API-5L-X52
Design code	ANSI B31-4
Coating material	Polyethylene
Nominal weight, lb/ft	62.64
Coating thickness, mm	2.5
Cathodic protection	Impressed current
Specified minimum yield strength, psi	52000
Design factor	0.60
Internal design pressure, psi	1463
MAWP as per last conducted test	950
Construction	Buried

TDH) at the intersection point of (Q-H) curve and system curve:

$$HFL = (\text{pump TDH}) - \Delta Z - HE \quad \text{(Shashi (2004))} \qquad (1)$$

Where: Pd = pump TDH, in pressure term if Ps = 0

$$HFL\ (@\ Qp) = K.\ Qp^2 \quad \text{(Sawhney, 2011))} \qquad (2)$$

$$K = \frac{HFL}{Q_P^2} \qquad (3)$$

For any selected (Qs): TDH of a system curve (for every selective Qs) =

$$K\ .\ Qs^2 + \Delta Z + HE \qquad (4)$$

$$Pd = \text{pump TDH} + Ps \qquad (5)$$

Generally, in Equation 1, gauge suction pressure (Ps = 0 psi) meaning that Hs = 0, then NPSHA = Ha ± Hs – Hvap. – Hfs = 33.9 + 0 – 0.58 – 0 = 33.4 ft water or 10.2 m water, NPSHA must be greater than NPSHR for the pump (determined by the manufacturer) to avoid cavitations (Ken and Maurice, 1999), by considering value for Hfs, NPSHA will decreases. However, in the present work (Ps) was never recorded as zero value. The pipeline is operated with first pumping station at Meleiha (Figure 3), its upstream is at point (A), while there are two down stream flow rates at points (B) and (C). The pump at (A) pushes flow till mid point at kilo point-83, where there is a boosting pumping station pumps flow rates till the end terminal at El-Hamra. First pumping station is at Meleiha at point (A), consists of two centrifugal pumps connected in series, its up stream flow rate is 90,000 BOPD (596 cu. m/h) as seen in Figure 4.

The boosting station consists of two centrifugal pump connected in parallel (Figure 5), recieves flow rates from points (A), (B) and (C) as up stream with total of 131,000 bbl/d (868 cu.m/h), while down stream of this boosting station is the flow rate at point (D), 28 km far from mid point. Differential pressure head of these two pumps is 469 m (37.5 bar), suction pressure of first pump is 21.2 bar, so final discharge pressure is 58.7 bar. As operating point in Figures 4 and 5 are 481 m and 473 m, respectively, so sum of TDH for the two pumping stations is 954 m (1106 psi), higher than MAWP (950 psi). So, it is a must to use the two pumping stations not only first one

Analyzing upgraded Phase 2

Analyzing effect of DRA

Drag reducing agent is called as flow improver (http://www.seykota.com/rm/friction/friction.htm), it is a long chain polymer chemical that is used in crude oil, refined products or non-potable water pipelines. It is injected in small amounts (PPM) and is used to reduce the frictional pressure drop along the pipeline's length. When the neat polymer is added, it reduces drag at internal pipe wall as it interacts with the oil and the wall to help reduce the contact of the oil with the wall as seen in Figure 6 (Désiré, 2010). DRA should never be used with any turbine fuels (such as jet fuel) because the polymer will accumulate on turbine blades and may damage the turbine.

Drag reducers were invented more than thirty years ago, its use has allowed pipeline systems to greatly increase in traditional capacity and extend the life of existing systems. Ideal molecules have a high molecular weight, shear degradation resistance, are quick to

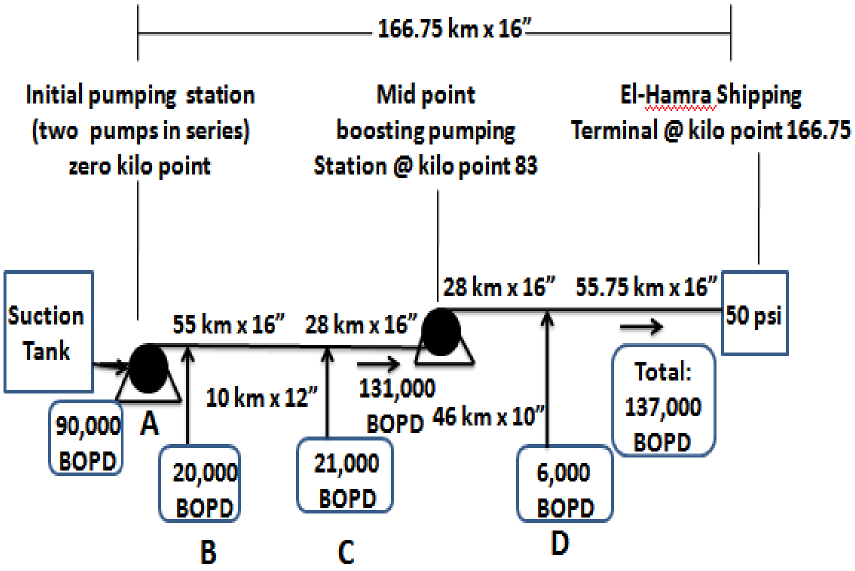

Figure 3. Pipeline sysem without both loops and DRA.

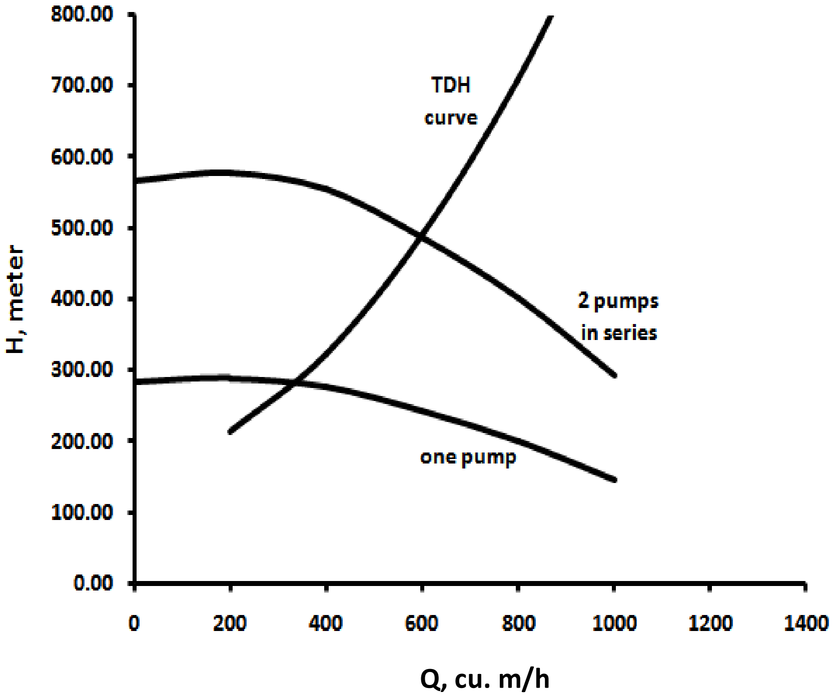

Figure 4. First half of the pipeline without both loop and DRA.

dissolve in whatever is in the pipe, and have low degradation in heat, light, chemicals, and biological areas.There are many factors play a role in drag reduction (http://www.tutorgigpedia.com/ed/Drag_reducing_agent). Main factor is temperature. At higher temperature, the drag reducing agent is easier to degrade. At a low temperature the drag reducing agent will tend to cluster together. This problem can be solved easier than degradation though, by adding another chemical, such as aluminum to help lower the drag reducing agent's attraction to one another. Another factor is the pipe diameter. With a decreasing pipe diameter, the drag reduction is increased. Going along with this, the

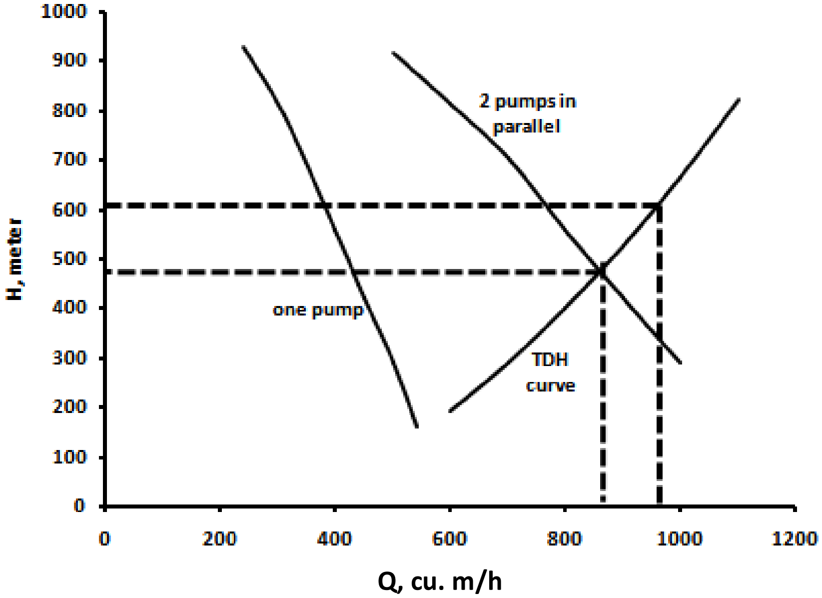

Figure 5. Second half of the pipeline without both loop and DRA.

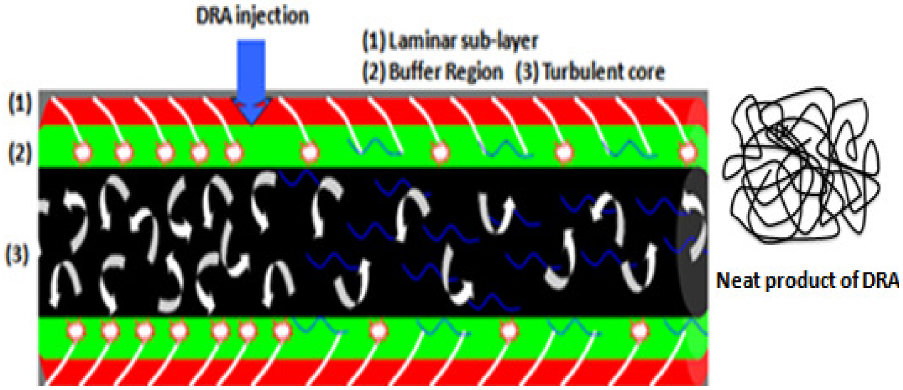

Figure 6. Drag reduction theory.

roughness of the inside of the pipe has a factor.

The rougher the inside, the higher the percent drag reduction occurring. Increasing the pressure in a pipe will help with drag reduction as well, but often that pressure is greater than what the pipe can withstand. Table 2 shows experemintal test results for one kind of such DRA.

$$\% \text{ reduction in HFL} = 34.524\, e^{(0.00424 * \text{PPM})} \qquad (6)$$

[Injected DRA in (gallon/h) versus concentration in (PPM)], relationship is derived as follows:

Density of DRA is 8 lb/gallon, so: 8 q = lb/h
Where: (q) is the injection rate of DRA in gallon/h

8 x q x 453.6 x 1000 = mg/h (a)

Q x [159 / 24] = lit/h (b)

Dividing (a)/ (b) results in:
q / [(1.8 x 10-6) Q] = mg/lit = PPM

$$\text{PPM} = \frac{q/Q}{1.8 * 10^{-6}} \qquad (7)$$

The DRA was first applied before using pipe loops, Figure 7 shows the obtained practical TDH for second half of the pipeline after application of DRA with 11.5 PPM (3 gallon/h) to reach 960 cu. m/h (144,900 BOPD), which is 10% over than the case without both loop and DRA where flow then was 868 cu. m/h (131,000 BOPD) as seen in Figure 5, by using Equation (6), reduction in HFL is 36.3%, which is closed to the practical percentage shown in Table 3. Also, final (Pd) is deduced.

Table 2. PPM of DRA vrsus percent reduction in HFL.

PPM	Experimental reduction in HFL, %
19.22	37.01
49.52	43.66
116.58	56.88
120	58.091
130	60.666
140	63.354
150	66.162
160	69.094

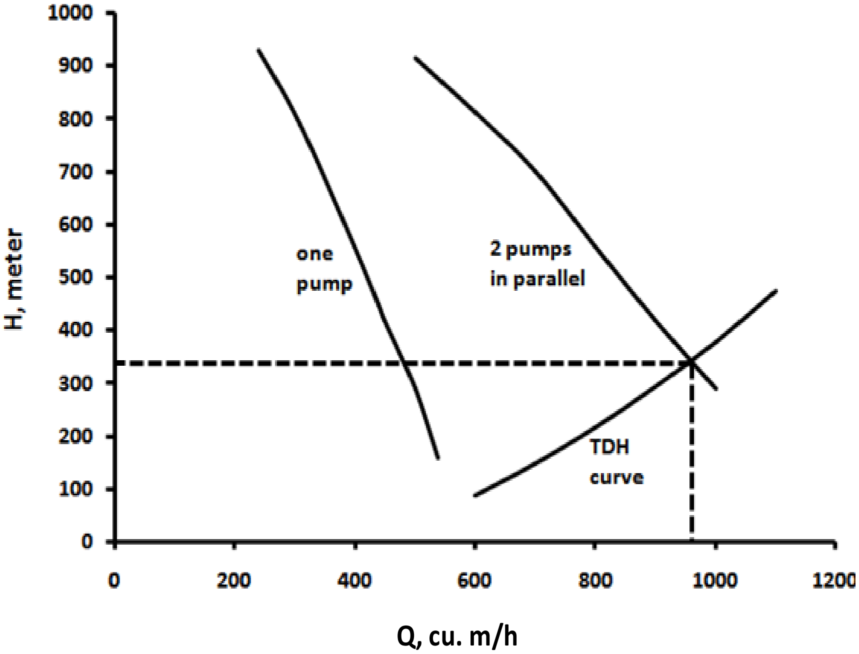

Figure 7. Second half of the pipeline without loop and with DRA.

Also, a similar analysis is made for the case of first half without loop and with DRA (Figure 7), as total flow rate at El-Hamra reached 960 cu. m/h (144,900 BOPD), (Q) coming from point (D) is deducted which was dropped down to 4,000 BOPD, then the upstream (Q) of the pump at mid point is 140,900 BOPD.

The upstream (Q) of the pump at zero point equals 140,900 BOPD minus sum (Q) from points (B) and (C), then such (Q) is 105,900 BOPD (701.6 cu. m/h) which is 17.7% over than the obtained rate (596 cu. m/h) as seen in Figure 4, reduced practical TDH with application of DRA (Figure 8) at 21 PPM (4 gallon/h) to reach the above mentioned up stream (Q) for first pump station, by using Equation (6), reduction in HFL is 37.8%, closed to the practical percentage shown in the next table.

Also, Pd is deduced. It is noted that without using DRA, the upstream (Q) cannot be obtained even with using three pumps connected in series.

Analyzing effect of pipeline loops

After the initial trial of application of DRA, two loops with total length 56 km x 16" O.D. (15.25" I.D.) were constructed, as 28 km from kilo point 55 to kilo point 83 and from kilo point 111 to kilo point 139.

Figure 9 shows that loop constructed for the first half of the pipeline, resulted in flow rate as 710 cu. m/h (107,160 BOPD), or 19.1% increase compared with case without loop (Figure 4), where flow rate is 596 cu. m/h (90,000 BOPD).

Figure 10 shows that loop constructed for the second half of the pipeline, resulted in flow rate as 960 cu. m/h (144,900 BOPD), or 11.6% increase compared with

Table 3. Practical Calculation for Percentage Reduction in HFL (Shashi, 2004); Sigurd and Isaksen (2003) Through Second Half of the Pipeline for the Case of Without Loop and with DRA.

No	Item	Data
1	ΔZ, m	– 137.5
2	HE, Pressure @ El-Hamra, m	43.1
3	TDH, m without DRA @ 960 cu. m./h (144,900 BOPD), Figure 5	602
4	TDH, m with DRA, Figure 6	344
5	Ps without DRA, m	100
6	Ps with DRA, m	63
7	Pd with DRA, m	407
8	HFL (m) with DRA @ 960 cu. m./h (144,900 BPPD)	501.4
9	Pd without DRA, m	702
10	HFL (m) without DRA @ 960 cu. m./h (144,900 BPPD)	796.4
11	% Reduction in HFL due to DRA	37

Figure 5, where flow rate is 860 cu. m/h (129,400 BOPD).

Analyzing the present pipeline situation

Present situation is seen in Figure 11, and is analyzed in Table 4, where crude oil is pumped through the pipeline with the two loops and with using DRA, so that the midpoint pumping station is not used temporarily. Pumping station at Meleiha is the only operating one, it could pump up to 139,000 BOPD, meaning 49,000 BOPD over the formal situation by 49,000 BOPD, which in turn increased final pipeline throughput up to 177,000 BOPD.

Analyzing effect of DRA in the present situation and deducing of (Pd)

DRA is injected at Meleiha as: q = 5 gallon/h, for Q = 920 cu. m/h ≈ 139,000 BOPD, hence: q = 20 PPM, from Equation (6): theoretical reduction in HFL is 37.7%. By inspection of Figure 12, it is concluded that actual reduction in HFL due to DRA is 40.4%, closed to the theoretical obtained percentage.

Also, Pd is deduced in Figure 12, TDH curve with loop and without DRA, results in by adding TDH curves in Figures (8) and (9) to each other. This figure shows performance chart for the pump at Meleiha with upgraded impeller size so that its general (Q-H) curve was slightly raised up, it is concluded that the obtained rate with DRA with two pumps connected in series, cannot be obtained even with using four pumps connected in series, which means that DRA save using other two pumps.

Discharge pressure of the two pumps connected in series at Meleiha

Pd of the pumping station at Meleiha is obtained theoretically and found closed to the actual recorded values seen in (Table 5). The used method is stated in Table 6.

Economic impact of DRA

An economic study (Table 7) shows money may be saved with using DRA. From Table (7), Total Cost (TC), million $/year for 5 gallon/h for pumping 177,000 BOPD do not include stand by rates is calculated as per Equation (8) as:

TC= ((28*5*24) + 45 + 30)*365 /10^6 = M$ 1.254 (8)

With using loops and without using DRA, TDH is calculated as follow:

$$\mathrm{Re} = \frac{3162.8\ \mathrm{sp.gr.} * X}{\mu * \mathrm{I.D.}} \quad \text{(Michael, 2002)} \tag{9}$$

Calculation of (F), as flow is always turbulent

$$F = \frac{1.325}{\left[\ln\left\{\left(\frac{e}{3.7\ I.D.}\right) + \frac{5.74}{R^{0.9}}\right\}\right]^{2}}$$

(PIPE-FLO Stock User's Manual, 2008)

for $5000 \le \mathrm{Re} \le 10^{8}$ (turbulent flow) and $10^{-6} \le \frac{e}{I.D.} \le 10^{-2}$ (10)

E = 0.0008 inch

$$\mathrm{HFL} = \frac{31.4\ F\ L\ X^{2}}{(\mathrm{I.D.})^{5}} \tag{11}$$

$$\mathrm{TDH} = \mathrm{HFL} + \Delta Z \tag{12}$$

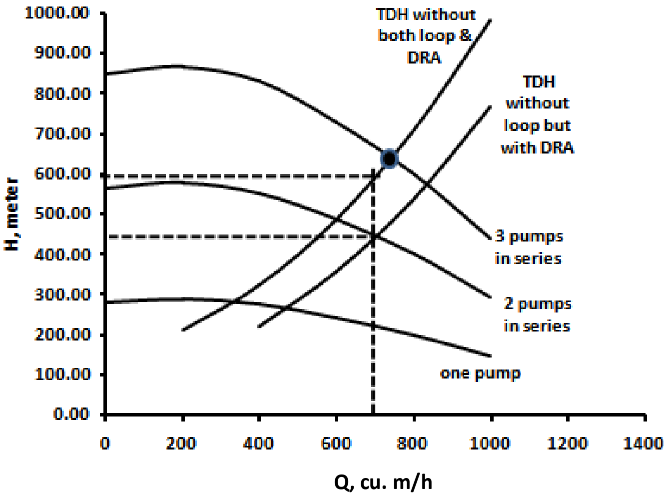

Figure 8. First half of the pipeline without loop and with DRA.

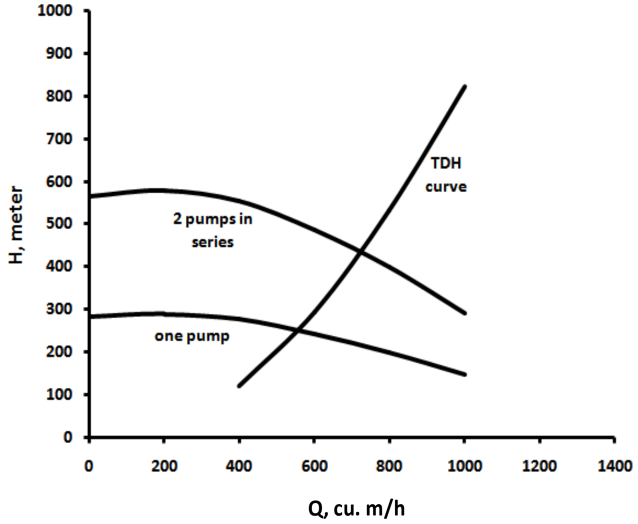

Figure 9. First half of the pipeline with loop and without DRA.

Calculation of HFL with loops

In the main Pipeline

L = 166.75 km and LP = 56 km

Re = 256,893 with developed flow rate; 104,145 BOPD (15.8 % increase than 90,000 BOPD), so X = 3038 GPM and F1 = 0.01533 (Othman, 2005).

In the loop

(X) is subdivided equally, meaning that flow rate through each loop is (0.5 X), then Re = 128,447 with 0.5 X = 52,073 BOPD = 1,519 GPM and F2 = 0.0173

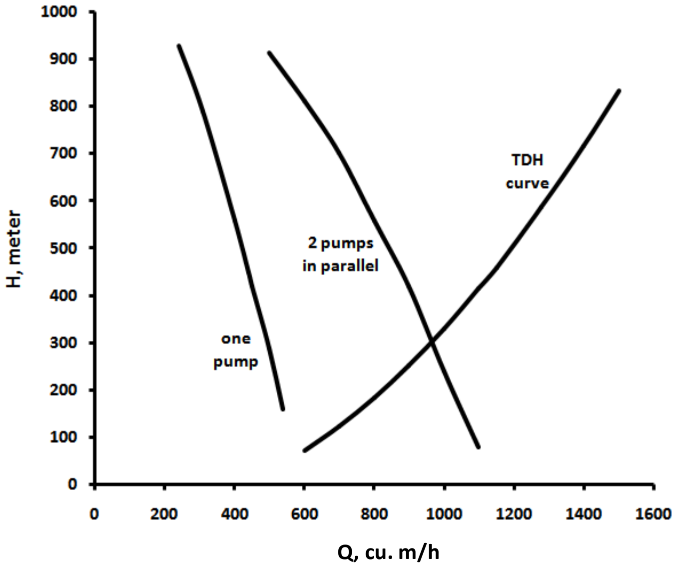

Figure 10. Second half of the pipeline with loop and without DRA.

$$\mathrm{THFL} = \mathrm{HFL1} + \mathrm{HFL2} \tag{13}$$

$$\mathrm{HFL} = \frac{31.1\ \mathrm{F1}\ (\mathrm{L} - \mathrm{LP})\ \mathrm{X}^2}{(\mathrm{I.D.})^5} + \frac{7.78\ \mathrm{F2}\,.\mathrm{LP}\,.\mathrm{X}^2}{(\mathrm{I.D.})^5} \tag{14}$$

HFL = 675 m and theoretical TDH = 675 – 232 + 43.1 = 486.1 m. So: TDH is closed to the practical one seen in Figure 12.

Estimation of annual power cost (APC) due to HFL Derivation of APC Formula (http://www.engrreview.com/Editorial_pages/2011/03_mr Ch_11/Pumps-Valves_Technofocus_07.html):

$$\text{Power, Horsepower} = \frac{(\mathrm{sp.gr.}) * (X * 62.4) * \mathrm{HFL}}{7.48 * 60 * 550 * \eta m * \eta p}$$

$$\text{Power, Kilowatt} = \frac{0.745 * (\mathrm{sp.gr.}) * (X * 62.4) * \mathrm{HFL}}{7.48 * 60 * 550 * \eta m * \eta p}$$

$$\mathrm{APC} = \frac{0.745 * (\mathrm{sp.gr.}) * (X * 62.4) * \mathrm{HFL} * T * U}{7.48 * 60 * 550 * \eta m * \eta p}$$

or

$$\mathrm{APC} = \frac{(\mathrm{sp.gr.}) * X * T * U * \mathrm{HFL}}{5308 * \eta m * \eta p} \tag{15}$$

Saved money due to reducing hydraulic friction losses as a result of using DRA is shown in Table 8.

Conclusion

a. Upgrading stages for capacity of the pipeline

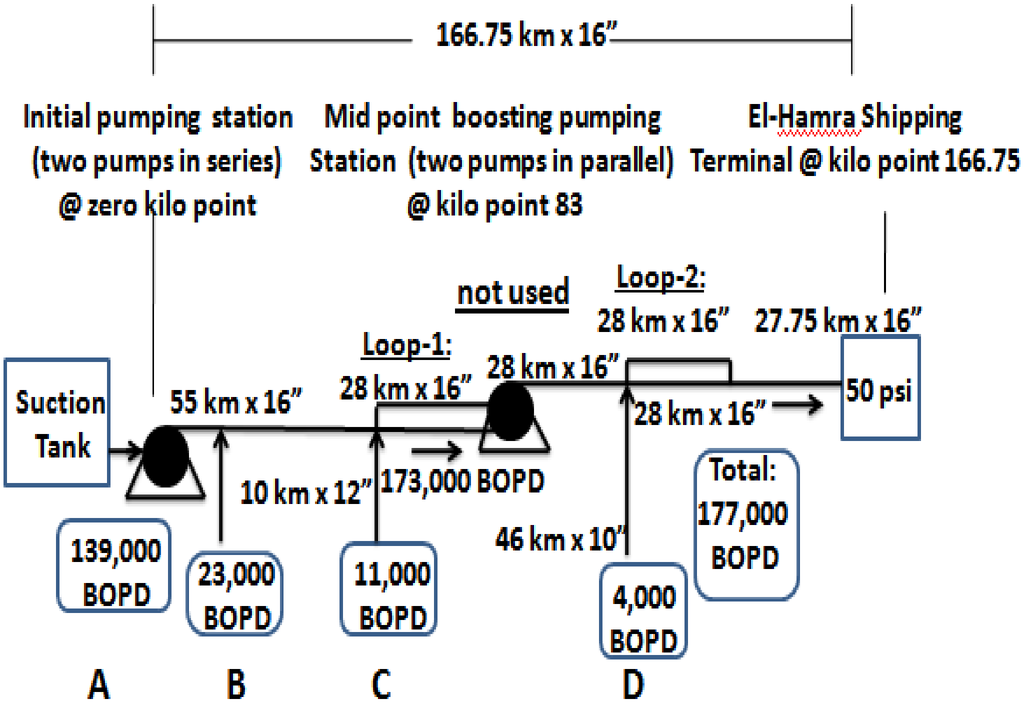

Figure 11. Pipeline sysem with loops and DRA.

Table 4. Practical Calculation for Percentage Reduction in HFL (Shashi, 2004; Sigurd and Isaksen (2003) for Case Seen in Figure 7.

No	Item	Data
1	ΔZ, m	– 94.5
2	HE, Pressure @ kilo point 83, m	88
3	TDH, m without DRA @ 701.6 cu. m./h (105,900 BOPD), Figure 7	598
4	TDH, m with DRA, Figure 7	440
5	Ps without DRA, m	180
6	Ps with DRA, m	60
7	Pd with DRA, m	500
8	HFL (m) with DRA @ 701.6 cu. m./h (105,900 BPPD)	506.5
9	Pd without DRA, m	778
10	HFL (m) without DRA @ 701.6 cu. m./h (105,900 BPPD)	784.5
11	% Reduction in HFL due to DRA	35.4

passed with:

i- Using of DRA.
ii- Using of DRA, with looping the pipeline with a pipeline; 56 km x 16" O.D.

b. By using of the mathematical methods applied, it could simulate the action of DRA from the point of view that it reduces HFL almost at (35 to 37%). In other words, by a reverse way and by knowing measured flow rates being pumped through the pipeline, closed figures for the final discharge pressures for each of the pumping stations at Meleiha and midpoint, by knowing suction pressures at these stations and ΔZ for each of the two halves of the pipeline.

c. Importance of this calculation technique assisted to take the decision to temporary abandoned of the midpoint pumping station, where discharge pressure of the pumping station at Meleiha did not exceed MAWP of the pipeline as 950 psi as per last conducted test for the pipeline.

d. From the previous economic analysis, it is shown that using DRA with loops realizes 33.5% annual money gain

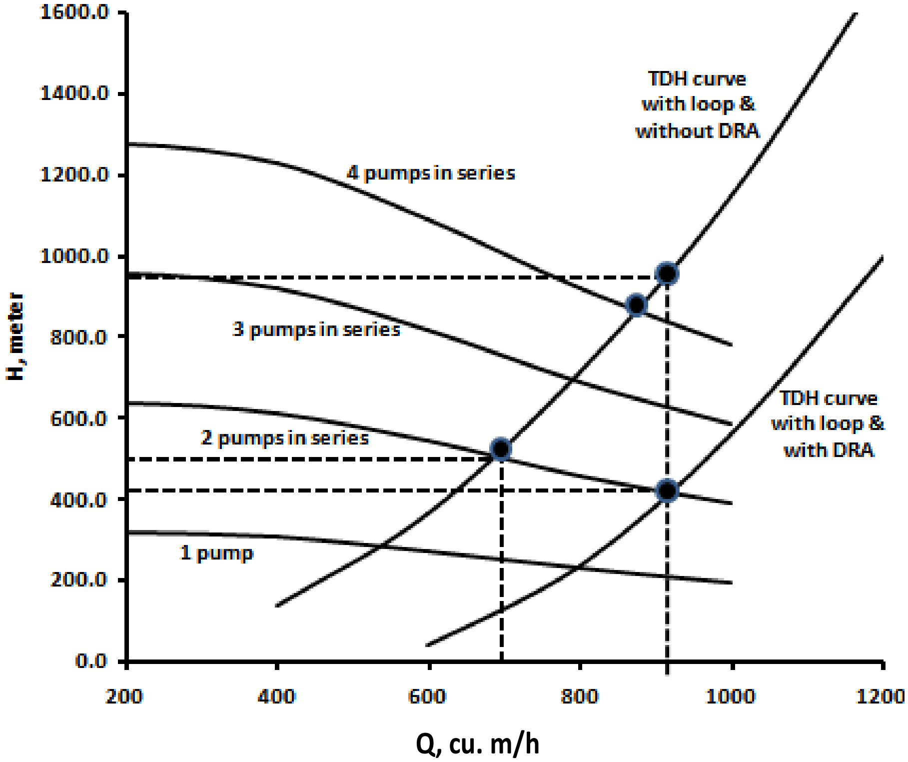

Figure 12. Full pipeline with loop (with and without DRA).

Table 5. Practical Calculation for Percentage Reduction in HFL (Shashi, 2004; Sigurd and Isaksen, 2003) Through Full Pipeline with Loop (with and without DRA).

No	Item	Data
1	ΔZ, m	- 232
2	Pressure @ El-Hamra, m	43.1
3	TDH, m with loop only @ 920 cu. m./h (139,000 BOPD)	950
4	TDH, m with DRA and two pumps in series = ΔP = Pd – Ps as seen in Figure 11	420
5	Ps without DRA, m	60
6	Ps with DRA, m	106
7	Pd with DRA, m	526
8	HFL (m) with DRA @ 701.6 cu. m./h (105,900 BPPD)	715
9	Pd without DRA, m	1010
10	HFL (m) without DRA @ 701.6 cu. m./h (105,900 BPPD)	1199
11	% Reduction in HFL due to DRA	40.4

gain more than using loops only.

ACKNOWLEDGEMENT

The author wishes to express gratitude to all who provided help and guidance in various ways at the different stages of this work. He convoyed deepest appreciation to Agiba pipeline team work at Meleiha field. Thanks also to Maintenance Department at Cairo head office.

NOMENCLATURES

API = American Petroleum Institute degree = (141.5/sp.gr.) – 131.5,
BOPD = Barrel Oil Per Day,

Table 6. Obtaining Pd of Meleiha pumping station.

No.	Item	Data
1	(ηm) of both motors for pump (1) and (2), %	95
2	(ηp) of both pumps (1) and (2),%	75
3	Flow rate, bbl/d	139000
4	Ps of pump-1, psi (m)	123 (106)
5	Volt	11000
6	Ampere for pump-1	36
7	Ampere for pump-2	42
8	Power Factor	0.8
9	HP to motor pump-1	735.5
10	HP to motor pump-2	858.1
11	ΔP on pump-1, psi	221.6
12	Pd of pump-1, psi	344.6
13	Ps of pump-2, psi	344.6
14	ΔP on pump-2, psi	258.5
15	Pd of pump-2, psi	603.1 (520.1 m)
16	Maximum motor power limit, HP	831
17	Loading of motor pump-1, percent	88.5
18	Loading of motor pump-2, percent	103.3

Table 7. Items of the economic study on using DRA.

Item	Value
$/gallon	28
Skid working rate, $/D	45
Skid stand by rate, $/D	35
Operator working rate, $/D	30
Operator stand by rate, $/D	20

Table 8. Calculation of the saved money due to reducing hydraulic friction losses by using DRA (http://www.engrreview.com/Editorial_pages/2011/03_march_11/Pumps-Valves_Technofocus_07.html).

No.	Item	With loop only	With loop and DRA
1	Crude oil sp.gr.	0.8156	0.8156
2	Daily pumped oil, BOPD from pump at zero point	104145	139000
3	Daily pumped oil (X), GPM	3038	4054
4	Pump utilization factor, U	0.96	0.96
5	Operating hours per year	8409.6	8409.6
6	Crude oil price, $/BOPD	100	100
7	Power cost (T), $/KWH	0.05	0.05
8	Annual pumped, million barrels = 365 * (D.R. No.2) * (D.R. No.4) / 10^6	36.49	48.71
9	Annual cost of DRA, M$/year, Equation (8)	0	1.254
10	Value of annual pumped, M$ = (D.R. No.6) * (D.R. No.8)	3649	4871
11	HFL, m	675	609
12	H, ft = 3.281 * (D.R. No.11)	2214.7	1998.1
13	Pump efficiency, %	75	75
14	Motor efficiency, %	95	95
15	Cost due to HFL, M$/year, Equation (15)	0.610	0.734
16	Final Annual Gain, M$/year = (D.R. No.10) – (D.R. No.9) – (D.R. No.15)	3648.4	4869

cu. m./h = Cubic meter per hour,
D = Day,
DRA = Drag reducing agent,
D.R. No. = Data raw number,
E = Pipe roughness (inch),
e = 2.7182818 (base of natural logarithm),
F = Friction loss factor,
F1 = Friction loss factor at full developed flow rate,
F2 = Friction loss factor at half,
m = Meter,
h = Hour,
HE = End pressure head (m),
HFL = Hydraulic Friction Losses in piping system (m),
Hfs = Hydraulic friction loss head in suction flow line, feet or meter,
HP = Horsepower,
Hs = Total suction head or lift, feet or meter,
K = HFL / Qm^2 (s^2/m^5),
KWH = Kilo Watt Hour,
L = Length of pipeline (km),
lit = Liter,
LP = Loop Length (km),
lb = Libra = 0.4536 kg,
GPM = Gallon per minute,
psi = Pound force per square inch,
I.D. = Inner diameter (inch),
km = Pipe length (kilometer),
MAWP = Maximum allowable working pressure, psi,
MSL = Main sea level,
M = Million,
mg = Milligram = 10^{-3} gram,
O.D. = Outer diameter (inch),
Pd = Discharge pressure head (m),
Ps = Suction pressure (m),
PPM = Part Per Million,
Q = BOPD,
q = Gallon per hour,
X = GPM,
Qp = Pump flow rate, cu. m/h. corresponding to (Pd–Ps) of a pump,
Qs = Any selected flow rate, cu. m/h,
Re = Reynolds Number,
sp.gr. = Specific gravity = ρ liquid density /ρ water,
TDH = Total dynamic head of a system, m,
THFL = Total hydraulic friction losses, m,
Z = Pipeline elevation in (m), relative to MSL,
$ = American United State Dollars,
°F = Degrees Fahrenheit,
°C = Degrees Celsius,
c.p. = Dynamic viscosity (centiopise) = 0.01gm/cm/s,
c.st. = Kinematic viscosity (c.p. / ρ) = 0.01cm^2/s,
ρ = Density in gm/cm^3 = sp.gr. x 1.0 gm/cm^3,
μ = Dynamic Viscosity (c.p.),
ln = Natural logarithm to the base (e),
ηm = Mechanical efficiency (%),
ηp = Overall pump efficiency (%),
ΔZ = Difference in elevation (m),
ΔP = Pump differential pressure (m).

REFERENCES

American Petroleum Institute (October 2004). "API SPECIFICATION 5L, 43rd Edition" Executive Director office of the Federal Register Washington, D.C., pp. 47-48; 164.
Désiré M (2010). "Flow Improver Solutions for Pipeline Drag Reduction," Pipeline Technology Conference Hannover, Germany. P. 5.
http://www.engrreview.com/Editorial_pages/2011/03_march_11/Pumps-Valves_Technofocus_07.html.
http://www.seykota.com/rm/friction/friction.htm.
http://www.tutorgigpedia.com/ed/Drag_reducing_agent.
Ken A, Maurice S (1999). “Surface Production Operations, Volume-1, 2nd Edition". Butterworth-Heinemann P. 350.
Michael F (2002). Certified in Plumbing Engineering (CIPE) and Certified in Plumbing Design (CPD), “Facility Piping System Handbook, 2nd Edition" The McGraw-Hill Companies Inc.," P. 1068.
Mohinder LN (2000). "PIPING HANDBOOK, 7th Edition" The McGraw-Hill Companies, Inc. P C.201.
Othman AK (2005). "Fluid Mechanics for Civil Engineers," Tutorial 4 – Unit 3: Application of Fluid Mechanics, Chapter 6: Flow in Pipelines, p. 42.
PIPE-FLO Stock User’s (2008). Manual and Method of Solution, Eq. 15, 19.
Sawhney GS (2011). "Fundamentals of Fluid Mechanics," International Publishing House pvt. Ltd. P. 661.
Shashi M (2004). "Piping Calculations Manual." 1:25-27.
Sigurd G, Isaksen OT (2003). "Experimental with Various Drag Reducing Additives in Turbulent Flow in Dense Phase Gas Pipeline," Pipeline Simulation Interest Group. P. 2.