Qualitative analysis of dynamic effects in oil pipelines

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Abstract

Pipelines are used in Mexico to transport different types of crude oil from the production areas to refineries and harbours. Pipeline systems have diameters of 20, 24, 30 or 36 inches and variable length, reaching several hundreds of kilometres in some cases. The distance between pumping stations is variable (from 10 to almost 200 km), depending mainly on topography. In some cases it is necessary to raise the fluid to the central plateau (more than 2,200 m above sea level); sectors of the conduits have to go across very rough terrains and need many changes of directions, particularly vertical. High discharge pressures are necessary in some pumping stations and pressure reduction valves are used in selected sections. As a result, in certain sectors of the pipeline system, head losses cannot be predicted with reasonable accuracy by conventional formulas, even considering corrections due to pipe aging or inlay deposits. An analysis, based on field measurements and supported on experimental and numerical concepts, shows that the friction factor is significantly influenced by dynamic effects, originated mainly in the curvature of the lines, which affects the velocity profile. The purpose of this paper is to show and describe these results, comparing different pipeline sectors with distinctive characteristics. The friction factor calculated with conventional equations (Swamee Jain) is compared with the one obtained from the Darcy Weisbach formula. An attempt is made to correlate the pipeline curvature with the friction factor in terms of a qualitative analysis. Further research should lead to the definition of adimensional parameters to be included in new algorithms, as was already proposed in other cases, particularly for aqueducts.
Keywords: oil pipelines, head losses, dynamic effects.

1 Introduction

Dynamic effects caused by direction changes in pressured conduits cause the occurrence of vortexes, separations zones and secondary flows, which in turn originate additional head losses. The works of Idelchik [1] and Miller [2] show that angular velocity components induce changes to the velocity profile and influence energy dissipation. Other related works were performed by Ortiz-Nuñez and Carmona-Paredes [3] and Carmona-Paredes *et al.* [4]; their studies were done for a concrete aqueduct of 2.1 m diameter and 42.6 km length, with remarkable direction changes; they show numerical-experimental evidence for the validity of a dynamic mechanism that results in the increase of head losses, which is more important than pipe aging due to scales or inlay deposits. Similar phenomena have been reported by El-Eman *et al.* [5], García and Tzátchkov [6] and Weiderhold [7]. The authors have already issued a preliminary report about the subject, Soto and Guaycochea [8]. A study based on field data for the oil pipeline Nuevo Teapa – Venta de Carpio (NT–VC) is presented in this paper. Results confirm the presence of dynamic effects and give elements that show its influence on the conduction capacity for different operation policies.

2 The case study

PEMEX, the Mexican public oil company, manages practically all aspects of the oil industry in the country, including the transportation of crude oil and refined products. Crude oil pipelines are variable in diameter (20, 24, 30 and 36 inches nominal diameters are employed). Crude oil is transported from the production areas, mainly located on the Eastern coast, to refineries and harbours. To accomplish this, oil pipelines have to go across long distances and, in some cases, rise to high areas of the Mexican Central Plateau. The case study of this paper, the Nuevo Teapa-Venta de Carpio oil pipeline system, fig.1, has two parallel pipes, 24 and 30 inches in diameter. The length is 567 km from Nueva Teapa (a station close to Minatitlan, on the Mexican Gulf coast) to Venta de Carpio, in the Central Plateau, 2,247 m above sea level; however the highest point is at 2,600 m. Both pipes can operate separately but lately they have been transporting the same fluid. They operate manifold systems in the pumping stations, so the hydraulic grade line (HGL) is the same for both tubes and the flow rates distribute accordingly. There are six pumping stations along the line; the typical pumping unit is a double stage pump powered by a gas turbine; in this way the performance can be regulated by adjusting the rotation speed and the number of pumps in service; every station has five to seven pumps.

The scope of this work will be limited to the segment defined between stations 1 to 5, particularly to sections Stn.1-Stn.2, Stn.2-Stn.3 and Stn.4-Stn.5. In general the conduction goes across rough terrains full of vertical curves; this situation is stronger in the last section and it may explain differences in the friction factors. Finally it is important to point out that the study was done only for the 30 inches conduit.

3 Field data analysis

An analysis was performed by processing field data, consisting of pressure and flow measures, which are taken as a routine procedure. Every data set includes the total flow rate in the pipeline system and pressure at the entrance and exit of every pumping station. Lengths, diameters and fluid properties are also known and the pipe roughness is calibrated, as explained later.

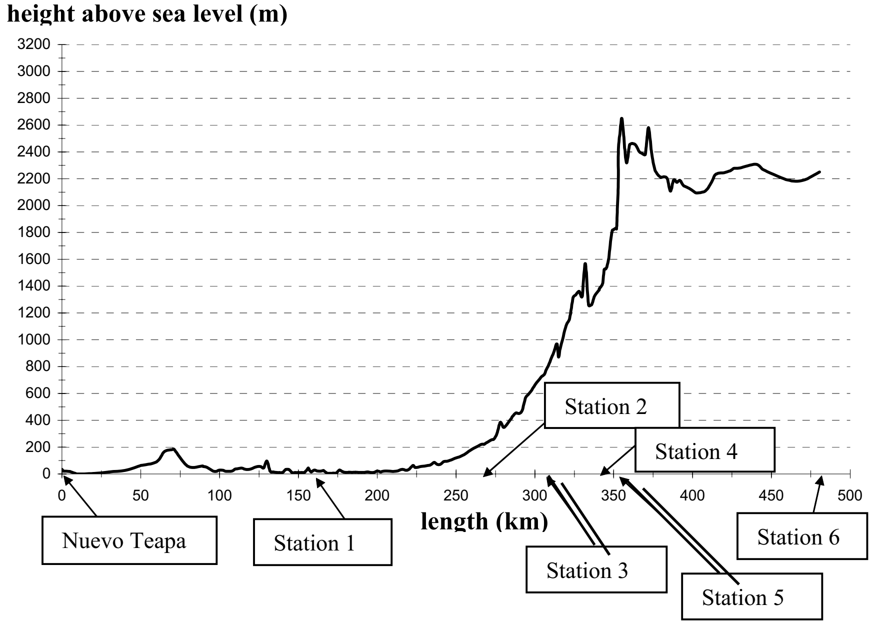

Figure 1: The Nuevo Teapa-Venta de Carpio oil pipeline system.

In total, 131 data sets were analyzed, reducing to 118, once some of them were disregarded. Since the flow rate was given for both conduits, an analysis was done to calculate the share of the 30 inches conduit, following classical methods. The equations employed for the analysis, for the three pipe sections, are as follows:

$$h_f = \left(z_i + \frac{p_i}{\gamma} \right) - \left(z_j + \frac{p_j}{\gamma} \right) \tag{1}$$

$$f_c = \frac{1.325}{\left[\ln\left(0.27\frac{\varepsilon}{D} + \frac{5.74}{\mathrm{Re}^{0.9}} \right) \right]^2} \tag{2}$$

$$f_m = \frac{2gDh_f}{LV^2} \tag{3}$$

where h_f is the head loss between stations i and j, z is the height above the sea level, p is the relative pressure, γ is the specific weight of the fluid, f_c is the friction factor, calculated with the Swamee Jain equation, ε is the absolute pipe roughness, D is the internal pipe diameter (0.7462 m in this case), Re is the Reynolds number (kinematic viscosity ν is assumed to be 19 cstk for crude oil), V is the flow speed and f_m is the friction factor, obtained from the Darcy Weisbach formula.

Both friction factors were compared. In the ideal case, they should be equal. The analysis showed that, in sections Stn1-Stn2 and Stn2-Stn3, for Reynolds numbers greater than 46,000, results are consistent. The first calculations were done with an absolute roughness $\varepsilon = 1$ mm but after adjusting to $\varepsilon = 0.5$ mm, the following results were obtained:

Table 1: f_m/f_c for Re > 46,000.

	Stn1-Stn2	Stn2-Stn3
average	1.0021	0.8552
standard deviation	0.0896	0.1335

Results are satisfactory, especially for the first section, fig 2. Most records correspond to high flow rates, because this is the normal pipeline operation condition but in certain occasions lower flow rates are transported and in these cases, it is observed that the quotient f_m/f_c becomes higher, particularly for section Stn2-Stn3, fig 3.

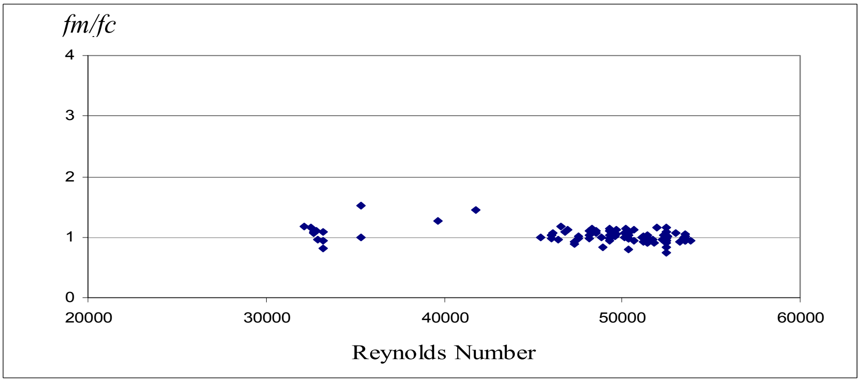

Figure 2: f_m/f_c for section Stn1-Stn2.

Regarding section Stn4-Stn5, fig. 4, the third one under study, the situation is different. Although the distribution pattern is similar to the previous figure, if absolute roughness ε is to be adjusted to reach the condition f_m/f_c equal to unity, it will rise to 7 mm, which is not a feasible value. Admitting that ε is still 0.5 mm in this case, the average f_m/f_c for Re > 46,000 is 1.669 and standard deviation is 0.2364.

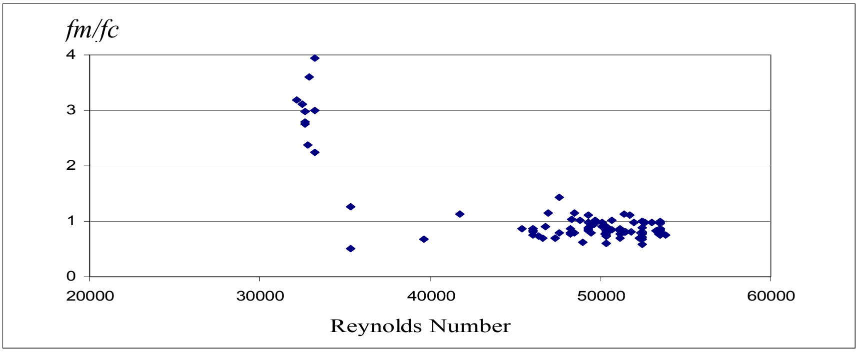

Figure 3: f_m/f_c for section Stn2-Stn3.

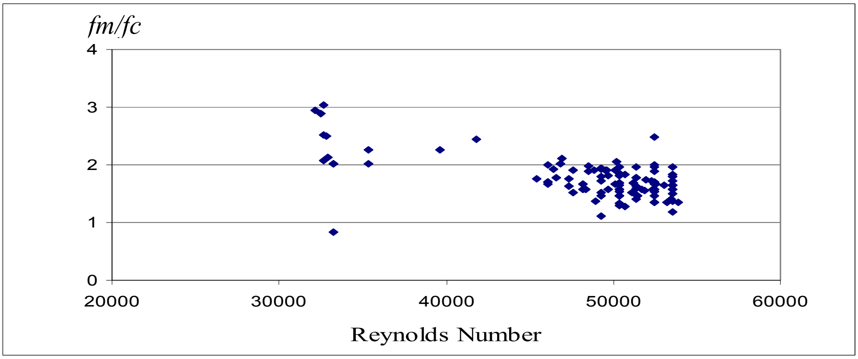

Figure 4: f_m/f_c for section Stn4-Stn5.

4 Pipeline profile

A more detailed profile than the one shown in fig. 1 is presented in fig. 5, for the last two sections. In both cases continuous vertical curves are present but they are more intense in section Stn4-Stn5, which is also steeper. It is important to point out that a two phase flow is improbable because pressures are high enough to avoid vaporization, at least in steady flow state.

5 Conclusions

Results show the influence of dynamic effects on energy dissipation. As can be seen, the friction factor is greater as the topographic profile is rougher. Evidence shown is that the ratio f_m/f_c is higher for low Reynolds numbers. According to the conventional equations, the calculated friction factor f_c increases as the Reynolds number decreases; thus the combined effect of these two elements will result in an even higher value. This increment cannot be explained by simply attributing the additional head losses to connections and accessories. Although minor losses coefficients may increase as the Reynolds number diminishes, Hooper [9], it does not happen in such proportion.

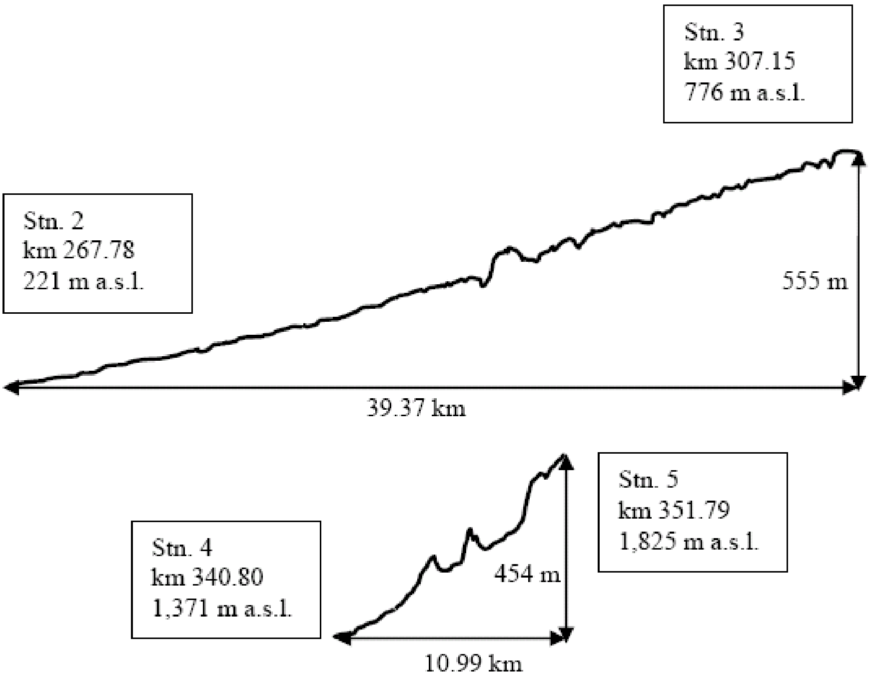

Figure 5: Topographic profiles, Stn2-Stn3 and Stn4-Stn5 (a.s.l.: above sea level).

The next step should be to study the correlation between the friction factor and a representative parameter of the pipeline curvature and to obtain a particular equation for the friction factor calculation, similar to the ones reported in some of the references, e.g. Ortiz-Nuñez and Carmona-Paredes [3]. The conventional formula presently employed to predict the operation of this particular pipeline system should be insufficient unless the influence of dynamic effects is considered.

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