Pipeline Hydraulics

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Introduction

- **This covers hydraulic and process issues as well as overall pipeline system design.**
- **The aim of this section is to give an overview of these topics and enable engineers to interface with specialist engineers or vendors.**
- **It does not provide a detail analysis and does not provide formulae or detail design tools.**

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Introduction

System design

- **Hydraulic terms and definitions**
- **Steady state**
  - **Liquid flow**
  - **Gas flow**
  - **Multi-phase flow**
- **Transient flow**
- **Facilities design**

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System design

- **Pipeline system design includes the prime driver and inlet conditions as well as outlet conditions and flowrate and other variables.**
- **Initial design often uses incomplete data and requires iteration of ideas and options.**
- **Pipelines are designed to a given design flowrate – often nominal**

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Information required

- **There is a certain amount of minimum information required to undertake even the most basic of system design work.**

  - **Fluid to be transported (fluid properties)**
  - **Length of pipeline**
  - **Inlet and outlet conditions**
  - **Flowrate / throughput**
  - **Route profile (especially for liquid pipelines)**

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System design

- **System design is about balancing the various factors that influence pipeline cost. The weighting and importance of each aspect differ between each pipeline and project.**

- **The balance between CAPEX, OPEX and future capacity requirements requires judgments to be made about the lower CAPEX from a smaller pipe or one operating at a higher pressure versus increased pumping or compressor cost.**

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Hydraulic Analysis

- **Steady state analysis programs provide quick and relatively simple tools to undertake initial design. Certain inputs can have an important effect on the output including internal roughness, especially for gas, fluid properties, and temperature.**
- **Sensitivity studies are recommended for all of these inputs to allow some idea of possible outcomes.**
- **Analysis accuracy is at best +/- 5% and often much worse. Beware of multiple decimal places indicating false accuracy.**
- **Also note ALL packages work on ID. Beware of not specifying correctly.**

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Basic relationships

- **Some basic relationships.**
- **Actual flow calculations are based on a variety of theoretical calculations, with empirical data added from laboratory and small scale pipeline loops.**
- **All of them exhibit the same fundamental properties.**
- **Pressure drop is proportional to fluid velocity^2 (same size pipe).**
- **So in the same size pipe, if you double the flow rate, you increase the pressure drop by a factor of 4.**
- **For same flow rate, velocity is inversely proportional to diameter^2.**
- **There are other effects so for the same flow rate, if you vary the ID of the pipe, the pressure drop falls by ~ (D_1/D_2)^5.**

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Basic formulae

- **Critical to get ID correct even by a few mm for long distance pipe.**
- **Parallel (Looping) pipes of different size connected at ends will flow at very different rates.**
- **e.g. a 12” ID pipe flowing alongside a 10” ID pipe flows at 400m3/hr compared t0 248m3/hr for same pressure drop**
- **Pressure often needs to be transposed into it’s equivalent head of a column of liquid.**
- **Conversion of Pressure into metres head**
- **m = P X 100 / SG X 9.81 (P in bar) SG of water is 1.0 (m= P x10.19 / SG)**
- **P = m x SG x 9.81 / 100 (P in bar) (P= m x SG / 10.19)**
- **Allows use of metres above sea level**

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Single phase liquids

- **Constant pressure loss per unit length (no changes in diameter or fluid properties)**
- **Virtually Incompressible**
- **Positive pressure at all points (profile required)**
- **Fluid flow relatively accurately modeled**
- **Economic flowrate of 2 to 2.5 m/sec for long pipelines is a good start point for pipe sizing.**
- **Flow regime should be turbulent**
- **DRAs valid for high velocity lines (> 3 m/sec)**
- **Potential for high surge pressures**
- **No accepted limit of flow velocity**

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Liquid pipeline design

- **Pressure in the pipeline needs to above 1 barg at all times regardless of pipeline elevation**
- **In pipelines going uphill in direction of flow or in areas where large elevation changes occur, different wall thicknesses may be able to be used (telescoping) by changing design pressure (+ or –).**
- **Pipelines with dips below start or end pts needs to be allowed for in pipeline pressure setting**
- **Pipeline must consider the case of locked in flow and upstream pump station flowing as the worst case MOP.**
- **Generate system curve and pump curve to determine flowrates.**

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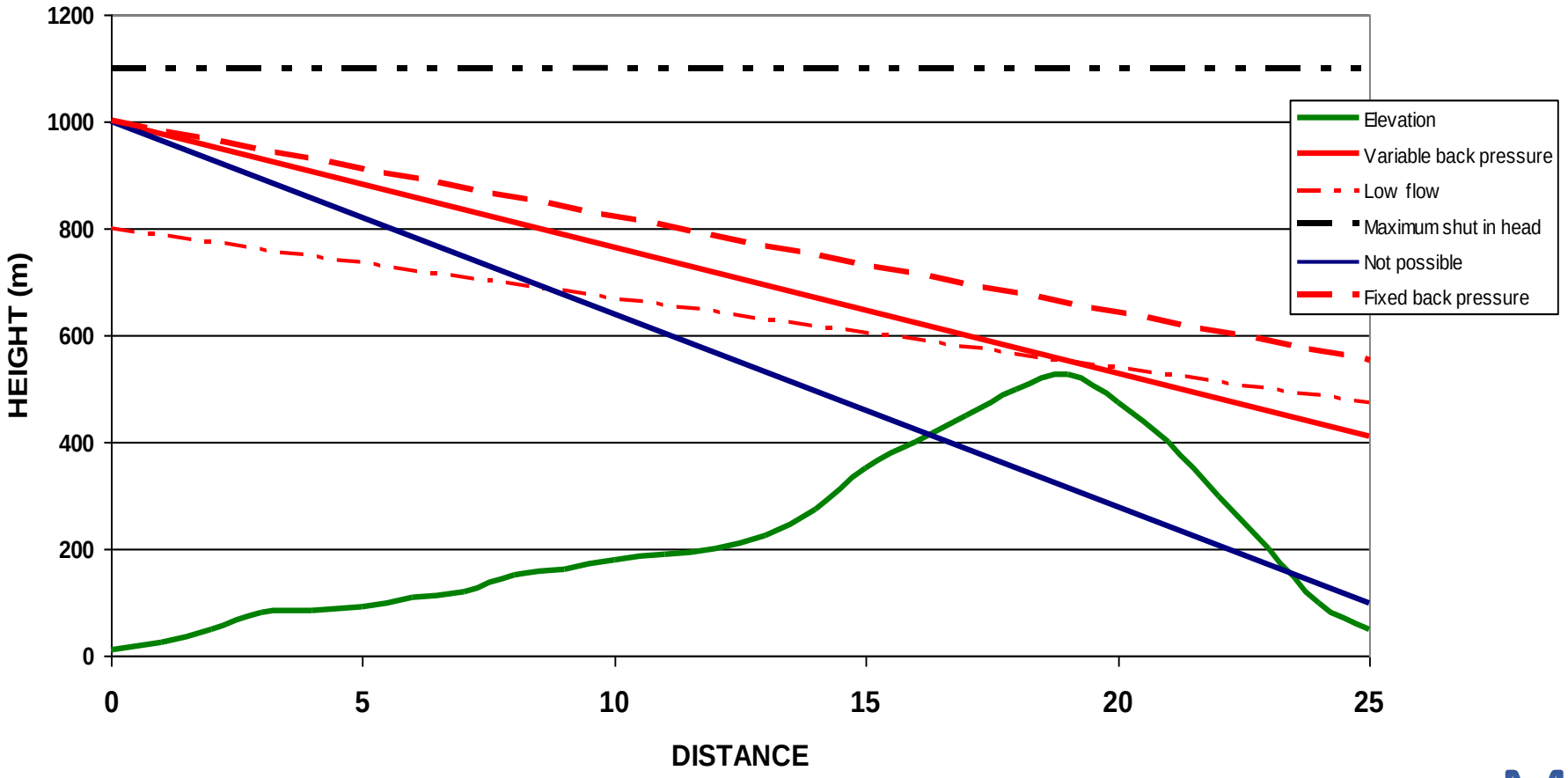
Liquid pipeline hydraulic graph



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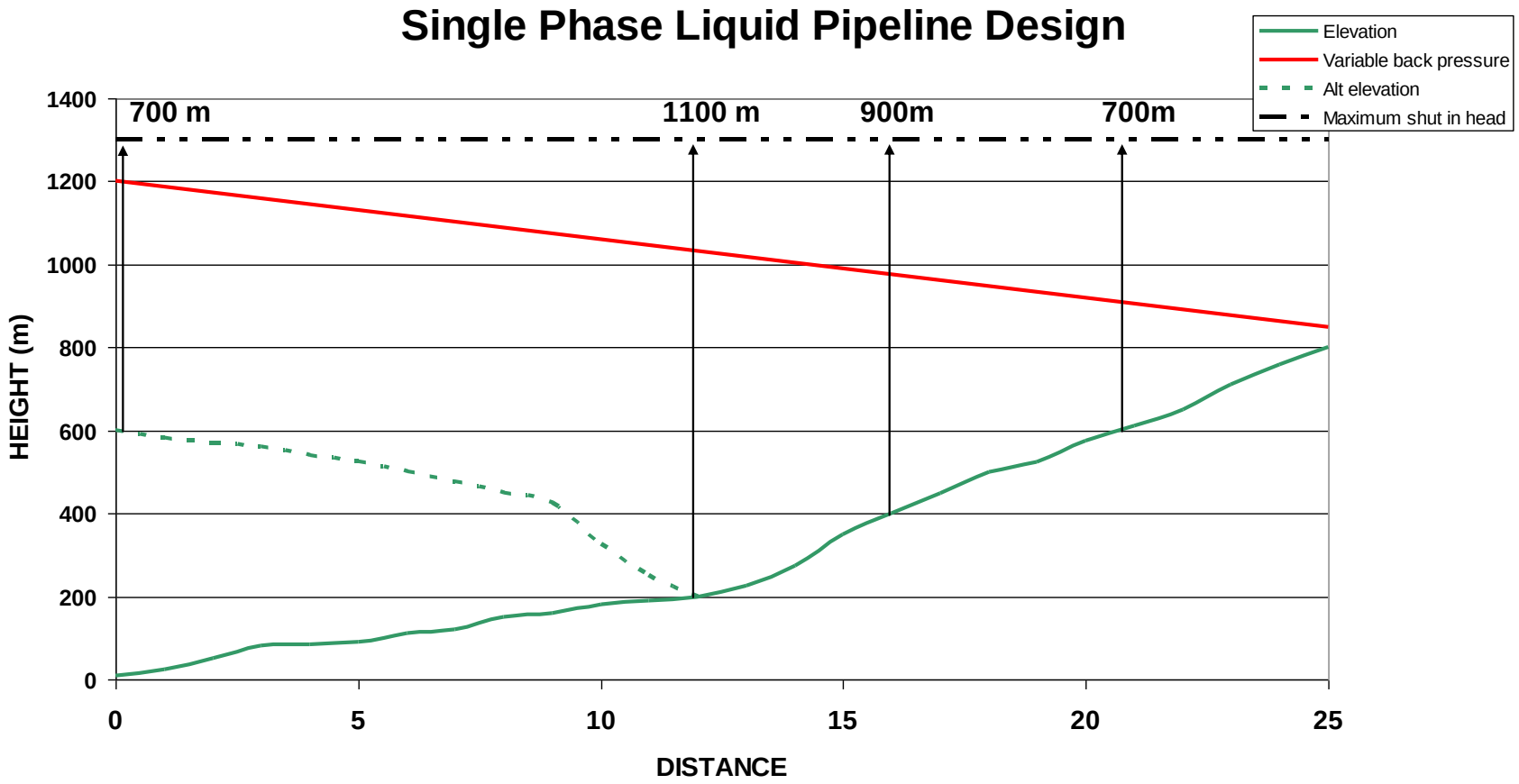
Liquid pipe design - telescoping



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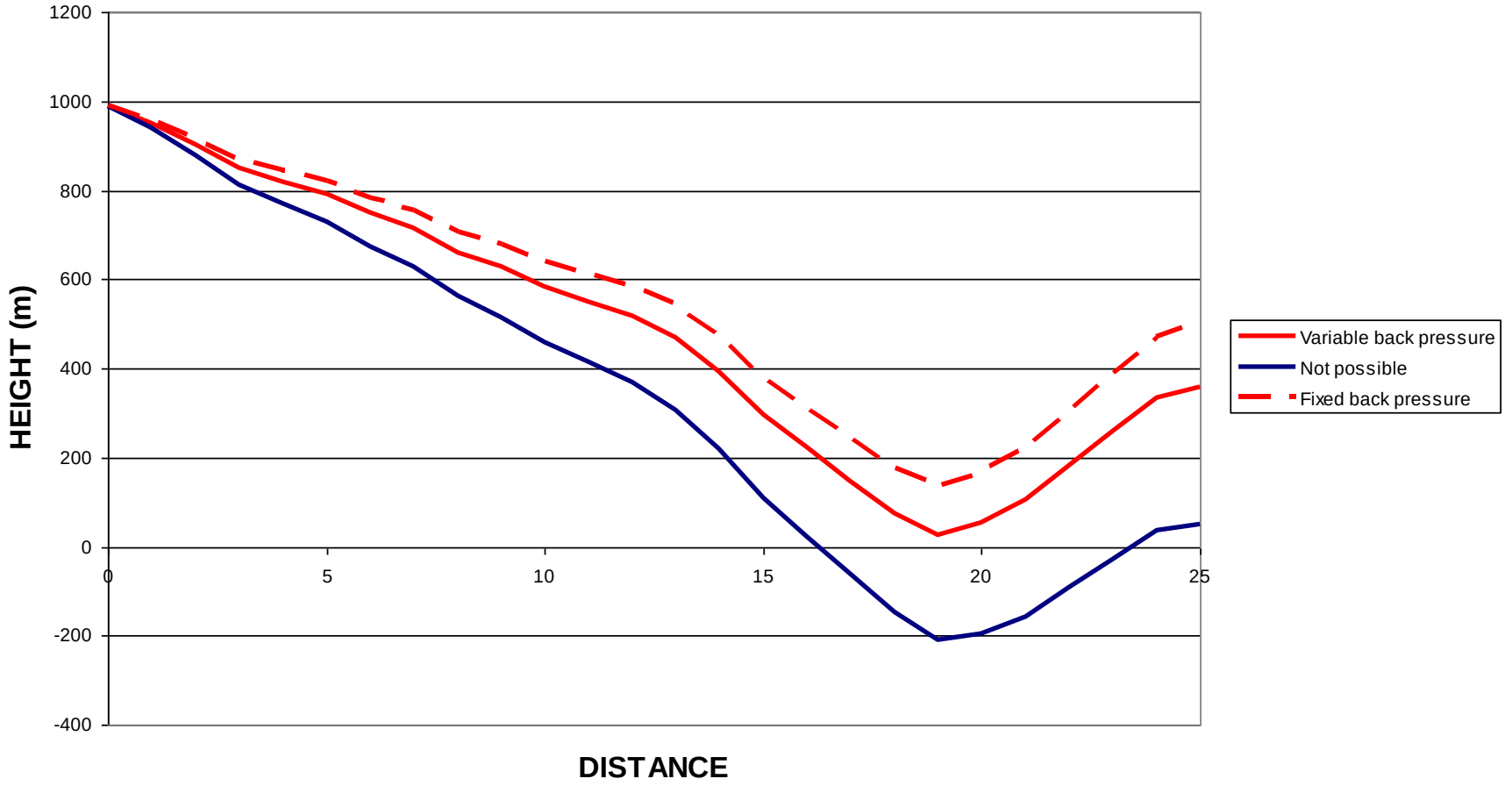
Pressure in pipeline



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Liquid pipeline design

- **To establish flow rate from a pump system curves are required**
- **Start point is the static head required to get any flow (High point or end point)**
- **Calculate pressure drop for multiple points**
- **Superimpose pump curve(s)**
- **Parallel pumps can be shown by doubling or tripling flow**
- **Can show impact of different fluids**
- **Intersection point is flow rate**
- **Adding pumps may not make any difference**

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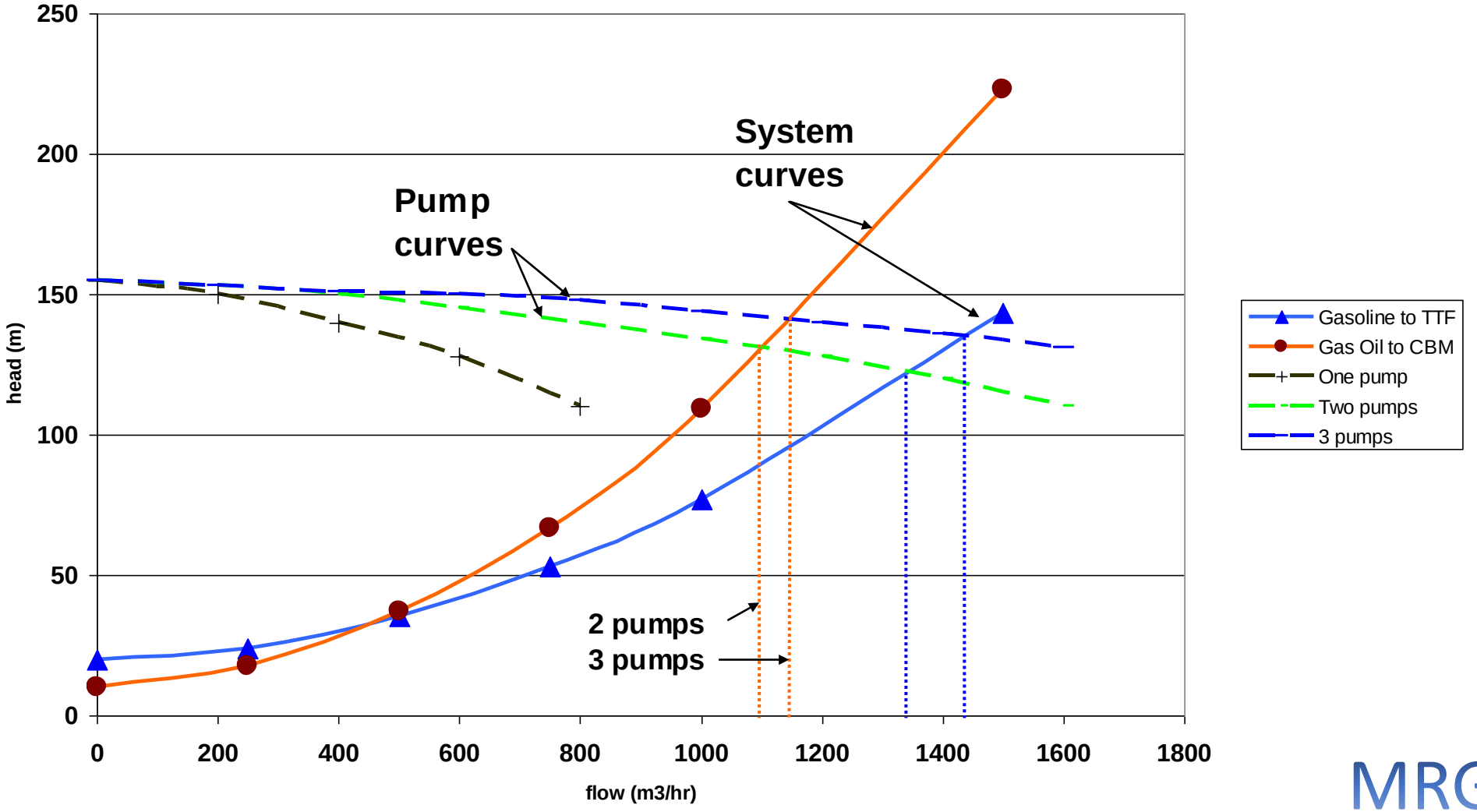
Pump and system curves



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Single Phase Gas

- **Variable pressure loss per unit length, increasing for lower pressures at the end of the pipeline.**
- **Pipeline looping starts at delivery end to increase capacity**
- **Compressible – line pack / de pack – no surge**
- **Profile relatively un-important**
- **Fluid flow modeled well**

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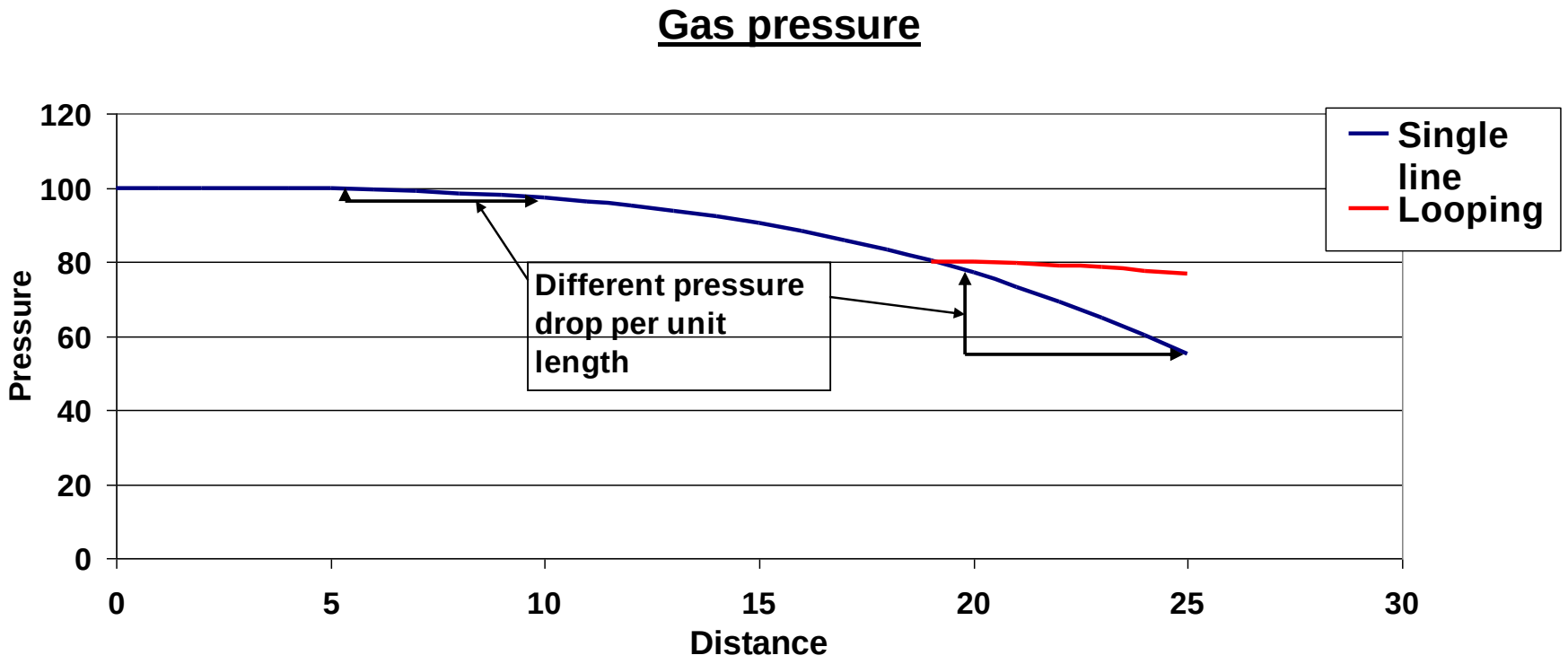
Gas pressure analysis



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Gas

- **Actual Velocity at outlet 10 to 12 m/sec at outlet for long pipelines is a good start point for sizing.**
- **Temperature can become critical**
- **DRA's not available for dry gas flow**
- **Size can increase due to line packing / storage requirement**

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Multi-Phase systems

- **Pressure gradient variable depending on GOR and water and liquid drop out.**
- **Compressible**
- **Various correlations available based on empirical models – lower levels of accuracy (+/- 10 % at best)**
- **Slugging and transient flow normally dominates design considerations**
- **Pressure drop more accurate than liquid hold-up and slugging criteria – should only be used as an indication of potential problems**

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Multi-phase steady state

- **As liquid content increases, type of flow changes**
  - **Mist**
  - **Annular**
  - **Stratified smooth**
  - **Stratified Wavy**
  - **Slugging (terrain and hydrodynamic)**
  - **Bubble flow**
- **As pressure decreases, gas content and velocity increases**
  - **Use of slug breakers**

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Multi-phase steady state

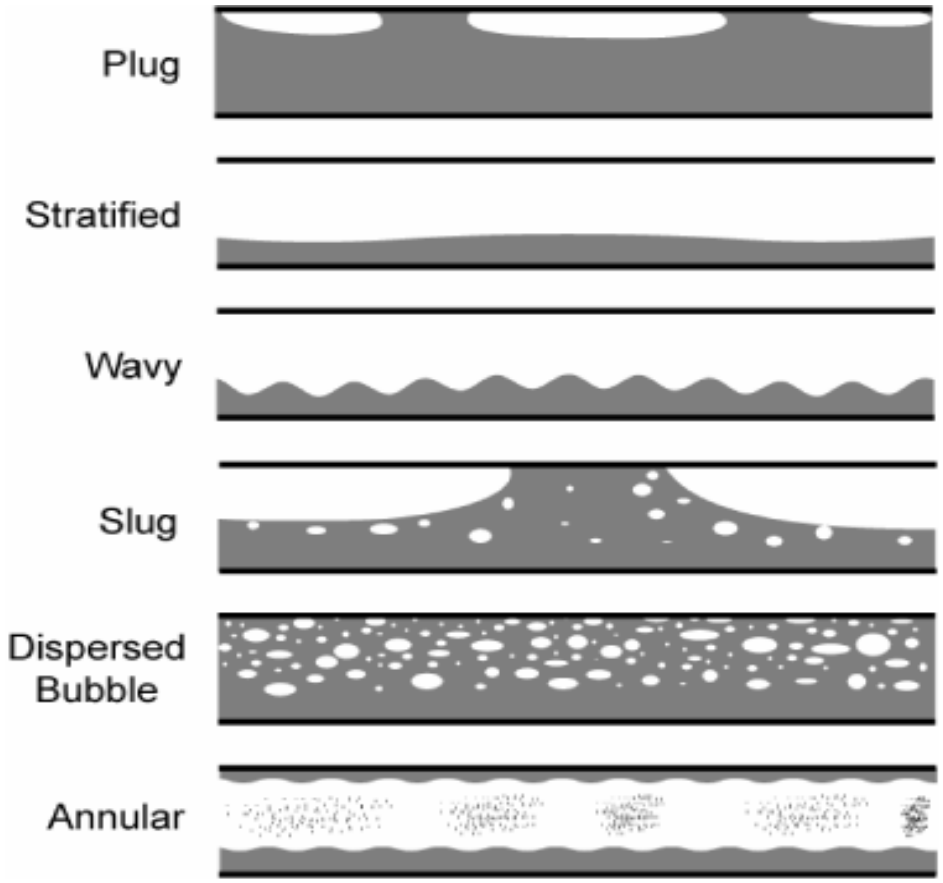

Figure 3. Flow patterns in horizontal and slightly upward inclined flow in a tube.

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Multi-phase steady state

- **Liquid hold-up can increase over time**
- **Gas velocity needs to be kept as high as possible to reduce liquid hold-up**
- **Liquid hold-up tends to have a critical point where large increases occur at small overall flowrate changes**
- **Operational Pigging often required on long wet gas lines with significant up slopes to remove liquid**
- **DRA's can be effective in high liquid content pipelines especially when slugging occurs.**

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Transient analysis

•Transient analysis is required for all operations involving significant changes to fluid flowrates, start/stop, slugging and transient conditions. Information commonly required includes:

•Pump characteristics

•Valve CV and opening / closure times

•Fluid composition

•Cases and options to be studied

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Transient analysis issues

- **Surge – Often an issue with relatively short liquid pipelines where high velocities (> 3m/sec) and sudden valve closure occur – typically loading lines have significant surge issues**
- **Line pack / de-pack Often used to buffer gas inlet and outlet variations over time. Line pack volume can be less than anticipated**
- **De-pressurisation can incur significant low temperature issues when a gas pipeline is de-pressurised or blown down. Blow down of pipelines not required under design codes**
- **Slugging – ramp up / down can cause significant liquid surges to occur at the inlet to a separation plant potentially causing the plant to trip.**

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Facilities design

Common items:

- **Protection of downstream facilities and shut off of incoming supply.**
- **Pressure regulation and metering facilities commonly included.**
- **Pigging facilities required**
- **Standby and duplication common, may be 2 x 100% or variations e.g. 3 x 50%.**
- **Pipeline design codes can be used, but ANSI B 31.3 common after first isolation valve.**

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Gas reception facilities / take offs

- **Pre-heating of gas *before* pressure reduction to maintain gas temperature due to Joule-Thomson cooling (approx 1 deg C per 2 bar pressure drop for pressures up to 70 barg)**
- **Gas heater commonly water bath or heat exchanger.**
- **Metering upstream or downstream of pressure regulators**
- **Conflict between ensuring continuous supply and protecting lower pressure pipe downstream may require higher level of back-up and elimination of single point failure locations.**

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Summary

- **This section has described :**
- **Pipeline hydraulics design terms and definitions.**
- **Steady state and transient analysis**
- **Outline facilities design**

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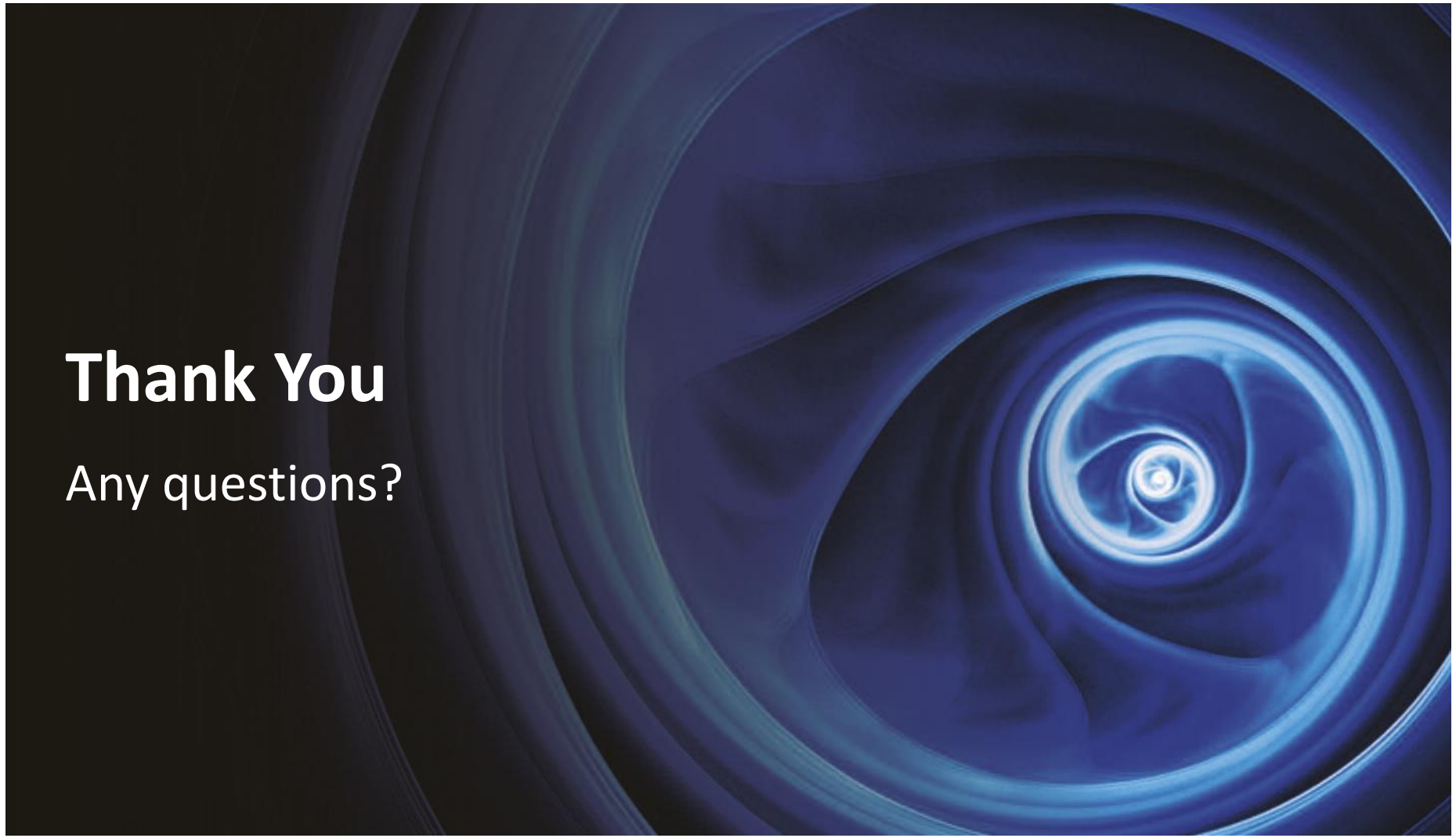

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