SUBCOURSE QM5203

EDITION A

HYDRAULICS IN PIPELINE OPERATIONS

AIPD

READINESS/ PROFESSIONALISM THRU GROWTH

THE ARMY INSTITUTE FOR PROFESSIONAL DEVELOPMENT

ARMY CORRESPONDENCE COURSE PROGRAM

HYDRAULICS IN PIPELINE OPERATIONS

Subcourse Number QM5203

EDITION A

United States Army Combined Arms Support Command
Fort Lee, Virginia 23801-1809

4 Credit Hours

Edition Date: May 1999

SUBCOURSE OVERVIEW

This subcourse is designed to introduce you to petroleum fluid hydraulics. This subcourse will assist you in starting the process where you will design an operational military pipeline or hose line.

There are no prerequisites for this subcourse.

This subcourse reflects the doctrine that was current at the time the subcourse was prepared. In your own work situation, refer to the latest official publication.

Unless otherwise stated, the masculine gender of singular pronouns is used to refer to both men and women.

TERMINAL LEARNING OBJECTIVE:

ACTION: You will learn to determine the advantages of military pipelines and hose lines, the best routes, and physical characteristics of petroleum fluids.

CONDITION: You will be the 92F responsible for supervising, planning, installing, and operating single and multiproduct fuel distribution systems in support of subordinate element missions.

STANDARD: To demonstrate competency of this task, you must achieve a minimum of 70 percent on the subcourse examination.

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OVERVIEW

LESSON DESCRIPTION: In this lesson you will learn the duties of the pipeline dispatcher; you will prepare a monthly consumption graph, prepare a monthly pipeline schedule, prepare a graphic progress chart, and review a daily pipeline order.

TERMINAL LEARNING OBJECTIVE:

ACTION: You will be responsible for supervising petroleum terminal operations and petroleum pipeline operations. You will also be responsible for determining the location of petroleum pump stations, terminals, and supply points. As the petroleum expert you will also be responsible for planning petroleum supply program m theater operations and petroleum distribution systems (fixed and tactical facilities).

CONDITION: You are the 92F responsible for supervising and providing both single product and multi-product fuel support to subordinate elements.

STANDARD: Identify and understand basic mathematics, understand basic hydraulic mathematics, identify and understand advantages and disadvantages of military pipeline and hoseline systems, determine head loss due to friction in military pipeline systems according to FM 10-67-1 and FM 5-482.

REFERENCES: The material contained in this lesson was derived from the following publications: FM 10-67-1, and FM 5-482.

INTRODUCTION

Since machines were first introduced to the battlefield, military leaders depended on continual sources of petroleum to power these machines. In fact, throughout the many wars of the 20th century, battles and wars have been won and lost based on who controls the fuel. As military weapon systems have become more lethal, they have also become vast consumers of petroleum fuels. In fact, a single U.S. Army mechanized infantry division of today uses over a million gallons of fuel in a single day during offensive operations. Our mission as Army petroleum leaders is to feed the ravenous hunger of our mighty war machine. It is important to make every attempt to protect the environment while still accomplishing this mission. As such, you must conduct an environmental assessment before beginning fuel operations. The unit environmental officer coordinates with the EPA representative, the unit petroleum officer, and the environmental regulators to make an assessment of the petroleum operation. This assessment is used to determine how the petroleum operation will affect the wildlife and local population within the unit's area of operation. Environmental compliance officers use the results from the assessment to verify whether or not the petroleum operation is IAW the prescribed environmental compliance. The unit environmental officer works with the following personnel: the environmental compliance officer, the EPA officer, the unit petroleum officer, and environmental regulators. As with any operation, the unit environmental officer must stress spill prevention.

The unit environmental officer is also responsible for knowing the governing spill contingency policy, the installation policy, the CONUS policy and or the OCONUS policy, and any host nation policy that applies to the area in which the petroleum operation will be conducted.

In the years since World War II, the U.S. Army Quartermaster Corps has operated petroleum pipelines throughout the world in locations such as Korea, Japan, Europe, and Alaska. More recently, tactical pipelines have been deployed to support Desert Shield, Desert Storm, and Somalia. Also, military exercises such as Roving Sands, Market Square, Bright Star, and Tandem Thrust have seen deployment of tactical, multiproduct pipelines.

Although often thought of as insignificant during peacetime, all petroleum NCOs and Officers will find themselves sought out by field commanders during wartime. Battles and wars hinge upon a leader's ability to bring overwhelming destructive firepower upon the enemy. Good leaders recognize they must include petroleum leaders during initial planning phases of any operation. Otherwise, they may find themselves and their command nonmission capable. All petroleum leaders must strive to educate their superiors on the importance of adequate petroleum support. You must also teach your subordinates to know, understand, and be able to execute their responsibilities to support the force.

1. Terms. Here are some of the terms and definitions you will encounter during this lesson.

a. Darcy-Weisbach Equation -- Used to calculate friction head loss in a pipeline.

b. Design Fuel - Fuel type for which a pipeline system is designed; military pipelines will most likely transport kerosene-based diesel and jet fuels.

c. Friction Loss - Loss of pressure, in terms of feet of head per unit of pipe length, from internal resistance to flow in the product itself (viscosity) and from resistance offered by pipe walls, pipe fittings, and reductions in pipe diameter.

d. Reynold's Number - An equation used to determine the friction factor required in the Darcy-Weisbach equation.

e. Specific Gravity - A physical property of liquids; the ratio of the weight of a volume of liquid to the weight of an equal volume of water.

f. API Gravity - Scale developed by the American Petroleum Institute (API) and used by the petroleum industry, that is based on reciprocals.

2. Basic Petroleum Mathematics.

Now that you are familiar with the terms related to petroleum hydraulics and pipeline design, we will begin with an introduction to mathematics. As a student in the petroleum officer course and, more importantly, as a petroleum officer, you will often encounter problems requiring more than just basic mathematical abilities. These problems will require an officer able to not only solve a given problem, but determine multiple unknowns along the way, each of which can greatly affect the final solution. This mathematical evaluation is designed to test not only your mathematical skills but also your analytical thinking abilities. To be successful, you must learn and understand flow rates and velocities. You must learn to perform basic calculation related to flow rates and velocities, determine mathematical hierarchies using rules of mathematics, and solve for an unknown variable given all other variables in an equation.

a. Flow Rates. Throughout the Petroleum Officer Course, you will encounter flow rates and their applicability in solving petroleum-related problems. It is very important to understand what flow rates are, how they are measured, and their significance to solve these problems.

(1) A flow rate can be defined as that which measures a specific volume of liquid delivered over a specified period of time. Note that the two most significant elements of this meaning are volume and time. Flow rates can be distinguished from velocities, which we will discuss later, by these units of measurement.

(2) If you know the amount of volume in a liquid and the amount of time it was measured in, you can determine the specific flow rate of that liquid. Flow rates are generally denoted by the abbreviation "Q".

(3) Volumes can be measured by many different units of measurement. The most common ones we use in the petroleum industry are cubic feet, gallons, and barrels. The most common time measurements we use when dealing with flow rates are seconds, minutes, hours and days.

(4) When you put volumes of measurement together with units of time, you have different measures of flow rates. Some of the more common flow rates we will discuss throughout the course are: gallons per minute, barrels per hour, and cubic feet per second.

b. Conversion of Flow Rates. Often, when working in the petroleum field, we are required to take a flow rate that is given in one unit of measurement and convert it to another in order to solve a specific problem. For example, we may be given a flow rate of gallons per minute but may have to convert that unit of measurement to barrels per hour to satisfy a specific scenario. Luckily, most flow rate conversions we are required to make have already been figured out mathematically and placed into FM 10-67-1, Appendix M. All you have to do is take the correction unit from FM 10-67-1 and multiply it by your answer to convert the flow rate. However, there may be some cases in which a specific flow rate is not listed in that reference manual. Therefore, we need to discuss how to perform these conversions so that you can understand how they were calculated.

(1) Let us take an example and solve it together. Problem: You re operating a hose line system, and you have a meter in-line. You have received 500 gallons over the past two minutes, but your supervisor needs to know how many cubic feet per second it equals. To solve, you follow this order:

(a) The first requirement in this example is to convert the time down to a minute of measurement. Since we are dealing with two minutes, divide by two to convert to a by-minute unit of measurement. Thus, 500 gallons over two minutes convert to 250 gallons per minute.

(b) Using FM 10-67-1, Appendix M, note that converting from gallons per minute to cubic feet per second requires multiplying your answer by 0.002228. By multiplying this factor by the 250 gallons per minute, we can determine that a flow rate of 250 gallons per minute is equal **to 0.557 ft^3/second**.

(2) Where do the conversions come from? As was previously stated, it is important to understand where these conversion factors in FM 10-67-1 come from, since not all possible flow rates are listed in that reference.

(a) All units of measurement are convertible, as long as you know their characteristics. For example, most people do not know offhand that 1 hour equals 3,600 seconds. But, everyone knows that 1 hour equals 60 minutes and 1 minute equals 60 seconds. By multiplying these two conversions together, we can quickly determine that 1 hour equals 3,600 seconds.

(b) Looking at the previous example, the flow rate gallons per minute had to be converted to cubic feet per second. How was this conversion derived? One of the first things to remember is that whenever we have measurement units in a numerator or denominator, the only way to cancel those units is to put them on the other side of the fraction.

(c) Starting with the flow rate gallons per minute, we can write that flow rate as a fraction, gallons over minutes. This flow rate must be converted to cubic feet per second, or cubic feet over seconds. Breaking these fractions down, we see that we are required to convert gallons to cubic feet for the volume measurement, and minutes to seconds for the time measurement.

(d) Gallons can be converted to cubic feet by determining the number of gallons in a cubic foot. That number is 7.48. So, if you start with your fraction gallons over minutes and multiply that by

1 cubic foot over 7.48 gallons, you can cancel out the gallons measurements in the numerator and denominator, and you are left with 1 cubic foot over minutes multiplied by times 7.48.

(e) For the minutes to seconds conversion, simply multiply the fraction by 1 minute over 60 seconds. This will cancel out the minutes in the equation. You now are left with a unit of measurement of cubic feet over seconds, just what you were supposed to convert to. The rest is just a math problem. Along with the factors, you have 1 multiplied by 1 in the numerator and 7.48 multiplied by 60 in the denominator.

That equals 1 over 448.8 or 0.002228, which is the conversion factor found in FM 10-67-1. Figure 1-1 illustrates how to accomplish this action.

WHERE DO THE CONVERSIONS COME FROM?

$$\frac{\text{GALLONS}}{\text{MINUTE}} \longrightarrow \frac{\text{CUBIC FEET}}{\text{SECOND}}$$

$$\frac{\cancel{\text{GALLONS}}}{\cancel{\text{MINUTE}}} \times \frac{1\ \text{CUBIC FOOT}}{7.48\ \cancel{\text{GALLONS}}} \times \frac{1\ \cancel{\text{MINUTE}}}{60\ \text{SECONDS}} = \frac{\text{CUBIC FEET}}{\text{SECOND}}$$

$$= \frac{1 \times 1}{7.48 \times 60} \quad = \frac{1}{448.8} \quad = \boxed{0.002228}$$

Figure 1-1. Finding Conversion Factors

c. Velocity. Velocity, like flow rate, uses one unit of measurement over another. While flow rate measures volume of liquid over time, velocity measures distance traveled over time. More simply stated, it is a measure of speed. The common abbreviation for velocity is "V."

(1) Distance is commonly measured in miles, feet, and inches. However, it can also be measured in metric measurements. Since the denominator in velocities (hours, seconds, etc.) is the same as for flow rates, common velocities we use in the petroleum field are: miles per hour and feet per second.

(2) Since there are no conversion factors for velocity listed in FM 10-67-1, we must convert all velocities by hand using the same process we used to convert flow rates.

(a) In this instance, the required conversion is from miles per hour to feet per second. As with the conversion for flow rates, both numerators are in the same type of measurement (distance) and both denominators are measured in time.

(b) To convert from miles to feet, multiply by 5,280 feet over 1 mile. This allows elimination of the miles and leaves you with 5,280 multiplied by feet over hour multiplied by one.

(c) Converting from hours to seconds can be done one of two ways: first, if you know that 1 hour equals 3,600 seconds, then you can multiply by 1 hour over 3,600 seconds to eliminate hours from the equation. In this example, we use the second method, first breaking hours down into 60 minutes and then breaking minutes down into 60 seconds.

(d) Once these conversions are completed, we now have the correct units, feet over seconds. All that is left is to perform the math calculations. On the numerator side, multiply 5280 times 1 times 1. On the denominator side, multiply 60 times 60. The resulting solution (5,280 over 3,600) equals 1.47 feet per second. Thus, through inferential mathematics, we can conclude that for every one-mile per hour, distance traveled in feet per second equals 1.47.

d. Area. Area is the unit of measurement defined inside a figure. For different types of figures, each has their own equation to figure out the area of that object. Area is always measured in square units. For instance, we may measure area in square feet, square inches, or square miles.

(1) The area for squares and rectangles is very easy to determine. Just multiply the length of two adjacent sides to determine the area inside the figure. For squares (which have all equal sides), just multiply the length of one side twice to determine the area.

(2) Determining the area of circles is more difficult since it involves rounded area Mathematicians in the past came up with a unit of measurement to figure the area of a circle, which they labeled π or pi. Pi is the ratio of the circumference of a circle to its radius. As you all know, pi is equal to approximately 3.14, which means that for any given circle, its circumference will always be 3.14 times greater than its radius.

(3) Computing the area for a circle can be performed in one of two ways. The first way is to take the radius and square it multiplying the product by pi (use 3.14 if you don't have a π button on your calculator). The second way is to multiply pi times the diameter squared (D) over four, or 0.785 times the diameter squared. Make sure that the units agree (both in feet or both in inches, etc.).

(4) Example. Although determining the area for a rectangle and square is fairly straight forward, many find determining the area of a circle to be more demanding. To illustrate, we will determine the area of a circle in two different ways. For our example, we want to find the area of a circle, in square inches, that have a diameter of two feet.

(a) After the calculation: Multiply the radius (one-foot) squared by 3.14. The area is 3.14 ft^2. To convert this to square inches, multiply by the number of square inches in one foot (12 x 12 = 144). Take 144 and multiply it by the answer (3.14 feet squared) and the final answer is 452.16 square inches.

(b) Before the calculation: Convert the radius from feet to inches (1 foot = 12 inches). Multiply the radius squared (144) by pi (3.14) and the answer is 452.16 square inches.

e. <u>Solving for Unknown Variables</u>. The last major section we must discuss is solving for unknown variables. When given an equation with multiple variables and all other variables are known, the equation can always be solved for the unknown variable. When solving for an unknown variable, always delete all other variables from that side of the equation to separate the unknown variable. The important thing to remember when solving for an unknown variable is that when deleting other variables from one side of the equation, you must perform the opposite calculation to remove that variable. Before solving for unknown variables, it is important to understand the hierarchies of mathematics to correctly solve equations.
The correct hierarchies are as follows:

(1) Perform all functions within parentheses first.

(2) If there are any exponents in the equation, perform those calculations directly after any parentheses, if there are any parentheses in the equation.

(3) Next, perform all multiplication and division required. Always perform these functions from left to right in the equation.

(4) Finally, perform any addition and subtraction required by the equation. Again, perform all addition and subtraction functions from left to right in the equation.

(5) For example, perform the following equation using the mathematics hierarchy:

$$1 + (10 - 2) \times 9 / 6^2 = x.$$

(a) According to the hierarchies of math, the first calculation to perform is the calculation within the parentheses. The calculation performed is 10-2 which equals 8. The equation now reads:

$$1 + 8 \times 9 / 6^2 = x.$$

(b) Next, perform the required exponential calculation. Six squared equals 36. The equation now reads

$$1 + 8 \times 9 / 36 = x.$$

(c) Now, perform the multiplication and division from left to right in the equation. The first calculation should be 8 multiplied by 9. The equation now reads

$$1 + 72 / 36 = x.$$

(d) Perform the other multiplication/division function, which is 72 / 36 equals two. The equation now reads

$$1 + 2 = x.$$

(e) The final calculation is addition/subtraction; one plus two equals three. Thus, the solution to the equation $1 + (10 - 2) \times 9 / 6^2 = x$ **is <u>3</u>**.

(6) Solving for Unknown Variables. Now that we have discussed mathematical hierarchies, we can solve equations for unknown variables. Given the following equation, solve for variable "A":

$$X * Y = \frac{(A + B)}{C}$$

Figure 1-2 shows the proper way to solve this problem:

$$C * X * Y = \frac{(A + B)}{\cancel{C}} * \cancel{C}$$

THE "Cs" CANCEL OUT THE RIGHT SIDE OF THE EQUATION, LEAVING YOU WITH:

$$C * X * Y = A + B$$

Figure 1-2. Solving for unknowns.

$$C * X * Y - B = A + \cancel{B} - \cancel{B}$$

TO REMOVE THE "B" FROM THE RIGHT SIDE OF THE EQUATION, SUBTRACT "B" FROM BOTH SIDES, LEAVING US WITH:

$$A = C * X * Y - B$$

Figure 1-3. Solving for unknowns.

3. Calculating Fuel Characteristics Using Mathematical Formulas.

a. It is very important to understand the concept of what API gravity and specific gravity are before performing calculations. It will give you a much better understanding of what the calculations mean when you understand the concept of those functions. Both definitions can be found in FM 5-482, Chapter 4 and in the glossary.

(1) Specific Gravity (SG). Specific gravity is a physical property of liquids. The specific gravity is the ratio of the weight of a volume of liquid to the weight of an equal volume of water. The API has given water at 60° F specific gravity of 1.0000. Traditional petroleum fuels, oils, and lubricants are lighter or less dense than water, and thus have a specific gravity of less than 1.0000. For example, MOGAS has a specific gravity of 0.7250, which is computed by comparing the weight of 1 gallon of MOGAS (6.04 pounds) to 1 gallon of water (8.33 pounds).

(b) API Gravity. API gravity is a scale used by the petroleum industry based on reciprocals of specific gravity and, therefore, produces whole numbers having a greater numerical spread. Both API gravity and specific gravity measure the density of liquids. During prior blocks of instruction, you learned that the API has established an arbitrary scale to express the gravity or density of liquid petroleum products. Each fuel takes on a certain range of API gravity values, as shown in Figure 1-3 below:

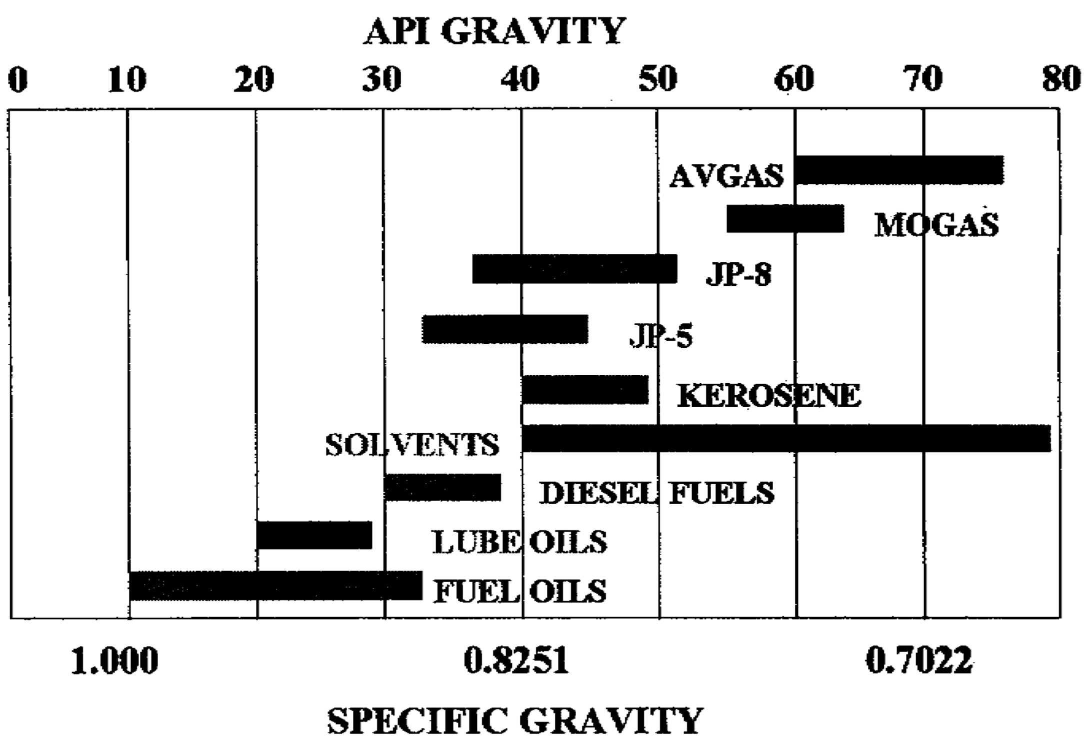

Figure 1-4. Specific Gravity Ranges of Fuels

As you see, this chart shows the specific gravity ranges for the major fuels, oils and lubricants we use in the military system. The numbers at the top of the chart are the API ranges, while the numbers at the bottom of the chart show a few of the specific gravity ranges. As would seem apparent, the fuel, oils, and lubricants are the heaviest petroleum products we use, and are nearly as dense as water.

b. Calculate API Gravity at 60° F.

(1) Normally, your API gravity reading will be at some temperature other than 60°F. To convert an API gravity reading to 60°F, we use ASTM Table 5B. The left and right margins of the table are annotated with the temperature of the sample. The upper margin lists the API gravity readings.

(2) Once you have located the temperature value, follow the row across until you intersect the column of your API value. The intersected value is your API gravity corrected to 60°F.

See if you get the correct answer for the following set of data. Determine the API gravity at 60°F:

Observed API	Temp(°F)	API
32	78	30.7
46	48	47.1
52	60	52.0
66	50	67.4

(3) Calculate Specific Gravity. The SG of a liquid is the ratio of the liquid's weight to the weight of an equal volume of water. Again, it is a measure of the density of a liquid.

SG(fuel) = SW fuel SW water (SW water = 8.33 lb/gal)

Specific Weight, SW = Fuel Weight Fuel Volume (Pounds/Gallons)

(4) Conversion Formulas. The following formulas are used for conversion between API gravity and specific gravity:

$$API = \frac{141.5}{SG} - 131.5 \qquad SG = \frac{141.5}{API + 131.5}$$

See if you get the correct answer for the following set of data. Convert the following APIs into SG:

API	SG
10	1.0000
40	0.8251
65	0.7201

Convert the following SG into API:

SG	API
.8445	36.1
.7252	63.6
.8112	42.9

f. Volume Correction to 60°F. Volume correction is the correction of a measured quantity of product, determined by gaging at observed temperature and gravity, and referenced to a gage table, to net quantity of product at 60°F after deducting bottom water and sediment. After determining API at 60°F, and using the average temperature of the product in the tank (measured during gaging), correct the fuel volume by using a volume correction factor obtained in ASTM Table 5B. Corrected volume = (Innage - BS&W) x CF

g. Feet of Head: The measure of pressure in terms of height of a column of a given fuel is known as feet of head (H_f). While this is a direct correlation to PSI (pounds per square inch), it is useful to us in the petroleum field in that we can measure friction loss pressures over distances with feet of head, while PSI can only measure pressure at one given point.

(1) Converting Feet of Head (H_f) to PSI:

$$\text{Pressure (PSI)} = \frac{\text{Head } (H_f) \text{ X SG}}{2.31}$$

(2) Converting PSI to Feet of Head (H_f):

$$\text{Feet of Head } (H_f) = \frac{2.31 \text{ X Pressure(PSI)}}{\text{SG}}$$

Determine the feet of head:

PSI	SG	H_f
20	0.7250	63.7
60	0.8420	164.6
100	0.8035	287.5

Determine pressure in PSI:

H_f	SG	PSI
120	0.7040	36.6
205	0.7777	69.0
500	0.8250	178.6

4. Basic Principle of Military Pipeline Systems.
Now that you have refreshed your memory on basic mathematical equations, you should feel comfortable with what is to come. After all, one of the most complex, challenging, and interesting aspects of petroleum operations is the study of hydraulics. Yet, knowing the basics will lead you through successful completion of this course, plus provide valuable guidance and knowledge for your use throughout you career as a petroleum leader head loss due to friction.

a. Advantages and Disadvantages of Military Pipelines. There are many advantages to using this distribution method unique to liquid logistics. However, pipelines and hose lines have their limitations also. Below we will discuss each.

(1) Advantages.

(a) Pipelines offer many advantages over other conventional means of transporting petroleum products. From an economic standpoint, the pipeline is the least expensive means in which to send large quantities of products over distances.

(b) Pipelines are all-terrain modes of transportation which allow access to areas not suitable for other forms of transportation.

(c) Pipelines relieve the burden of fuel transportation from rail and road nets, which are more expensive and congested. Remember, approximately sixty percent of logistical tonnages is bulk petroleum. Our current tactical pipeline system, the IPDS, can deliver almost one million gallons of fuel forward each and every day. This frees up a least 200 military tankers to move forward to support the tactical fight.

(d) Pipelines offer extremely poor targets for enemy aircraft.

(e) Pipeline damage can be repaired much faster than damaged railroads or highways.

(f) Pipeline operations are not affected by adverse weather conditions.

(g) Pipeline use releases large numbers of personnel and vehicles for other logistical activities.

(2) Disadvantages.

(a) Pipelines are subject to disruptions by sabotage and guerrilla attacks.

(b) Marine terminals, pump stations, and tank farm complexes are attractive targets for enemy air and missile attacks.

(c) Locating leaks and damage is time consuming.

(d) The pipeline construction rate may lag behind the rate of combat advance.

b. Future Role of the Military Pipeline System. Although the face of modem warfare continues to evolve, one thing remains certain. For the next several decades, our military machines will continue to rely upon petroleum fuels. As such, our doctrine must continually expand to meet new missions.

(1) Bulk Supply Concepts.

(a) Conventional warfare with large-scale military operations will be supplied with bulk fuel up to or near front lines. It is reasonable to expect that packaged fuels will be only used as a supplement to bulk supply methods when some forward areas are not accessible to bulk fuel transporters; or in some cases, when rapidly advancing tactical situations dictate the need for additional fuels to exploit the situation. To some extent, some fuels may be packaged strategically and delivered directly into a combat theater to the end used. Regardless, throughput will be used as much as possible to bypass levels of storage. Velocity forward is the key.

(b) Petroleum products will be shipped overseas to ports, harbors, and beachheads in large tankers. The fuel will be pumped ashore by the use of a marine dock facility, a submarine (underwater) pipeline, a floating pipeline, or by lightening the tanker by the use of large flat bottom barges. Ashore, the products will be at major marine-terminal storage facilities constructed to offer as unprofitable a target as possible, to ensure the products' security. To meet these requirements, the facility may consist of an existing commercial marine terminal, portable bolted steel storage tanks, or collapsible fabric storage tanks. Obviously, these are not the only solutions to bulk storage problems in the future.

(c) From the marine-terminal storage facility, fuel will be pumped forward through pipelines to large intermediate or head terminal tank farms. In forward areas one may find collapsible drums, collapsible tanks, flexible hose line systems, large capacity cross-country mobile dispensing vehicles as well as tank trucks, trailers, and pods.

(2) Concepts of Warfare.

(a) Conventional warfare will employ pipelines in much the same way as they were during World War II and the Korean War. Although equipment and technology change, the concept does not change. Employment, however, will require increased quantities of fuel and a pipeline system capable of quick deployment and emplacement.

(b) Limited nuclear warfare will modify the use of the military petroleum pipeline system. More reliance will be made upon dispersed storage collapsible fabric storage tanks rather than in highly vulnerable aboveground fixed facilities. Also, the use of flexible hose line systems is expected to increase during limited nuclear warfare.

(c) Unlimited nuclear warfare will place the greatest emphasis on stabilizing an area and capitalizing on the existing facilities, which will be used depending on their state of repair. All in all, the bulk supply concept will still need to be performed.

(3) Pipeline System Concepts.

(a) When classified according to use, pipeline systems fall into three general types: assault, tactical, and logistical.

(1) An assault system is generally a temporary system, which can be quickly installed to provide petroleum products in rapidly moving combat situations.

(2) A tactical system is one that can be rapidly constructed or relocated in order to provide sufficient fuel to a larger area or scope of operations.

(3) A logistical system is a more permanent pipeline designed to provide large quantities of fuel to stabilized areas.

(b) When classified according to construction, pipeline systems also fall into three general types: hoseline, coupled, and welded. All three methods of construction may be found in a military bulk distribution system. Usually, these construction types parallel the use classifications.

(1) Hose line systems are constructed of collapsible hose mounted for rapid placement as a temporary extension of lateral from a more permanent location. The pumping units are portable with relatively low flow rates and pressures.

(2) Coupled systems are constructed by stringing the pipe (placing the pipe along the route and then stove-piping it one joint at a time like a chimney stovepipe). Various coupling methods may be used including bolted joiners or mechanical clamps.

(3) Welded construction is used almost exclusively for civilian or industrial petroleum applications. In comparison, welded construction is a bulk military distribution system that is used largely for ship-to-shore tankers unloading lines (submarine or dock) or at locations where the situation dictates buried pipelines.

c. Army Pipeline Responsibilities. While many personnel think of pipelines as a pure Quartermaster Corps mission, it is truly a team effort among several branches of the service as discussed below.

(1) Quartermaster Corps responsibilities are to:

(a) Establish POL use requirements.

(b) Operate military pipeline systems.

(c) Provide organizational level maintenance to pipeline systems once in place.

(2) Engineer Corps POL responsibilities include designing, constructing, and maintaining:

(a) Pipelines.

(b) Bulk storage facilities.

(c) Marine terminal facilities.

(d) Fixed dispensing equipment.

(3) Other technical service responsibilities:

(a) The Transportation Corps responsibility for movement of POL by means other than pipeline and local distribution.

(b) The Ordnance Corps maintains and forms petroleum product specifications because of their role as developer and maintainer of engines requiring fuel.

(c) The Signal Corps provides communications support to pipeline operations.

d. Design Fuel. Before we build any pipeline, many factors must be taken into account. The first we will discuss is the design fuel. The definition for design fuel is the heaviest fuel making up 24 percent or more of the total annual fuel requirement. Below is an example of how to determine the design fuel:

(1) Given the following total annual fuel requirement for a theater by fuel type:

JP-8: 1,200,000 BBL

DF-2: 900,000 BBL

MOGAS: 1,600,000 BBL's

Total: **3,700,000 BBL's**

(2) Divide each product by the total barrels.

JP-8: 32.4%

DF-2: 24.3%

MOGAS: 43.3%

(3) Discard from consideration any not meeting criterion of 24 percent or more. Here, however, all three products met the criterion of 24 percent or more. We must now determine which product is the heaviest. Using FM 5-482, Table 4-1, find the average specific gravity for each product. Since DF-2 is the heaviest product, it will become the Design Fuel.

e. Theory of Flow. Theory of flow studies the characteristics of liquids in motion. This is of particular importance when we design pipelines. To ensure we correctly place our pump stations along the pipeline and can maintain a desired flow rate we must understand how flow rates are affected by friction. There are several steps, which must be done to determine head loss due to friction (Hf). Understand that when a liquid moves through a pipe, friction occurs between the liquid and the inside pipe wall. It is this friction that causes the liquid to slow its advance forward. We can overcome our head loss due to friction if we know what the head loss per given distance is going to be. The Reynolds number is the pivotal formula in determining our head loss due to friction. Remember, Reynold's number is dimensionless.

(1) The effect of pipe diameter, internal forces, and viscous forces is considered in the Reynold's number. Two formulas can be used in determining Reynold's number depending on whether the pipeline is in a developmental stage or in place. If the pipeline is in development, use the Design Data formula; otherwise, use the field data formula.

(a) Formula for Reynold's Number using design data:

$R = \frac{V\ D}{Y}$ Where: V = velocity in feet per second

D = inside diameter of pipe in feet

Y = Kinematic viscosity in squared feet per second

(b) Formula for Reynold's Number using field data:

$R = \frac{3160 \times Q}{d \times k}$ Where: 3160 = constant.

Q =flow rate in GPM

d = inside diameter of pipe in inches

k = Kinematic viscosity in centistokes

(c) Now, let's solve a problem. Given the following data, determine Reynold's number using the design data formula.

Velocity = 540 ft/min

ID = 6.415 inches

Fuel = DF2 @ 50 F

Find V in ft/sec

$$\frac{540\ \text{ft}}{\text{min}} \times \frac{1\ \text{min}}{60\ \text{sec}} = 9\ \text{ft/sec}$$

Find D in feet

$$6.415\ \text{in} \times \frac{1\ \text{ft}}{12\ \text{in}} = .534\ \text{ft}$$

Find Y in ft/sec squared (FM 5-482, Figure C-7)

$$\frac{4.9\ \text{cs}}{92{,}900} = .0000527\text{ft}^2/\text{sec}$$

Solve for R

$$\frac{9\ \text{ft/sec} \times .534\ \text{ft}}{.0000527\ \text{ft}^2/\text{sec}} = 91195.446$$

Finally, convert to a scientific notation

91195.446 = **9.12×10^4**

(d) Now, let's solve a problem using the field data formula.

Given the following data determine Re using the field data formula.

Q = 350 GPM

d = 6.415 in

K= JP4 @ 50F

Solve for R

$$\frac{3160 \times 350}{6.415 \times 1.19} = \frac{1106000}{7.63385} = 144881$$

Convert into scientific notation

144881 = **1.45×10^5**

(e) Now that you know how to find Reynold's number, it is time to interpret it and put it to good use in designing a military pipeline. Quite simply put, Reynold's number is used to determine the type of flow in a pipeline, and is broken down into three categories:

(1)	0 - 2000	Laminar (smooth and well defined)
	2000 - 4000	Transitional (not smooth)
	4000 - UP	Turbulent (chaotic, not defined)

In a multiproduct pipeline, a turbulent flow is desired, as it reduces the size of the interface by reducing the amount of product mixing during flow.

(2) Determine Friction Factor for a Pipeline. The friction factor is a function of the roughness of the pipe and of the Reynold's number. The friction factor is determined by using Reynold's number, nominal pipe size, and Figure C-8, FM 5-482,

(a) Given the following information, determine the friction factor.

$R = 8.0 \times 10^4$

4 in nominal pipe size

(FM 5-482, Figure C-8)

F = .021

(3) Determine head loss due to friction (Hf). The Darcy-Weisbach equation is used to determine Hf. As with the Reynold's Number, this equation has two formulas: Design and Modified as shown below in the figures:

$$H_L = \frac{f \times L \times V^2}{64.4 \times D}$$

- **f = FRICTION FACTOR**
- **L = LENGTH OF PIPE IN FEET**
- **V = VELOCITY IN FT/SEC**
- **D = INSIDE DIAMETER OF PIPE IN FEET**

Figure 1-5. Darcy-Weisbach Design Model Equation

$$H_L = \frac{0.031 \times f \times L \times Q^2}{d^5}$$

- **f = FRICTION FACTOR**
- **L = LENGTH OF PIPE IN FEET**
- **Q = FLOW RATE IN GPM**
- **d = INSIDE DIAMETER OF PIPE IN INCHES**
  (PG 2-2 , FM 5-482)

Figure 1-6. Darcy-Weisbach Design Model Equation

(4) Given the following data, determine Hf using the design formula:

Pipe =.701 ft

Fuel = DF2 @ 50F

Vel = 4.0 ft/sec

Length of pipeline = 4000 ft

First, we must find "f"

Determine Reynold's Number $R = \frac{V \times D}{Y}$

V = 4.0 ft/sec (Given)
D =.701 (Given)
$Y = \frac{4.9 \text{ cs}}{92{,}900} = .0000527$ ft/sec

$Re = \frac{4.0 \text{ ft/sec} \times .701 \text{ ft}}{.0000527} = \mathbf{53206.8 \text{ or } 5.3 \times 10^4}$

From FM 5-482, Figure C-8 f = .0216

$Hf = \frac{.0216 \times 4000 \times 16}{64.4 \times .701} = \frac{1382.4 \text{ ft}}{45.1444}$

Hf= 30.62 ft

(5) Given the following data, determine Hf using the field modified formula:

Pipe = 8.415 inches

Fuel = DF2 @ 50F

Q = 700 GPM

Pipe Length = 4000 ft

First, you must find "f"

Determine Reynold's Number $Re = \frac{3160 \times Q}{d \times k}$

3160 = constant

Q = 700 GPM (Given)

d = 8.415 (Given)

k = 4.9 cs (FM 5-482, Figure. C-7)

$Re = \frac{3160 \times 700}{8.415 \times 4.9} = \frac{2212000}{41.234}$

Re = 53645.05 or 5.35 x 10^4

From FM 5-482, Figure C-8 f=.0216

Next, determine d^5

Appendix C, TABLE C, ACCP 5203, pg. C-1

$8.415^5 = 42,196$

So, $Hf = \frac{.031 \times 4000 \times 490,000}{42,196} = \frac{1,312,416}{42,196}$

Finally, you find the total headloss due to friction, Hf= **31 feet**.

f. Advanced Hydraulics Mathematics. Now you have a basic understanding of the reason for pipelines, and general characteristics and properties of petroleum fluids. Next we will attempt to familiarize you with some of the advanced petroleum math computations that will help you in your future petroleum assignments. Specifically, you will be able to calculate volume correction, feet of head, flow velocity, flow type, and head loss.

(1) You must be able to quickly apply each principle you have learned thus far before you can begin to physically design a pipeline or hose line. Therefore, a thorough problem solving exercise must be completed. Let us begin:

(a) Volume Correction to 60°F: Volume correction is the correction of measured quantity of product to the net quantity of product at 60°F after deducting bottom sediment and water.

(1) After determining API at 60°F, and using the average temperature of the product (measured during gaging) in the tank, correct the fuel volume by using a volume correction factor obtained in ASTM Table 6B. The correction factor (CF) is used as a multiplier.

(2) Corrected volume = (Innage - BS&W) x CF

Calculate the corrected volume at 60°F

Data: Innage = 24,816 gallons
BS&W = 240 gallons
API @ 60°F = 58.5
Avg Temp = 70°F

SOLUTION: CF = .9932 (TABLE 6B)

Corrected volume = (24,816 - 240) x .9932
=24,576 x .9932
= 24,409 gallons

(b) Feet of Head: The measure of pressure in terms of height of a column of a given fuel is known as feet of head (HL).

$$\text{Pressure (PSI)} = \frac{\text{Height (ft)} \times \text{SG}}{2.31} \qquad \text{Height} = \frac{2.31 \times \text{Pressure}}{\text{SG}}$$

PROBLEM: Determine the feet of head: SOLUTION:

PSI	SG	HL
25	.7250	79.7
50	.8420	137.2
100	.8035	287.5

PROBLEM: Determine pressure in PSI: SOLUTION:

HL	SG	PSI
100	.7040	30.5
250	.7777	84.2
500	.8250	178.6

(c) Velocity of Flow: It is the flow speed usually measured in feet per second, equal to flow rate (Q) in cubic feet per second, divided by the cross sectional area (A) of the pipe in square feet.

$V = Q/A$ $\quad A = 0.785 \times D^2$ $\quad D$ = Inside diameter in feet

PROBLEM: Determine the flow velocity in ft/sec:

Data: Q = 1,000 barrels per hour
D = 6 inches

SOLUTION:

$$Q = \frac{1000\text{BBL}}{\text{Hr}} \times \frac{42\text{ Gal}}{1\text{ BBL}} \times \frac{1\text{ ft}^3}{7.48\text{ Gal}} \times \frac{1\text{ Hr}}{60\text{ Min}} \times \frac{1\text{ Min}}{60\text{ Sec}} = \frac{1.56\text{ ft}^3}{\text{Sec}}$$

$$D = 6\text{ in} \times \frac{1\text{ ft}}{12\text{in}} = .5\text{ft}$$

$$A = .785 \times .5^2 = .785 \times .25 = .2\text{ ft}^2$$

$$V = \frac{1.56}{.2} = 7.8\text{ ft/sec}$$

(d) Flow Type: There are three types of flow Laminar, transitional, and turbulent. To find out the flow type in a military pipeline we use the Reynold's number (Re) formulas.

(1) Re formula using field data formula:

$$Re = \frac{3160 \times Q}{d \times K}$$

Where Q = Flow rate, GPM
d = Pipe inside diameter, inches
K = Viscosity, centistokes, cSt

(2) Re formula using design data:

$$Re = VD/Y$$

Where V = Velocity, ft/sec
D = Pipe inside diameter, feet
Y = Viscosity, ft^2/sec

(3) Re vs Flow type: Remember the different types of flow. Always maintain turbulent flow within a multiproduct pipeline.

<u>Reynold's Number</u>	<u>Flow Type</u>
0 <Re<2000	Laminar
2000 <Re<4000	Transitional
4000 < Re	Turbulent (Preferred in military pipelines)

PROBLEM: Given: V = 3.7 mile/hr
ID = 6.145 in
Y = 0.08 ft^2/min

Calculate Re, and determine the flow type.

SOLUTION:

V = 3.7 mile/hr x 5280 ft/mile x 1 hr/3600sec = 5.43 ft/sec

ID = 6.145 in x 1ft/12in = 0.512 ft
Y = 0.08 ft^2/min x 1min/60sec = 0.0013 ft^2/sec
$$Re = \frac{5.43 \times 0.512}{0.0013} = 2{,}138 \quad \text{(TRANSITIONAL)}$$

PROBLEM: Given: V = 5 mile/hr
ID = 8.145 in
Y= 12 ft^2/min
Calculate Re, and determine the flow type.

SOLUTION:
V = 5 mile/hr x 5280 ft/mile x 1 hr/3600 sec = 7.33 ft/sec
ID = 8.145 in x 1ft/12in = 0.679 ft

Y = 12ft^2/min x 1min/60sec = 0.2 ft^2/sec

$$Re= \frac{7.33 \times .678}{.2} = 24.8 \text{ (Laminar)}$$

PROBLEM: Given: Q = 500 BPH
ID = 6 in
K = 42 cSt
Calculate Re, and determine the flow type.

SOLUTION:
Q = 500 x 42/60 = 350 GPM

$$Re = \frac{3160 \times 350}{6 \times 42} = 4{,}389 \text{ (Turbulent)}$$

g. Head Loss (H_L): It is the pressure loss in a pipeline due to friction, measured in feet of head. The most accurate method of determining H_L, is using the Darcy-Weisbach's equations.

(1) Darcy-Weisbach equation (Design Model)

$$H_L = \frac{f \times L \times V^2}{64.4 \times D}$$

Where f = Friction factor, dimensionless
L = Pipe length, feet
V = Velocity, ft/sec
D = Inside diameter, feet

(2) Darcy-Weisbach equation (Modified Model)

$$H_L = \frac{0.031 \times f \times L \times Q^2}{d^5}$$

Where f = friction factor
L = Pipe length, feet
Q = Flow rate, GPM
d = Inside diameter, in

PROBLEM: Given:
f = 0.035
L = 0.5 mile
V = 300 ft/min
D = 0.5 ft
SG = 0.8260

Determine H_L in PSI.

SOLUTION:

L = 0.5 mile x 5280 ft/mile = 2640 ft

V = 300 ft/min x 1min/60sec = 5 ft/sec

$V^2 = 25\ (\text{ft/sec}^2)$

$$H_L = \frac{0.035 \times 2640 \times 25}{64.4 \times 0.5} = 71.7 \text{ FT}$$

$$PSI = -\frac{H_L \times SG}{2.31} = \frac{71.7 \times 0.8260}{2.31} = \mathbf{25.7}$$

PROBLEM: Given:
f = 0.92
L = 2 miles
Q = 300 BPH
d = 8 in LWST
SG = 0.8448

Determine H_L in PSI.

SOLUTION:

L = 2 miles x 5280 ft/mile = 10,560 ft

Q = 300 BBl/hr x 42 Gal/BBL x 1hr/60min = 210 GPM

$Q^2 = 44,100$

$d^5 = 32,768$

$$H_L = \frac{0.031 \text{ x} .92 \text{ x } 10,560 \text{ x } 44,100}{42,196} = 315 \text{ ft}$$

$$PSI = \frac{H_L \text{ x SG}}{2.31} = \frac{315 \text{ x } 0.8448}{2.31} = \mathbf{115.2}$$

PRACTICE EXERCISE

The following items will test your grasp of the material covered in this lesson. There is only one correct answer for each item. When you complete the exercise, check your answers with the answer key that follows. If you answer them incorrectly, study again that part of the lesson, which contains the portion, involved.

1. When determining design fuel, we only consider those high volume products, which consist of at least what percentage of total products?

   A. 20 percent.
   B. 24 percent.
   C. 33 percent.
   D. 50 percent.

2. What is the purpose of the Darcy-Weisbach equation?

   A. Finds the friction factor, in feet per second.
   B. Determines API gravity in degrees API.
   C. Shows head loss due to friction in feet.
   D. Volume corrects to cubic feet.

3. Which of the following is NOT a flow rate (Q) ?

   A. Miles per day.
   B. Cubic feet per second.
   C. Gallons per hour.
   D. Barrels per day.

4. A petroleum supply specialist has received 4200 gallons of fuel into his terminal in the past hour. What is the flow rate in barrels per minute?

   A. 70 barrels per minute.
   B. 100 barrels per hour.
   C. 1.67 barrels per minute.
   D. 1.67 barrels per hour.

5. Using the mathematics hierarchy, solve the following equation for “B”:

$$(A + B) * C = \frac{X * Y}{Z}$$

where: A = 5
C = 6
X = 12
Y = 9
Z = 2

A. 1.8
B. 4
C. 14
D. 319

6. If a petroleum product is found to have an API gravity of 60°. What is its specific gravity?

A. 0.6822
B. 0.7109
C. 0.7389
D. 0.8451

7. The intake pressure gage of a pump reads 30 PSI when fuel is being pumped. What is this pressure in feet of head if the specific gravity of the fuel is 0.8260?

A. 10.7 Feet
B. 83.9 Feet
C. 107 Feet
D. 839 Feet

8. Given the following data, what is the Reynold's Number and determine the type of flow:

Flow velocity: 15 mph
Pipe ID: 0.5 feet
Viscosity: 2.2 ft^2 / min

A. 147; Laminar
B. 297; Laminar
C. 2973; Turbulent
D. 4404; Turbulent

9. Given the following information, determine the pressure loss due to friction:

Friction factor: .015
Pipe length: 2.2 miles
Flow velocity: 3.8 ft/sec
Pipe size: 6" LWST
Fuel SG: 0.5725

A. 5 PSI
B. 18 PSI
C. 73 PSI
D. 294 PSI

10. What branch of the Army has responsibility for fuel specifications?

A. Quartermaster Corps.
B. Engineer Corps.
C. Medical Service Corps.
D. Ordnance Corps.

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LESSON

PRACTICE EXERCISE

ANSWER KEY AND FEEDBACK

Item Correct Answer and Feedback

1. B. 24 percent.
Fuels must make up at least 24 percent of the total annual requirement to qualify as a design fuel.

2. C. Shows the head loss due to fiction in feet.
From paragraph e (3), page 19.

3. A. Miles per day.
From definition, "A flow rate can be defined as that which measures a specific volume of liquid delivered over a specified period of time." (paragraph 2 a (1), page 6).

4. C. 1.67 barrels per minute.
As shown below:

Convert gallons to barrels: 4200 gallons per hour / 42 gallons per barrel = 100 barrels per hour
Convert to barrels per minute: 100 barrels per hour /60 minutes/hour = 1.67 barrels per minute

5. B. 4.
As shown below:

$$(5 + B) \times 6 = \frac{12 \times 9}{2}$$

$$(5 + B) \times 6 = \frac{108}{2}$$

$$(5 + B) \times \frac{6}{6} = \frac{54}{6}$$

$$(5 + B) = 9$$
$$\underline{-5 \qquad -5}$$

$$\underline{B = 4}$$

6. C. 0.7389
   As shown below:

$$SG = \frac{141.5}{131.5 + °API} = \frac{141.5}{131.5 + 60} = \frac{141.5}{161.5} = \underline{\mathbf{0.7389}}$$

7. B. 83.9 Feet.
   As shown below:

$$\text{Feet of Head} = \frac{\text{PSI x 2.31}}{\text{SG}} = \frac{\text{30 PSI x 2.31}}{.8260} = \underline{\mathbf{83.9\ feet}}$$

8. B. 297; Laminar.
   As shown below:

   Flow velocity: 15 mph Converts to:V = 15 mph x 1.47 = 22 ft/sec
   Pipe ID: 0.5 feet
   Viscosity: 2.2 ft^2/min Converts to:Y = 2.2 ft^2/min ÷ 60 = 0.037

$$R_e = \frac{\text{V x D}}{\text{Y}} = \frac{\text{22 x 0.5}}{0.037} = \mathbf{297\ LAMINAR}$$

9. B. 18 PSI
   As shown below:

$$\mathbf{H_f = \frac{f \times L \times V^2}{64.4 \times D} = \frac{.015 \times 11{,}616 \times (3.8)^2}{64.4 \times .535} = \frac{2516}{34.45} = 73\ feet}$$

$$\mathbf{\frac{73 \times .5725}{2.31} = 18\ PSI}$$

10. D. Ordnance Corps. (page 1-13, para (3)(b).