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ŞEHİR DOĞAL GAZ DAĞITIM ŞEBEKELERİ İÇİN EKLER

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SUPPLEMENTS FOR CITY NATURAL GAS DISTRIBUTION NETWORKS

M.Sc. THESIS

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FOREWORD

In realizing this study my goal was to show the different aspects of natural gas industry. I tried to prove that petroleum engineers could take part in the economic evaluation of a natural gas distribution network as well as designing it.

I wish to express my gratitude to my academic advisor Dr. Hakan ALKAN. Without his invaluable guidance and endless patience this study would have never been completed.

I am also grateful to my family who have been supporting me for twenty seven years.

Thanks are also extended to my all friends who have borne me during the preparation of the work.

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Fatih CAN, Petroleum Engineer

TABLE OF CONTENTS

NOMENCLATURE

Roman

AW	=	Annual worth method
CR	=	Capital recovery
d	=	Pipe diameter, ft
$(DG)_y$	=	Degree - day product summation for one year, °C - day
e	=	Absolute pipe roughness, inch, ft
$\underline{E}$	=	Annual equivalent expenses
E_k (1)	=	Kinetic energy, Btu/lbm
E_k (2)	=	Net receipts including investments for the k^{th} year
E_p	=	Potential energy, Btu/lbm
ERR	=	External rate of return method
f'	=	Fanning friction factor
f	=	Moody friction factor
F_k	=	Future cash flow at the and of period k
g	=	Gravitational acceleration, ft/sec^2
g_c	=	Conversion factor for gravity
H	=	Entalphy, Btu/lbm
HP	=	Horsepower
IUSP	=	Industrial unit selling price, \$/1000 m^3
IRR	=	Internal rate of return method
i	=	Interest rate
i'	=	Internal rate of return
k	=	Index for compounding period ($0 \leq k \leq N$)
l_w	=	Mechanical energy converted to heat, ft-lbf/lbm

MARR	=	Minimum attractive rate of return
N	=	number of periods in the planning horizon or project life or study period
NCE	=	Node connecting elements
nNCE	=	Number of node connecting elements
N_{Re}	=	Reynolds number
P	=	Pressure, psi
PW	=	Present worth method
q	=	Volumetric flow rate
Q	=	Heat transfer rate, Btu/lbm
Q_g	=	Gas consumption, nm^3
Q_T	=	Annual fuel load, kcal
$\underline{R}$	=	Annual equivalent receipts
R_k	=	Net receipts or savings for the k^{th} year
RUSP	=	Residential unit selling price, \$/1000 m^3
S	=	Entropy, Btu/lbm
s	=	Sign factor
T	=	Temperature, °F
T_o	=	Lowest temperature that do not need heating, 18.7 °C
T_h	=	Daily average temperature, °C
U	=	Internal energy, Btu/lbm
u	=	Velocity of flowing gas, ft/sec
$\overline{UA}$	=	Average heat loss coefficient of a residence, kcal / (day - °C)
W	=	Work, Btu/lbm
W_s	=	Shaft work, Btu/lbm
Y	=	Mole fraction
Z	=	Elevation from datum, ft
z	=	Gas compressibility factor

Greek

ε (1)	=	Average roughness, inch
ε (2)	=	External rate of return

γ = Specific gas gravity (relative to air)

μ = Gas viscosity, cP

μ_1 = Gas viscosity at atmospheric conditions, cP

θ = Angle of inclination from horizontal

ρ = Density, lbm/ft^3

τ_ω = Wall shear stress

ω = Acentric factor

Special Constants

R = Universal gas constant, 10.732 psia-ft^3/lb-mole-°R

π = 3.14159

Subscripts

av = Average

c = Critical

i = Index of nodes

pr = Pseudo reduced

r = Reduced

sc = At standard conditions

LIST OF FIGURES

LIST OF TABLES

SUMMARY

The study comprises the two aspects of natural gas industry. In the first six chapters the basic concepts that are necessary to understand and study the isothermal flow of natural gas under steady state conditions are introduced. Properties of natural gas are outlined with the appropriate equations so that they can easily be adapted in a computer programme. Within this scope, two network analysis methods are introduced and a simulator, in FORTRAN-77 programming language, computing the pressure map of a given network with Hardey-Cross network analysis method is presented. The results of the simulator are compared with the data taken from literature and its validity have been verified.

In chapters seven and eight fundamental project evaluation methods are introduced. The definition of financial terms used are supplied where necessary. In this part a feasibility study, based on real figures, for a city natural gas distribution network is made. The goal of such feasibility study is to compute a unit distribution price that would yield a certain internal rate of return which is also attractive for the investor. All financial statements and graphs in the second part have been prepared by using EXCEL spread sheet programme, which is a very powerful tool for that kind of tasks.

Any investment needs some time to generate its inflows. Construction of natural gas distribution networks are the investment fields where considerable amount of money is required while the rate of return is quite high. The net present value and internal rate of return of an investment are the criterion being used in evaluating the yield of investments and comparing them with other investment alternatives such as investing in financial assets. Both methods discount future cash in-outflows and find a present value . Investor can decide where to invest or whether invest or not, by using net present value and internal rate of return methods. These concepts are explained in detail in Chapter I of Part II with examples.

Results of the feasibility study, i.e., different unit transmission prices for different cases, were interpreted with their underneathing assumptions. Different rate of returns resulting from different scenarios have been discussed.

ÖZET

ŞEHİR DOĞAL GAZ DAĞITIM ŞEBEKELERİ İÇİN EKLER

Şehir Doğal Gaz Dağıtım Şebekeleri İçin Ekler adlı çalışmada Petrol Mühendisi olan bir kişinin eğitimi süresince çok yakından ilgilendiği ve yaygın olarak kullandığı bir çok temel kavram ve prensibin, bu kez çok yakından ilgili olmadığını düşünmekle birlikte aslında Petrol Mühendisliği'nin direkt alanı içine giren bir konu olan Doğal Gaz İletim ve Dağıtım Hatlarının Dizaynında nasıl uygulama imkanı bulduğu gösterilmeye çalışılmıştır.

Çalışmada ele alınan hayali bir şehrin ihtiyaçlarına uygun ve yeterli bir doğal gaz dağıtım şebekesini kurarken kullanılan teknik parametreler, yapılan hesaplamalar kesitler halinde verilmeye çalışılmıştır. Konuların akışı ve veriliş düzeni bu çalışmadan yararlanacak Petrol Mühendislerinin teksti okurken eski bilgilerini önce bire bir olarak tazelemelerini ve sonra da kazandıkları temel bilgilerlerin teknik bölümlerin sonunda ele alınan basit bir network probleminde nasıl uygulandığını görmelerini amaçlar.

Şebeke dizaynı yapan bir mühendisin karşılaştığı problemlerin oldukça tipik olduğu söylenebilir. Ama bu, şebeke dizayn etmenin kolay olduğu anlamına gelmemelidir. Mühendis genellikle kendisine iletim hattı çıkışında bir noktada teslim edilen gazı farklı tüketimler yapacak birden fazla merkeze teknik ve ekonomik açıdan en iyi şekilde teslim edecek bir şebeke tasarlamak için uğraş verir. Bu açıdan şehir doğal gaz dağıtım şebekelerinin dizaynı aşamasında bir çok faktörün ve değişkenin dikkate alınması ve doğru değerlendirilmesi gerekmektedir.

Şehir şebekeleri yapıldıktan sonra en az yirmi - otuz yıl işletilecek şekilde tasarlanırlar. Uzun işletme süresi, dizayn aşamasına gelmeden önce şebekenin, inşaa edilmesi planlanan şehirde, tüketim merkezlerinin özelliklerinin saptanabilmesi için çok iyi bir pazar araştırması yapılmasını gerektirir. Sözkonusu pazar araştırması günün koşullarını çok iyi saptamakla kalmayıp, ele alınan merkezlerinin gelecekteki tüketim tahminlerini de içermelidir. Fakat pazar araştırmalarının geleceğe ait projeksiyonları içermeleri de yeterli olmayacaktır. Çünkü, örneğin İstanbul gibi çok dinamik olarak gelisen şehirlerde beş - on ya da yirmi yıl sonra mevcut merkezlerin tüketimlerini ve/veya nerelerde yeni yerleşim (türketim) merkezleri oluşacağını ve bunların tüketim miktarlarını doğru olarak tahmin etmek imkansızdır. Öyleyse dizayn, şebekenin kapasitesinin ve erişim alanının yapılacak ek yatırımlarla kolay ve ucuz bir şekilde genişletilmesine de imkan tanımalıdır.

Şehirlerde doğal gaz kullanımı birinci derecede ısınma amaçlıdır. Bu amaçla tüketilecek gaz miktarı mevsimsel sıcaklık değişimlerine paralel olarak değişim gösterir. Bir şehirin toplam doğal gaz tüketimini, genellikle kişi başına düşen kapalı yaşama alanını seçilen bir ortalama sıcaklıkta sabit olarak tutabilmek için bir yılda kullanılacak doğal gaz miktarını şehirin toplam kapalı yaşama alanıyla çarparak bulan dizayn mühendisi, tasarımında kışın "peak" noktada yapılacak maksimum çekişleri de göz önüne almak zorundadır. Ortalama büyüklükte bir sehirde tüketim merkezlerinin sayısı toplam tüketim miktarına, yada daha büyük ölçüde, yapılan tasarımın duyarlılığına bağlı olarak yüz ile on bin arasında değişebilir. Tüketim merkezleri pratikte birbirlerinden farklı yüksekliklerde olacaklardır. Bu durum, basınç hesaplamalarında kullanılacak formüllerin kod farkını içeren değişkenleri içermesini gerektirir.

Gerçekte gece ve gündüz arasındaki ısı farklılıkları ve günün değişik saatlerinde yapılacak farklı çekişler şebeke içerisinde izotermal -kararlı bir akış yerine ısı alıverişinin meydana geldiği ve bir çok parametrenin zamanın fonksiyonu olarak değiştiği kararsız akış anlamına gelmektedir. Açıklanan bütün bu noktaların eğer doğru ve başarılı bir dizayn amaçlanıyorsa sorumlu mühendis tarafından dikkate alınması zorunludur.

Dizayn aşamasında çok sık karşılaşılan ve çözümleri için zaman, emek ve para harcanan bu problemlerin her biri aslında başlı başına bir çalışma konusudur. Bununla birlikte bu çalışmada dağıtım şebekeleri tasarımı hakkında tam bir fikir verebilmek ve biraz da okuyucuların dikkatlerini kendi çalışmalarına konu yapabilecekleri problemlere çekebilmek için incelenen konular gazın boru içindeki akışı izotermal kararlı akış kabulu altında sınırlanmıştır.

Buradan hareketle, doğal gazın borularda izotermal - kararlı akışının incelenebilmesi için gerekli olan kavramlar açıklanmış, sapma (z) faktörü, sürtünme faktörü, vizkozitesi gibi fiziksel özellikleri tanıtılmış, daha sonra kararlı durumda temel akış denkleminin çıkarılışı gösterilmiş ve buradan da bu denklemin doğal gaz iletim ve dağıtım hatlarına uygulanmasına geçilmiştir.

Bunlara ek olarak altıncı bölümde doğal gaz boru şebekelerinin analizinde kullanılan iki temel yöntem olan Hardey - Cross ve Stoner yöntemleri anlatılmıştır. Verilen bilgilerin ışığı alltında herhangi bir doğal gaz şebekesinin basınç haritasını şebekenin yüksek ya da alçak basınç altında çalışmasına bağlı olarak Hardey - Cross yöntemi ile hesaplayan iki ayrı bilgisayar programı FORTRAN 77 dilinde yazılmıştır.

Literatürden bulunan tipik bir düşük basınçlı şebeke problemi bu bilgisayar programı aracılığı ile çözülmüştür. Bilgisayar programından elde edilen sonuçlar orijinal sonuçlarla karşılaştırılmış ve aradaki farkların yuvarlamadan ortaya çıktığı ve ihmal edilebilir derecede olduğu kanıtlanmıştır.

Uygulamalı mühendisliğin ekonomik boyutuna yeteri kadar önem vermemek özellikle günümüz koşullarında büyük hata olur. Bu yalnızca doğal gaz şebekelerinin dizaynında değil, uygulamalı mühendislik disiplinlerinden herhangi birisi kapsamında gerçekleştirilecek bütün projeler için geçerlidir.

Sonuçta, bir doğal gaz dağıtım şebekesi projesi teknik açıdan ne kadar mükemmel düşünülmüş, kusursuz tasarlanmış olurda olsun ancak ekonomik açıdan fizibıl ise yapılabilir ve/veya işletilebilir. Çünkü şehirde yaşayan insanlara doğal gazı götürmek yalnızca bir hizmettir. Bu hizmetin insanlar tarafından kabul görmesini ve kullanılmasını diğer yakıtlara göre daha ucuz yada daha pahalı olması belirleyecektir. Bu nedenle çalışma şehir doğal gaz dağıtım şebekelerinin teknik dizayn esasları ile kısıtlı bırakılmamış, ayrıca bu tür yatırım projelerinin ekonomik açıdan yapılabilir olup olmadıklarını bir başka deyişle fizibilitelerini araştıran ekonomik bölümler de çalışmaya dahil edilmiştir.

Ekomik değerlendirimeye geçilmeden önce, proje değerlendirme için temel yöntemler anlatılmış ve gerekli görülen finansal terimlerin tanımları verilmiştir.

Bütün yatırımcılarımcıların sahip oldukları fonlardan maksimum yararı elde etmeye çalışacakları noktasından hareketle bir yatırımcının realize etmeyi düşündüğü herhangi bir projeden elde edeceği geliri, fonlarını sözkonusu projeye yatırmaması ve başka bir şekilde değerlendirmesi durumunda elde edeceği gelirlerle karşılaştırması, yatırım kararını bu şekilde alması çok doğaldır. Yatırımcının parasını projeye yatırmaması, bunun yerine örneğin güvenilir bir bankada faiz alabileceği bir hesapta bekletmesi her zaman mümkün olan alternatif yatırımlardan yalnızca birisidir. Yatırımcı elindeki parayla daha az risk taşıyan bir yatırım yapması alternatifindeki getiriye, planladığı yatırımda karlşılaşabileceği sorunları temsil eden risk faktörünü ekleyerek fonlarının alternatif maliyetini hesaplayabilir.

Bir faiz oranı cinsinden de ifade edilebilecek alternatif maliyetin yatırımdan beklenen getiri ile karşılatırılması işleminin sonucunda yatırıma girme yada girmeme kararı alınacaktır.

Yatırımın net bugünkü değeri ve yatırımın iç karlılığı, yatırımın getirilerinin değerlendirilmesinde ve bu getirilerin finansal varlıklara yatırım yapmak gibi diğer alternatiflerle karşılaştırılmasında kullanılan proje değerlendirme yöntemleridir. Her iki yöntem de gelecekteki net nakit akışlarını bu günkü değere indirgeme esasına dayanırlar.

Yatırımın net bu günkü değeri paranın alternatif maliyetini kullanarak projenin şimdiki zamanda yaratacağı net nakit akışlarının toplamını hesaplar. Toplam sıfıra eşit ya da sıfırdan büyükse yatırımcı fonlarının alternatif maliyetlerinden dah büyük bir gelir elde edecek demektir ve bu da yatırımın onun açısından yapılabilir olduğunu gösterir. Net şimdiki değer sonuçlarını açıklarken iskonto oranı olarak kullanılan alternatif maliyetler her zaman belirtilmelidir.

Yatırımın iç karlılığı ise günümüzde gittikçe popüler olan ve daha sık kullanılır hale gelen bir yöntem olmuştur. Yatırımın iç karlılığı yöntemi projenin faydalı ömrü süresinde yaratacağı net nakit akışlarını şimdiki anda sıfıra eşitleyen iskonto oranını hesaplar. Hesaplanan oran (ya da faktör) yatırımcının sahip olduğu fonlarını alternatif maliyetiyle karşılaştırılır, eğer iskonto oranı alternatif maliyetten eşit ya da büyük ise proje yatırımcı açısından karlı demektir, tersi ise kabul edilen alternatif maliyetle incelenen projeye girmenin ekonomik olmayacağını gösterir.

Yedinci bölümde, yatırımın şimdiki net değeri ve iç karlılığı dışında başka yöntemlerde açıklanmaya çalışılmıştır. Proje değerlendirme yöntemlerini kullanırken dikkat edilmesi gereken en önemli husus bu yöntemlerin hemen hepsinde temellerindeki varsayımlarından ileri gelen zayıflıklar bulunduğu ve hiç birisinin tek başına bir yatırım projesinin kaderini belirlemesine izin verilmemesi gereğidir. Bir yatırım projesini gerçekleştirip gerçekleştirmemeye ya da mevcut projelerden hangisinin gerçekleştirimeye değer olduğuna karar verirken yapılacak en sağlıklı değerlendirme birden fazla değerlendirme yöntemini uygulamak ve sonuçlarını birlikte değerlendirmektir.

Çalışmanın sekizinci bölümünde nufusu ve iklimsel şartları tamamen rasgele seçilen hayali bir şehirde gerçekleştirilecek bir şehir doğal gaz dağıtım şebekesi için gerçek değerlere dayanan bir fizibilite çalışması da yapılmıştır. Bu fizibilite çalışmasının amacı yatırımdan geri dönüşü (yatırımın karlılığını) belli bir düzeye çıkaracak ve yatırımı, girişimci için çekici hale getirecek bir doğal gaz birim fiyatı nasıl hesaplanabileceiğini göstermektir.

Sözkonusu fizibilite çalışması bir çok ekonomik kabul ve birbiriyle ilişkilendirilmiş tablo ve çizelgeden oluşmaktadır. Sözkonusu tablolar sırasıyla;

- Yatırım tablosu,
- Gaz satışları tablosu,
- Kredi kullanım tablosu,
- Nakit akım ve kaynak kullanımı tablosu,
- Gelir tablosu,
- Gelir kalemleri tablosu,
- Faaliyet giderleri tablosu,
- Mali karlılık tablosu'dur.

Bir yatırım projesini değerlendirirken üzerinde en çok durulması geren nokta yatırımın maliyetinin çok doğru olarak saptanmasıdır. Örneğin şehir doğal gaz dağıtım projeleri gibi milyonlarca dolara malolacak büyük projelerde atlanan ya da eksik alınan bir kalem projenin hesaplananın aksine zarar etmesine yol açabilir. Bunun tersi de doğrudur. Yani maliyetleri çok fazla olduğu için yapılmamaya karar verilen bir proje gerçekçi maliyetlerle aslında çok karlı da çıkabilir.

Yatırım miktarının doğru hesaplanması dışında, yatırım miktarının uygulamanın başlama tarihine uygun olarak eskale edilmesi de çok önemlidir. Örneğin 1998 fiyatları ile çok doğru bir şekilde hesaplanmış bir şebeke yatırımı eğer 2000 yılında başlayacak ise fiyatların iki yıl için kabul edilecek bir enflasyon oranında eskale edilmesi gerekecektir. Basit gibi gözüken bu nokta ne yazık ki uygulamada bir çok ekonomik analizde gözardı edilmektedir.

Bir şehir doğal gaz dağıtım şebekesinin yaratacağı geliri birinci derecede gaz satışları etkiler. Gaz satış projeksiyonu yalnızca gelirleri etkilemekle kalmayıp başta da açıklandığı gibi şebekenin dizayn kriterlerini ve buradan hareketle ilk yatırım miktarlarına, takip eden yıllarda ilave yatırımların zamanlamasına karar verecektir. Gaz satış projeksiyonları bir kaç senaryo üzerine kurulmalı ve değişik senaryolar altında gerçekleşebilecek satışların projenin karlılığını nasıl etkileyeceği test edilmelidir.

Hiç bir yatırımcı doğal gaz şebekeleri gibi tamamlanma maliyetleri yüz milyonlarca doları bulan büyük projeleri tek başına finanse etmeye kalkışmaz. Bunun yerine bu tip projelerin hemen hemen tamamına yakın bir kısımı özkaynak ve banka kredilerinden oluşan bir kaynak paketi ile gerçekleştirilirler. Bankalar yaptıkları tüm işlemlerde olduğu gibi yatırım projelerinin finansmanı için de belli bir fiyat talep ederler. Böyle bir ek maliyetin yatırımın nakit akışına ve dolayısı ile karlılığına etkisi iyice hesaplanmalı ve değerlendirilmelidir.

Bir işletmenin operasyonlarını devam ettirmesi için giderlerini bir şekilde karşılamasına bağlıdır. Bu iki şekilde gerçekleşebilir; işletme operasyona geçtiği günden itibaren elde ettiği gelirlerle giderlerini karşılar ya da bunun mümkün olmadığı durumlarda giderler dışarıdan bir kaynak bulunarak finanse edilir. Ekonomik analizde bir projenin tahmin edilen gelirleri ve giderleri arasındaki farkın yıllara göre nasıl dağılacağı ve bu dağılım sonrasında ortaya çıkan fonların ya da ihtiyaç duyulacak kaynakların büyüklüğünü görmek açısından iyi bir nakit akışı tablosu hazırlanması çok önemlidir.

Her yatırım normal koşullar altında faaliyete geçtikten belli bir süre sonra vergi ödemekle yükümlüdür. Vergi, gelirler ve giderler arasında fark, yatırımın gerçekleştirilmesinde kullanılan finansmanın maliyeti ve operasyon sırasında sabit kıymetlerin değerlerinde oluşan azalma göz önüne alınarak hesaplanan net kar üzerinden ödenir. Bir işletmenin ödeyeceği verginin hesaplanabilmesi için bütün bunları içerecek bir gelir tablosunun hazırlanması şarttır.

Bir şehire kurulacak doğal gaz dağıtım şebekesi yalnızca doğal gaz satışlarından para kazanmayacaktır. Yapılan yatırımı daha çabuk geri almak ve/veya gaz satışlarının düşük olduğu aylarda işletme gelirlerini en azından sabir giderleri karşılayacak bir seviyede tutabilmek amacıyla sayaç kirası, sabit servis ücreti ve sayaç depozitosu gibi ek kalemlerinden elde edilecek ek gelirler mümkün olur. Sözkonusu kalemler ve büyüklükleri gelir kalemleri tablosunda gösterilmiştir.

Faaliyet giderleri, bir yatırımın ekonomik analizinde en az yatırım miktarlarının doğru hesaplanması kadar önemlidir. Kapsamlı ekonomik analizler yatırım gider kalemlerinde beklenmeyen değişmeleri test eden duyarlılık analizlerini içermelidirler. Çalışmada bir şehir doğal gaz dağıtım şebekesi için tipik işletme giderleri olan; bakım, sigorta, müşavirlik ve mühendislik, personel, bina masrafları, sitem kaybı ve sayılan başlıklar altında toplanamayacak başka masrafları içeren diğerleri kalemlerinden oluşan bir faaliyet giderleri tablosu vardır.

Son olarak, sözü edilen proje değerlendirme kriterlerinin uygulanabilmesi için gerekli net nakit akışını oluşturmak üzere nakit akış tablosunun yeniden düzenlenmesi sonucu bir mali karlılık tablosu oluşturulmuştur. Bu tabloda zamana karşı elde edilen net nakit akışından hesaplanan net şimdiki değer ve iç karlılık değerleri ile yatırımın yapılan varsayımlar altında karlı olup olmadığı test edilmiştir.

Yedinci ve sekizinci bölümlerde yer alan tüm tablolar ve grafikler bu tür uygulamaların gerçekleştirilmesini çok kolay bir hale getiren EXCEL tablolama programı kullanılarak yapılmıştır.

Her yatırım kendi nakit akışını yaratabilmek için belirli bir süreye ihtiyaç duyar. Doğal gaz dağıtım şebekelerinin yapımı büyük miktarlarda kaynağa ihtiyaç duyulmakla birlikte karlılığın oldukça yüksek olduğu yatırımlardır.

Sekizinci bölümün sonunda ekonomik analiz için EXCEL'de geliştirilen modelden elde edilen sonuçlar ya da başka bir deyişle farklı durumlar için hesaplanan değişik gaz satış fiyatları beraberlerinde ki kabullerle birlikte yorumlanıp ve değişik seneryolar sonucunda ortaya çıkan farklı karlılık oranları tartışılmıştır.

Bu bölümde finanman şartları, işletme giderleri, yatırım miktarları için yapılan kabuller sabit tutulmuş ve gaz fiyatını değiştirerek hesaplanan değişik karlılıklar grafikler halinde gösterilmiştir. Bu grafiklerden yatırımı, kabul edilen giderlerin sabit kalması durumunda başa baş noktasına getirecek gaz satış fiyatını ya da ve gaz fiyatındaki bir artmanın ya da azalmanın yatırımın karlılığını nasıl etkileceği kolayca görülmektedir.

CHAPTER I

INTRODUCTION

Natural gas is simply a naturally occurring mixture of combustible hydrocarbon (HC) gases and impurities. The hydrocarbon gases normally found in natural gas are methane, ethane, propane, butanes, pentanes, and small amount of hexanes, octanes, and heavier gases. Usually, the propane and heavier hydrocarbon fractions are removed for additional processing because of their high market value as gasoline-blending stock and chemical plant raw feed stock. What usually reaches the transmission lines for sale as natural gas is mostly a mixture of methane and ethane with some small percentage of propane. The typical composition of natural gas and the composition of natural gas imported from Russian Federations are shown in Table 1.1.

The non-hydrocarbon components of natural gas consist of two types of materials: diluents, such as N_2, CO_2, water vapor and contaminants, such as H_2S and other sulfur compounds. Diluents are non-combustible gases that reduce the heating value of the gas. They are not very harmful, and may actually be used sometimes as "filler" to reduce the heat content of the supply gas. The disadvantages of having diluents in the composition are requirement of greater horse-power and pipelining requirements for the same energy content of the gas, greater internal corrosion, and freezing. Contaminants are very detrimental to production and transport equipment (some are hazardous pollutants), and primary reason for gas conditioning and processing is to remove them as soon as possible from the gas stream. Hundreds of processes and processing plants have been developed to deal with this problem. Some of the major contaminants in natural gas are:

1. Acid gases, chiefly H_2S, and to some extent CO_2.
2. Water vapor in excess of about 5-7 lbm / MMscf.
3. All entrained free water, or water in condensed form.
4. Any liquids in the gas, such as well inhibitors, lube oil, scrubber oil, methanol, and heavier-end hydrocarbons.

5. All solid-matter, sometimes called "pipeline trash", that may be presented. This includes silica "sand", pipe scale, and dirt.

Table 1.1. Typical composition of natural gases and composition of natural gas imported from Russian Federations

Category	Component	Amount, %	Amount, % (Russian's Gas)
Paraffinic HC's	Methane (CH_4)	70-98%	Min. 85%
	Ethane (C_2H_6)	1-10%	Max. 7%
	Propane (C_3H_8)	trace- 5%	Max. 3%
	Butane (C_4H_{10})	trace-2%	Max. 2%
	Pentane (C_5H_{12})	trace-1%	Max. 1% (Including Heavier Hydrocarbons)
	Hexane (C_6H_{14})	trace-0.5%	
	Hexane & higher (C_7+)	none-trace	
Cyclic HC's	Cyclopropane (C_3H_6)	traces	
	Cyclohexane (C_6H_{12})	traces	
Aromatic HC's	Benzene (C_6H_6), others	traces	
Non-hydrocarbons	Nitrogen (N_2)	trace-15%	Max. 5%
	Carbon dioxide (CO_2)	trace-1%	Max. 3%
	Hydrogen sulfide (H_2S)	trace occasionally	Max. 5.10mg/m^3
	Helium (He)	trace - 5%	
	Other sulfur and nitrogen compounds	trace occasionally	
	Mercaptan sulfur		Max. 15.30 mg/ m^3
	Total sulfur content		Max. 102.30 mg/ m^3
	Max. heating value		9360 kcal/ m^3
	Min. heating value		8750 kcal/ m^3

Like all gases, natural gas is a homogeneous fluid of low density and viscosity. It is odorless; odor-generating additives are added during processing to enable detection of gas leaks. Natural gas is one of the most stable flammable gasses. It is flammable within the limits of a 5-15% mixture with air, and its ignition temperature ranges from 1100 - 1300 °F (590 - 705 °C). Typically, natural gas has an energy content of 1100 BTU / SCF (9200 kcal / m^3), which is an important parameter while making contracts with the customers and for its pricing in some cases.

Natural gas can be classified in three different groups due to methane and sulphur content as follows [1, 2];

1. **Dry Sweet Gas:** Contains mainly methane (up to 90%).
2. **Sweet Wet Gas:** Contains heavier hydrocarbons such as ethane, propane, butane with water.
3. **Sour Gas:** Contains impurities such as hydrogen sulphur, components with sulphur more than 500 mg/Nm^3, and non-hydrocarbon gases.

In Table 1.2. all constituents of oil including natural gas classes are shown.

Table 1.2. Constituents of Petroleum [3]

Name	Formula	Normal boiling point °F	°C	Product of Commerce containing constituent	General range of constituents in field stream
Methane	CH_4	-259	-162	Natural gas	
Ethane	C_2H_6	-128	-89	Natural gas	
Prophane	C_3H_8	-44	-42	Natural gas, propane	
Isobutane	i-C_4H_{10}	11	-12	Natural gasoline, butane	
n-Buthane	n-C_4H_{10}	31	-1	Natural gasoline, motor fuel, butane	
Pentanes	C_5H_{12}	90	32	Natural gasoline, motor fuel	
Hexanes	C_6H_{14}	145	63	Natural gasoline, motor fuel	
Heptanes	C_7H_{16}	195	91	Natural gasoline, motor fuel	
Octanes	C_8H_{18}	245	118	Natural gasoline, motor fuel	
Decanes	$C_{10}H_{22}$	345	174	Motor fuel	
Tetradecane	$C_{14}H_{30}$	490	254	Kerosene, light furnace oil	
Hexadecane	$C_{16}H_{34}$	549	287	Mineral seal oil, furnace oil	
Triacontane	$C_{30}H_{62}$	855	457	Light lubricating oil, heavy fuel oil	
Tetracontane	$C_{40}H_{92}$	1012	544	Lubricating oil, heavy fuel oil	
Asphaltane	$C_{80}H_{162}$ +	1200+	649+	Asphalt, road oil, dunker fuel oil	

Dry gas; Field Seperator gas; Gas condensate well effluent; Reservoir gas phase Crude oil well; Stock tank crude oil; Stock tank condensate; Debutanized; Natural Gasoline; LP gas

CHAPTER II

PHYSICAL PROPERTIES OF NATURAL GAS

Modeling both isothermal and non-isothermal flow of natural gas in a pipeline, requires physical and thermodynamic properties of natural gas. These are z-factor, viscosity, enthalpy, isobaric and isochoric heat capacities, and friction factor. All these properties are dependent on pressure and temperature, and are evaluated at a given condition by solving some empirical equations. The accuracy of these correlations have significant role in simulating a given situation correctly.

2.1. z-Factor and Direct Calculation Methods of z-Factors

The ideal gas describes the behavior of most gases at pressure and temperature conditions close to atmospheric. To correct for the deviation between the measured or observed volume and that calculated using the ideal gas law, an empirical factor z, called z-factor is used. The definition of z-factor is the ratio of actual volume of n moles of gas at certain p and T to the Ideal (Calculated) volume of n moles of gas at same p and T

Since compressibility factor appears in almost every equation related with natural gas many studies have been conducted in order to calculate it directly. Five different methods found in literature for direct calculation of z-factor are as follows;

1. **Hall - Yarborough Method (1973)**
2. **Dranchuk, Purvis and Robinson Method (1974)**
3. **Dranchuk - Abou Kassem Method (1975)**
4. **Gopal Method (1977)**
5. **Three Parameter Equation of State (EOS) (Peng Robinson Method (1975)**

2.1.1. Hall - Yarborough Method (1973) [4]

The Hall - Yarborough equations, developed using the Starling - Carnahan equation of state, (EOS), are;

$$z = \frac{0.06125 p_{pr} t e^{-1.2(1-t)^2}}{y} \tag{2.01}$$

where

p_{pr} = the pseudo reduced pressure

t = the reciprocal pseudo reduced temperature (T_{pc} / T)

y = the reduced density, which can be obtained as the solution of the equation

$$F = -0.06125 p_{pr} t e^{-1.2(1-t)^2} + \frac{y + y^2 + y^3 - y^4}{(1-y)^3} - \left(14.76t - 9.76t^2 + 4.58t^3\right) y^2 + \left(90.7t - 242.2t^2 + 42.2t^3\right) y^{(2.18+2.82t)} = 0 \tag{2.02}$$

2.1.2. Dranchuk - Purvis and Robinson Method (1974) [4]

This method fits the Standing - Katz z-factor correlation by means of eight coefficient Benedict - Webb - Rubin type equation of state. The z-factor equation is

$$z = 1 + \left(A_1 + A_2 / T_r + A_3 / T_r^3\right) r\rho_r + \left(A_4 + A_5 / T_r\right)\rho_r^2 + A_5 A_6 \rho_r^5 / T_r + A_7 \rho_r^2 / T_r^3 \left(1 + A_8 \rho_r^2\right) \exp\left(-A_8 \rho_r^2\right) \tag{2.03}$$

where

$$\rho_r = 0.27 p_r / \left(z T_r\right) \text{ and} \tag{2.04}$$

A_1=0.3150637 A_2=-1.40670980 A_3=-0.57832729 A_4=0.53530771
A_5=-0.61232032 A_6=-0.10448813 A_7=0.68157001 A_8=0.68446549

2.1.3. Dranchuk - Abou Kassem Method (1975) [5]

Dranchuk - Abou Kassem developed the following equation from the Starling equation of state:

$$z = 1 + \left(A_1 + \frac{A_2}{T_r} + \frac{A_3}{T_r^3} + \frac{A_4}{T_r^4} + \frac{A_5}{T_r^5} \right) \rho_r + \left(A_6 + \frac{A_7}{T_r} + \frac{A_8}{T_r^2} \right) \rho_r^2 - A_9 \left(\frac{A_7}{T_r} + \frac{A_8}{T_r^2} \right) + A_{10} \left(1 + A_{11} \rho_r^2 \right) \frac{\rho_r^2}{T_r^3} \exp\left(- A_{11} \rho_r^2 \right) \qquad (2.05)$$

where

$$\rho_r = \frac{Z_c P_r}{Z T_r}, \qquad z_c = 0.27 \qquad (2.06)$$

and

$A_1 = 0.3265$ $A_2 = -1.0700$ $A_3 = -0.5339$ $A_4 = 0.01569$ $A_5 = -0.05165$ $A_6 = 0.5475$
$A_7 = -0.7365$ $A_8 = 0.1844$ $A_9 = 0.1056$ $A_{10} = 0.6134$ $A_{11} = 0.7210$

2.1.4. Gopal Method (1977) [4]

This method fits the straight line equations to different portions of the z-factor chart. It uses a general equation of the form

$$z = p_r \left(A T_r + B \right) + C T_r + D \qquad (2.07)$$

The values of constants A, B, C, and D for various combinations of p_r and T_r are shown in the Table 2.1. below;

2.1.5. Three Parameter EOS (Peng - Robinson Method (1975)) [6]

Peng - Robinson proposed the following Equation of State, EOS;

$$P = \frac{RT}{v - b} - \frac{a(T)}{v(v + b) + b(v - b)} \qquad (2.08)$$

Eq. 1.2.8. can be rearranged as

$$z^3 - (1 - B)z^2 + (A - 3B^2 - 2B)z - (AB - B^2 - B^3) = 0 \tag{2.09}$$

Table 2.1. Gopal's Equations for Z-Factors [4]

Reduced Pressure P_r Range Between	Reduced Temperature T_r Range Between	Equations	Eq. No
0.2 and 1.20	1.05 and 1.20	$P_r(1.6643T_r - 2.2114) - 0.3647T_r + 1.4385$	1
	1.2+ and 1.40	$P_r(0.5222T_r - 0.8511) - 0.0364T_r + 1.0490$	2
	1.4+ and 2.00	$P_r(0.1391T_r - 0.2988) + 0.0007T_r$[a] $+ 0.9969$	3[b]
	2.0+ and 3.00	$P_r(0.0295T_r - 0.0825) + 0.0009T_r$[a] $+ 0.9967$	4[b]
1.2+ and 2.80	1.05 and 1.20	$P_r(-1.3570T_r + 1.4942) + 4.6315T_r - 4.7009$	5[c]
	1.2+ and 1.40	$P_r(0.1717T_r - 0.3232) + 0.5869T_r + 0.1229$	6
	1.4+ and 2.00	$P_r(0.0984T_r - 0.2053) + 0.0621T_r + 0.8580$	7
	2.0+ and 3.00	$P_r(0.0211T_r - 0.0527) + 0.0607T_r + 0.9549$	8
2.8+ and 5.40	1.05 and 1.20	$P_r(-0.3278T_r + 0.4752) + 1.8223T_r - 1.9036$	9[b]
	1.2+ and 1.40	$P_r(-0.2521T_r + 0.3871) + 1.6087T_r - 1.6635$	10[b]
	1.4+ and 2.00	$P_r(-0.0284T_r + 0.0625) + 0.4714T_r - 0.0011$[a]	11
	2.0+ and 3.00	$P_r(0.0041T_r + 0.0039) + 0.0607T_r + 0.7927$	12
5.4+ and 15.0	1.05 and 3.00	$P_r(0.7110 + 3.66T_r)^{-1.4667} - 0.637/(0.319T_r + 0.522) + 2.071$	13

[a] These terms may be ignored.
[b] For a very slight loss in accuracy, Eqs. 3 and 9 and 10 can, respectively, be replaced by the following two equations.
$z = P_r(0.0657\ T_r - 0.1751) + 0.0009\ T_r^* + 0.9968$
$z = P_r(-0.2384\ T_r + 0.3695) + 1.4517\ T_r - 1.4580$
[c] Preferably use this equation for P_r up to 2.6 only. For $P_r = 2.6+$, Eq. 9 will give slightly better results. Also, preferably, use Eq. 1 for $1.08 \le T_r \le 1.19$ and $P_r \le 1.4$.

where

$$A = \frac{aP}{R^2T^2} \tag{2.10}$$

$$B = \frac{bP}{RT} \tag{2.11}$$

$$z = \frac{Pv}{RT} \tag{2.12}$$

Eq. 2.9 yields one or three roots depending upon the number of phases involved in the system. In the two - phase region, the largest root corresponds to compressibility factor of the vapor while smallest positive root is for the liquid phase.

At the critical point the results of application of Eq. 2.8 are as follows

$$a(T_c) = 0.45724 \frac{R^2 T_c^2}{P_c} \tag{2.13}$$

$$b(T_c) = 0.07780 \frac{RT_c}{P_c} \tag{2.14}$$

$$z_c = 0.307 \tag{2.15}$$

At other temperatures *a(T)* and *b(T)* are corrected to

$$a(T) = a(T_c).\alpha(T_r, \omega) \tag{2.16}$$

$$b(T) = b(T_c) \tag{2.17}$$

where $\alpha(T_r, \omega)$ is a dimentionless function of reduced temperature and acentric factor and equals unity at the critical temperature. For all substances Peng & Robinson linearized the relationship between α and T_r as follows

$$\alpha^{1/2} = 1 + \kappa(1 - T_r^{1/2}) \tag{2.18}$$

where κ is a constant characteristic of each substance. The correlating equation of κ against acentric factors

$$\kappa = 0.37464 + 1.54226\omega - 0.26992\omega^2 \tag{2.19}$$

for mixtures attraction parameter - scaling factor product, $a\alpha$, defined as

$$a\alpha = \sum_i \sum_j x_i x_j (a_{ij} \alpha_{ij}) \tag{2.20}$$

where a, the attraction parameter used by Eq. 2.13.

$$\alpha_{ij} = \left(1 - \delta_{ij}\right) a_i^{1/2} a_j^{1/2} \tag{2.21}$$

and b, the coefficient used in Eq. 2.14.

$$b = \sum_i x_i b_i \tag{2.22}$$

here δ_{ij} is an empirically determined binary interaction coefficient characterizing the binary formed by component i and component j. The constants A and B defined in Peng - Robinson EOS, Eqs. 2.10. - 2.11., can be redefined for mixtures as

$$A = \sum_i \sum_j x_i x_j A_{ij} \tag{2.23}$$

$$B = \sum_i x_i B_i \tag{2.24}$$

where A_{ij} equals

$$A_{ij} = \left(1 - \delta_{ij}\right)\left(A_i A_j\right)^{0.5} \tag{2.25}$$

Note that in Eq 2.25 δ_{ij} is equal to zero.

Peng - Robinson reported that their EOS can be used to accurately predict the vapor pressures of pure substances and equilibrium ratios of mixtures. They also reported that in regions where engineering calculations are frequently required their equation has a reliable agreement between predictions and experimental P - V - T data.

2.2. Friction Factor

Friction factor can be defined as

$$f' = \frac{\tau_w}{\rho u^2 / 2 g_c} = \frac{\text{wall shear stress}}{\text{kinetic energy per unit volume}} \qquad (2.26)$$

Eq. 2.26 defines a dimentionless group, which reflects the relative importance of wall shear stress to the total losses. The wall shear stress can be easily evaluated from a force balance between pressure forces and viscous forces:

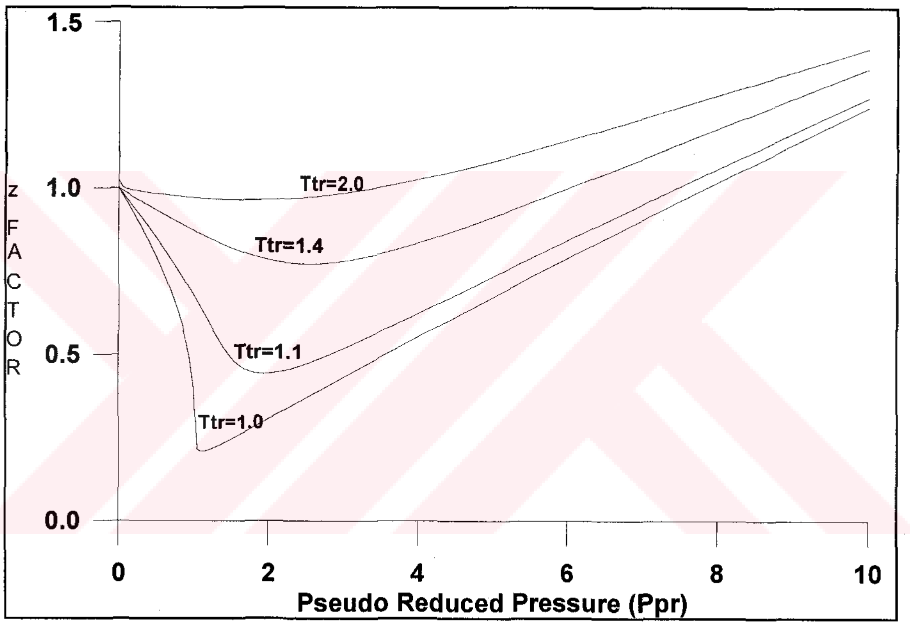

Figure 2.1. Compressibility Factor of Natural Gases as a Function of Reduced Pressure and Temperature (by Hall - Yarborough z- Factor Correlation)

$$\tau_w = \frac{D}{4}\left(\frac{dp}{dL}\right)_f \qquad (2.27)$$

Using this in Eq. 2.26. yields

$$\left(\frac{dP}{dL}\right)_f = \frac{2 f' \rho u^2}{g_c D} \qquad (2.28)$$

This is the Fanning equation and *f'* is called the Fanning friction factor. In terms of the Moody friction factor, *f* = *4f'*, Eq. 2.28. becomes

$$\left(\frac{dP}{dL}\right)_f = \frac{f' \rho u^2}{2g_c D} \tag{2.29}$$

The equation that relates lost work per unit length of pipe and the flow variable is

$$\frac{d(lw)}{dL} = \frac{f\rho u^2}{2g_c D} \tag{2.30}$$

where

lw = mechanical energy converted to heat, ft-lbf/lbm

u = flow velocity, ft/sec

gc = gravitational conversion factor = 32.17 lbm ft/lbf sec^2

D = pipe diameter, ft

f = Moody friction factor

Integration of Eq. 2.30. results in

$$lw = \frac{fu^2}{2g_c}\frac{L}{D} \tag{2.31}$$

In cases where the friction factor is preferred to be calculated, instead of taken to be an average, N_{Re}, must be calculated to decide on flow regime. The Reynolds number, N_{Re}, is a dimentionless group defined as

$$N_{\text{Re}} = \frac{D(\text{ft})u(\text{ft / sec})\rho(\text{lbm / cu ft})}{\mu(\text{lbm / ft sec})} \tag{2.32}$$

The dimentionless group, $N_{Re}= D \ u \rho / \mu$, is the ratio of fluid momentum forces to shear forces. The change from laminar to turbulent flow is usually assumed to occur at a Reynolds number of 2100 for flow in circular pipe. If units of ft, ft / sec, lbm / cuft, and centipoise are used, Eq. 2.32. becomes

$$N_{\text{Re}} = 1488\frac{Du\rho}{\mu} \tag{2.33}$$

The relative roughness, e / D, another dimentionless parameter for determining the friction factor, can be defined as the ratio of the absolute roughness to the pipe internal diameter:

$$\text{Relative Roughness} = \frac{e\ (\text{ft})}{D\ (\text{ft})} \text{ or } \frac{e\ (\text{in.})}{D\ (\text{in.})} \tag{2.34}$$

Eq. 2.33. can be rearranged as follows,

$$N_{\text{Re}} = 710.39 \frac{P_{sc}}{T_{sc}} \frac{q_{sc}\gamma_g}{D\mu} \tag{2.35}$$

While, Moody friction factor for laminar single phase flow is:

$$f = 64 / N_{\text{Re}} \tag{2.36}$$

for partially turbulent and fully turbulent single phase flow, friction factor is dependent on N_{Re} and e / D. In literature, many correlations for this chart have been reported [5, 8]. For instance; for smooth pipes Prandt's formula or Blasius formula can be applicable. Further, Colebrook's equation is convenient for rough pipes. An explicit correlation for friction factor was presented by Swamee and Jain [5, 8].

$$\frac{1}{\sqrt{f}} = 1.14 - 2\log\left(\frac{\varepsilon}{D} + \frac{21.25}{N_{\text{Re}}^{0.9}}\right) \tag{2.37}$$

Eq. 2.37. is reported to be applicable for $10^{-6} < \varepsilon / D < 10^{-2}$, and $5000 < N_{Re} < 10^{8}$, with errors within 1%.

2.3. Natural Gas Viscosity

As mentioned above, for situations where friction factor has to be found as a dependent variable rather than an average value, viscosity of natural gas must be known. In petroleum and natural gas industry, natural gas viscosities are commonly determined by applying Carr, Kobayashi and Burrows correlations [4, 5]. The Carr et al. correlations are presented in graphical form. The method consists of a simple two step procedure. In the first step μ_1, the viscosity at atmospheric pressure, P, and temperature, T, is estimated using the apparent molecular weight or gravity of the gas and the temperature at which the gas viscosity is desired. If the gas contains impurities such as N_2, H_2S or CO_2, then μ_1 value is corrected

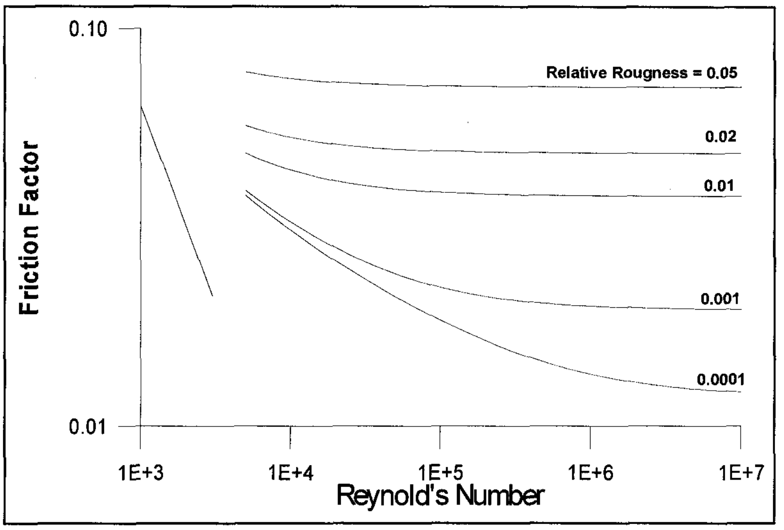

Figure 2.2. Moody Friction Factors for Flow in Pipes [5,8]

for each impurity, depending upon the concentration of each impurity in the natural gas and the gas gravity. In the second step the ratio of the viscosity of the gas at desired temperature and pressure to μ_1 is obtained using the reduced pressure and temperature of the gas at the conditions required.

Since this method employs graphical representations, they could not be used in machine calculations in their original form. To overcome this difficulty Dranchuk et al. [9] expressed the graphical representation of μ_1 and μ/μ_1 by means of polynomial expressions.

Gas viscosity, as distinct from liquid viscosity, increases as temperature increases, decreases as molecular weight increases, and is independent of pressure at medium pressures. At atmospheric pressure, viscosities of hydrocarbon gases vary linearly with temperature between 32 and 328 °F .

Viscosity of natural gas at desired pressure and temperature is estimated by mathematical expressions representing Carr et al. graphical correlation. They used orthogonal polynomial expressions they used to generate μ and μ/μ_1 values. μ_1 may be expressed as:

$$\mu_1 = (\mu_{1\ \text{uncorrected}}) + (N_{2\ \text{correction}}) + (CO_{2\ \text{correction}}) + (H_2S_{\text{correction}}) \tag{2.38}$$

where

$$(\mu_{1\ \text{uncorrected}}) = \left[1.709 \cdot 10^{-5} - 2.062 \cdot 10^{-6}\gamma_g\right]T + 8.188 \cdot 10^{-3} - 6.15 \cdot 10^{-3}\log\gamma_g \tag{2.39}$$

$$(N_{2\ \text{correction}}) = Y_{N_2}\left[8.48 \cdot 10^{-3}\log\gamma_g + 9.59 \cdot 10^{-3}\right] \tag{2.40}$$

$$(CO_{2\ \text{correction}}) = Y_{CO_2}\left[9.08 \cdot 10^{-3} \log \gamma_g + 6.24 \cdot 10^{-3}\right] \tag{2.41}$$

$$(H_2S_{correction}) = Y_{H_2S}\left[8.49 \cdot 10^{-3} \log \gamma_g + 3.73 \cdot 10^{-3}\right] \tag{2.42}$$

They divided μ / μ_1 vs. P_r surface into three regions A, B and C, and they fitted these regions to orthogonal polynomials of the form:

$$\log(\mu / \mu_1) = \sum_{i=0}^{N} \sum_{j=1}^{i+1} \alpha_{ij} (\log P)^{j-1} (\log T)^{i-j+1} \tag{2.43}$$

where

$$\log P = \frac{\log(P_r) - \log(P_{r\,\min})}{\log(P_{r\,\max}) - \log(P_{r\min})} \tag{2.44}$$

$$\log T = \frac{\log(T_r) - \log(T_{r\min})}{\log(T_{r\max}) - \log(T_{r\min})} \tag{2.45}$$

These correlations were reported to be reproduce viscosities with a mean absolute error of 0.95%. By means of this method, Carr et al. charts were reproduced to show whether this approach works properly or not (see Figure 2.3.)

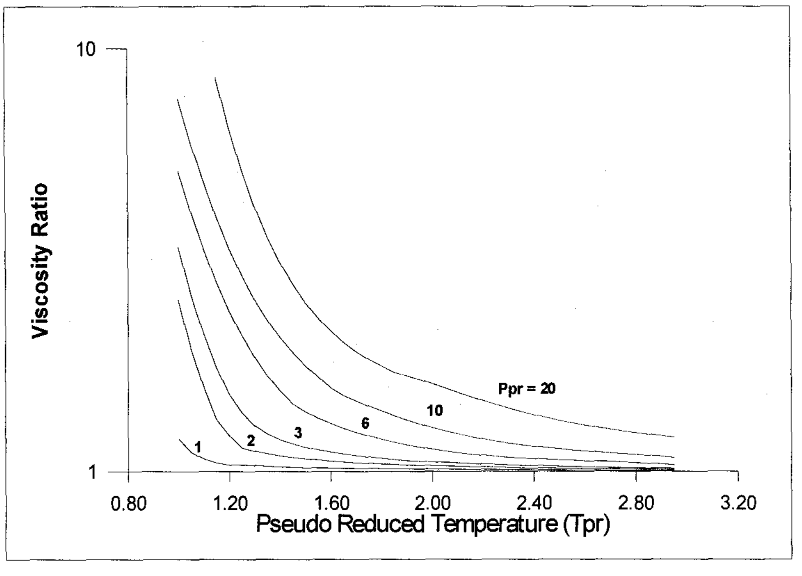

Figure 2.3. Viscosity Ratio vs. Reduced Temperature [9]

CHAPTER III

STEADY STATE FLOW OF NATURAL GAS THROUGH PIPELINES

3.1. The Derivation of the Basic Steady State Flow Equation

The first law of thermodynamics is a generalization of conservation of energy principle i.e. total energy change of a system is same as that of surroundings. The total energy of a system may consist of various forms of energy depending on the system under consideration. For most systems, including gas flow in a pipeline, it is sufficient to account only for the internal, kinetic and potential energy. No other forms of energy such as nuclear, electro - magnetic, etc. will be considered.

Since we presumed that flow is in steady state condition (no time dependence of flow parameters), all rates must be constant. Therefore, energy balance equation, on the unit mass basis can be written as

$$\Delta U + \Delta E_k + \Delta E_p - Q + W = 0 \qquad (3.01)$$

For mathematical treatment it is more convenient to express Eq. 3.1. in differential form as follows.

$$dU + dE_k + dE_p - dQ + dW = 0 \qquad (3.02)$$

In the absence of potential and kinetic energy changes, the change in internal energy of a system is

$$dU = dQ - dW \qquad (3.03)$$

It is well-known form of the first law of thermodynamics for a closed system.

The choice of signs to be used with Q and W depends on which direction of transfer is regarded as positive. Convention is to regard a quantity of heat positive when it is transferred to the system from surroundings. On the other hand, a quantity of work is usually regarded as positive when it is transferred from the system to the surroundings.

Q and W in above equations, represent all the heat added and work extracted per unit mass of fluid flowing through the control volume. In fact, W is the sum of work done by/on the fluid due to expansion or contraction, and shaft work done by/on the fluid flowing through control volume. The shaft work is transmitted by a shaft which either rotates or reciprocates. Thus

$$dW = d(PV) + dW_s \tag{3.04}$$

Substitute this total work into energy balance equation, then Eq. 3.2. becomes

$$dU + dE_k + dE_p - dQ + d(PV) + dW_s = 0 \tag{3.05}$$

By definition, the enthalpy is

$$H = U + PV \tag{3.06}$$

Differentiating Eq. 3.6. gives

$$dH = dU + d(PV) \tag{3.07}$$

or

$$dH = dU + PdV + VdP \tag{3.08}$$

The combination of Eq. 3.7. with Eq. 3.5. to eliminate internal energy term gives

$$dH + dE_k + dE_p - dQ + dW_s = 0 \tag{3.09}$$

This equation is mathematical expression of first law for steady state flow process. All the terms are expressions for energy per unit mass of fluid, absolutely, the same unit of energy must be employed for all terms when numerical calculations are made.

The second law of thermodynamics may be stated as: all spontaneous processes are irreversible. Such irreversible processes always involve a degradation of energy. This characteristics of energy provides us with a general principle: The total entropy change is always positive. The entropy of a system customarily denoted by *S*, has been defined so that its differential change is equal to *dQ / T*, when all changes of the system take place reversibly, that is,

$$dQ = TdS \tag{3.10}$$

Let *dW* represent the infinitesimal quantity of work done by a system of a gas confined in a cylinder having a frictionless and weightless piston. The quantity of reversible work done due to the compression or expansion of the gas is

$$dW = PdV \tag{3.11}$$

Substituting the last two equations into Eq. 3.1. gives

$$dU = TdS - VdP \tag{3.12}$$

Substitution for *dU* by Eq. 3.8. yields

$$dH = TdS - VdP \tag{3.13}$$

As a result of the irreversibilities such as friction, the energy that is wasted through such an irreversibilities other than to accomplish the desired change is called lost work. It is defined as the difference between the reversible work calculated for the change in state of the process and the actual work of the process for steady state flow, this difference is

$$W_{lost} = W_{ideal} - W_s \tag{3.14}$$

W_S represents actual work done by/on the system in which the work is interchanged between the system and the surroundings through the shaft.

In case of steady flow process, the energy balance given by Eq. 3.9. can be written

$$dW_s = dQ - dH - dE_k - dE_p \tag{3.15}$$

If all changes within the system and also heat transfer between the system and surroundings are reversible, the second law requires Eq. 3.10., and the work resulting will be called the ideal work, or $W_{ideal.}$ Substituting for *dQ* by Eq. 3.10. into Eq. 3.13., for the ideal work instead of *Ws*, yields

$$dW_{ideal} = TdS - dH - dE_k - dE_p \tag{3.16}$$

Substitution the last two equations into differential form of Eq. 3.13. provides

$$dW_{lost} = TdS - dQ \tag{3.17}$$

or

$$dQ = TdS - dW_{lost} \tag{3.18}$$

Substitution Eq. 3.18. and Eq. 3.13. into Eq. 3.9. energy balance can be written as

$$VdP + dE_k + dE_p + dW_s + dW_{lost} = 0 \tag{3.19}$$

Writing kinetic and potential energy changes in differential form on the unit mass basis, and neglecting the shaft work, Eq. 3.19 becomes

$$VdP + \frac{u}{g_c}du + \frac{g}{g_c}dz + dW_{lost} = 0 \tag{3.20}$$

Eq. 3.20 may be written in terms of pressure gradient by multiplying throughout by ρ / dL

$$\frac{dP}{dL} + \frac{\rho u}{g_c}\frac{du}{dL} + \frac{g}{g_c}\rho \sin\theta + \rho\frac{dW_{lost}}{dL} = 0 \tag{3.21}$$

or

$$\frac{dP}{dL} + \frac{\rho u}{g_c}\frac{du}{dL} + \frac{g}{g_c}\rho \sin\theta + \rho\left(\frac{dP}{dL}\right)_f = 0 \tag{3.22}$$

where the pressure gradient due to viscous shear or frictional losses have been expressed as

$$\left(\frac{dP}{dL}\right)_s = \frac{f\rho u^2}{2g_c d} \tag{3.23}$$

In Eq. 3.23. f is the Moody friction factor.

Substitution of Eq. 3.23. into Eq. 3.22., and neglecting kinetic energy term yields

$$\frac{dP}{dL}+\frac{g}{g_c}\rho\sin\theta+\frac{f\rho u^2}{2g_c d}=0 \tag{3.24}$$

Gas density, ρ and velocity u in Eq. 3.24., are as follows

$$\rho=\frac{PM}{ZRT} \tag{3.25}$$

$$u=q_{sc}\left(\frac{P_{sc}}{T_{sc}}\right)\left(\frac{ZT}{P}\right)\left(\frac{4}{\pi d^2}\right) \tag{3.26}$$

By substituting ρ and u into Eq. 3.24, we obtain

$$\frac{dP}{dL}+\frac{g}{g_c}\frac{PM}{ZRT}\sin\theta+\frac{f}{2g_c d}\frac{PM}{ZRT}\left(\frac{4q_{sc}ZTP_{sc}}{PT_{sc}\pi d^2}\right)^2=0 \tag{3.27}$$

This equation is the same general pressure drop equation for steady state flow, including the effect of flow over hilly terrain. It is applied to a given control volume to calculate the pressure loss. However, it is still in differential form. To solve it analytically, without complexity, temperature is assumed constant and *z*-factor is evaluated at average pressure and temperature (formulas for average pressure and temperature are given in Eq. 3.31 and Eq. 3.32). Solving Eq. 3.27 over the incremental length *dL*, between points *i* and *i+1* gives the following equation. In field units;

$$q_{sc}=5.63538\left(\frac{T_{sc}}{P_{sc}}\right)\left(\frac{\left(P_i^2-e^s P_{i+1}^2\right)d^5}{\gamma_g z_{av}T_{av}f\Delta L_d}\right)^{0.5} \tag{3.28}$$

$$\Delta L_d=\frac{e^s-1}{s}\Delta L \tag{3.29}$$

$$s=0.03747\frac{\gamma_g}{z_{av}T_{av}}\Delta z \tag{3.30}$$

$$T_{av} = \frac{T_1 + T_2}{2} \tag{3.31}$$

$$P_{av} = \frac{P_i^2 + P_i P_{i+1} + P_{i+1}^2}{P_i + P_{i+1}} \text{ [5]} \tag{3.32}$$

3.2. Commonly Used Practical Equations for Horizontal Flow

Several semi-empirical equations for gas flow have been derived from equation 3.28. to avoid trial and error to compute friction factor. These equations differ only in the friction factor correlation assumed. Since friction factor vary over a wide range with Reynolds number and pipe roughness, none of these equations is universally applicable. Therefore any of these equations must be tested whether or not they suit the particular field conditions before they are employed in any computation. In some cases modified versions that give more accurate results can be used. Some of these practical equations are as follows;

3.2.1. Weymouth Equation [5]

Weymouth proposed the following relationship for friction factor as a function of pipe diameter in inches:

$$f = 0.032 / d^{1/3} \tag{3.33}$$

Substituting for *f* from Eq. 3.33. into Eq. 3.28. and taking into consideration that flow is horizontal, i.e., $e^S=0$, we have;

$$q_{sc} = 31.5027\left(\frac{T_{sc}}{P_{sc}}\right)\left(\frac{\left(P_i^2 - P_{i+1}^2\right)d^{16/3}}{\gamma_s z_{av} T_{av} \Delta L}\right)^{0.5} \tag{3.34}$$

This is known as the Weymouth equation for horizontal flow. It is used most often in designing gas transmission systems because it generally maximizes pipe diameter requirements for a given flow rate and pressure drop.

3.2.2. Panhandle (Panhandle A) Equation [5]

This equation assumes *f* is a function of Reynolds number as follows:

$$f = 0.0768 / N_{\mathrm{Re}}^{0.1461} \tag{3.35}$$

Substituting for *f* from Eq. 3.35 into Eq. 3.28 and using field units

$$q_{sc} = 32.6491\left(\frac{T_{sc}}{p_{sc}}\right)^{1.07881}\left(\frac{p_1^2 - p_2^2}{z_{av}T_{av}L}\right)^{0.53940}\left(\frac{1}{\gamma_g}\right)^{0.46060}\frac{d^{2.661821}}{\mu_g^{0.07881}} \tag{3.36}$$

The Panhandle A equation is applicable to large diameter pipelines, at high flow rates.

3.2.3. Modified Panhandle (Panhandle B) Equation [5]

Panhandle B equations assumes that *f* is a function of Reynolds number as follows:

$$f = 0.00359 / N_{\mathrm{Re}}^{0.03922} \tag{3.37}$$

The pipeline equation thus given as follows:

$$q_{sc} = 109.364\left(\frac{T_{sc}}{p_{sc}}\right)^{1.020}\left(\frac{p_1^2 - p_2^2}{z_{av}T_{av}L}\right)^{0.510}\left(\frac{1}{\gamma_g}\right)^{0.490}\frac{d^{2.530}}{\mu_g^{0.020}} \tag{3.38}$$

This is one of the most widely used equations for long transmission lines. It is most applicable to large diameter pipelines, at high values of Reynolds number.

3.2.4. Clinedinst Equation [5]

The Clinedinst Equation rigorously accounts for the deviation of natural gas from ideal behavior instead of assuming an average gas compressibility factor, z_{av}, and dependence of friction factor, f, on Reynolds number and pipe roughness, leading to a *trial and error* scheme. The integral $\int(p/z)dP$ must be evaluated. In order to generalize this evaluation, it is converted into the following:

$$\int(p/z)dp = \int\left[\left(p_{pc}p_r / z\right)p_{pc}dp_r\right] = p_{pr}^2\int\left(p_r / z\right)dp_r \tag{3.39}$$

where

p_{pc} = pseudo critical pressure of the flowing gas mixture, psia

p_r = reduced pressure $(p_r = p / p_{pc})$

Tables are available for valuation of the integral function $\int(p_r / z)dp_r$. Rearranging this equation in Eq. 3.28. for horizontal flow, i.e., $e^S=0$, with the field units commonly known Clinedinst Equation can be obtained,

$$q_{sc} = 7.969634\left[\frac{p_{pc}T_{sc}}{p_{sc}}\right]\left[\frac{d^5}{\gamma_g T_{av} L f}\right]^{0.5}\left[\int_0^{p_{r1}}(p_r, Z)dp_r - \int_0^{p_{r2}}(p_r, Z)dp_r\right]^{0.5} \tag{3.39}$$

CHAPTER IV

NETWORK COMPONENTS

Natural Gas transportation and distribution facilities, so called natural gas networks consist of nodes and node connecting elements (NCE).

Nodes represent points where one or more node connecting elements terminate and where flow enters or leaves the system. Nodes are also the reference points for system pressures.

Node connecting elements can be described the set of all possible elements that can be included in a system but mainly classified as pipelines, compressors, pressure control valves or regulators.

4.1. Nodes

Since nodes are just junction points, and flow process is very rapid, flow through nodes can be considered as steady state even if there exist transient flow in elements connected to that particular node. As a result at steady state flow regime, mass and energy balance must be satisfied at each node. Consider node *i*, with *m* NCE's connected to the node, mass balance can be written as,

$$\sum_{j=1}^{m} s_j^{(i)} q_j^{(i)} = 0 \tag{4.01}$$

and energy balance

$$\sum_{j=1}^{m} s_j^{(i)} q_j^{(i)} H_i^{(j)} = 0 \tag{4.02}$$

These two equations are used with a sign convention (represented by *s*) which is equal to *+1* for flow entering node, *-1* for flow leaving node. $s_j^{(i)}Q_j^{(i)}$ describes the flow through j^{th} NCE from node *i*.

Energy balance equation (Eq. 4.2.) cannot be easily satisfied as simple as mass balance. It is accomplished by equalizing the temperature of gas leaving node to weighted average of entering flow temperature. Figure 4.1. shows a node with five NCE's. Arrows indicate flow directions.

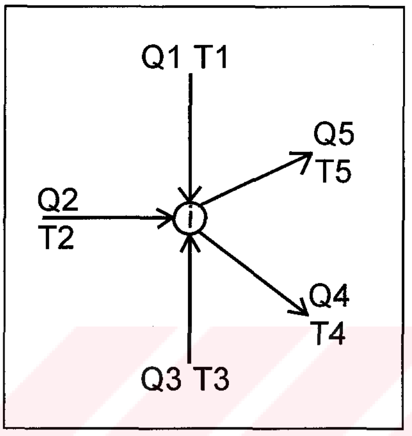

Figure 4.1. Example of a Node

Temperature of flows leaving node *i*, (i.e. q_4 and q_5), can be calculated as follows;

$$T_4 = T_5 = \frac{q_1 T_1 + q_2 T_2 + q_3 T_3}{q_1 + q_2 + q_3} \quad (4.03)$$

where Q_i's are volumetric flow rates. Although they are volumetric quantities, they can be considered as mass flow rates, because they are evaluated at standard pressure and temperature.

4.2. Node Connecting Elements

4.2.1. Pipelines

Understanding of the relations of fluid movement through a pipeline is based on the following principles: Conservation of mass, Newton's second law of motion, and the first law of thermodynamics. Supplementary experimental data and empirical equations contributes to this understanding.

Although the basic equations of fluid movement mechanics are often written to apply at a point in space and time, practical applications of thermodynamics usually are to finite amounts of material undergoing finite changes in state. It is necessary to select an elemental volume called control volume convenient to model of physical problem. Consider the control volume shown in Figure 4.2. This volume is an arbitrary volume moving in space, enclosed by pipe wall and physically unidentified lateral surfaces which permits to transfer matter. In thermodynamic terminology, the system, is this control volume and surroundings are adjacent control volumes and physical environment surrounding it.

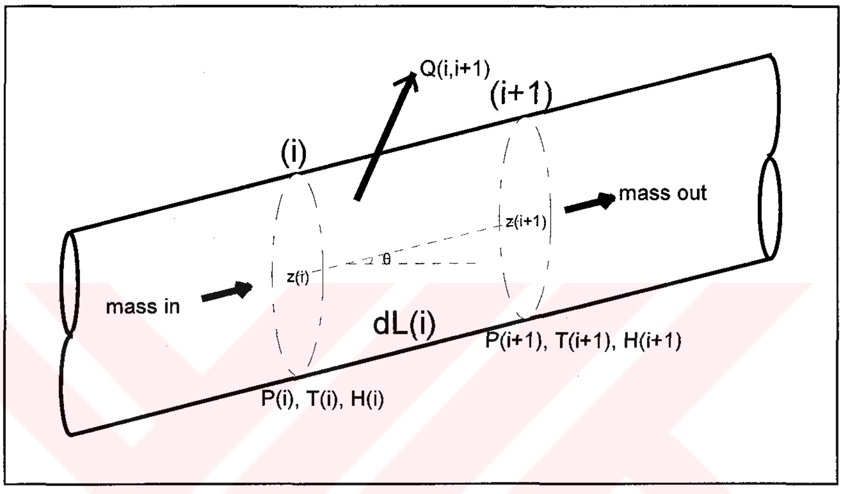

Figure 4.2. Control Volume of a Pipeline

Before the application of aforementioned principles to flow process, some idealizations, having practical importance must be done [10]. These imposed idealizations are:

- The flow is unidirectional at the cross section between two control volumes where thermodynamics, kinetic, and dynamic properties are assigned or evaluated.

- At such a cross section these same properties do not vary from point to point along any line perpendicular to the direction of flow. Thus the properties assigned or evaluated for the cross section have values which represent appropriate averages over the cross section.

- Potential and kinetic energy changes of the fluid within the control volume occur with negligible rates. This also implies that the elevation, *Z*, must be measured from the center of mass of the control volume.

Conservation of energy law for an incremental part of a pipeline states:

$$dH + dE_k + dE_p - dQ + dW_s = 0 \qquad (4.04)$$

Substituting the equivalent formulations for kinetic and potential energy changes and neglecting shaft work, Eq. 4.4 becomes

$$dH + \frac{u}{g_c} du + \frac{g}{g_c} dz - dQ = 0 \tag{4.05}$$

By means of above assumptions and principles, the representative pipe flow Equation, Eq. 3.28, for incremental length of an inclined pipeline (between points *i* and *i+1*) under isothermal flow conditions has been given as follows

$$q_{sc} = 5.63538\left(\frac{T_{sc}}{P_{sc}}\right)\left(\frac{\left(P_i^2 - e^s P_{i+1}^2\right)d^5}{\gamma_g Z_{av} T_{av} f \Delta L}\right)^{0.5} \tag{4.06}$$

The derivation of Eq. 4.6. is given in detail in Chapter 3. Eq. 4.6. can be rearranged to calculate downstream pressure of the pipe increment

$$P_{i+1} = e^{-s/2}\sqrt{P_i^2 - \frac{q_{sc}^2 P_{sc}^2 \gamma_g Z_{av} T_{av} f \Delta L}{31.7575 T_{sc}^2 \quad d^5}} \tag{4.07}$$

In case of non-isothermal flow heat transfer between flowing gas and its surroundings must be taken into consideration.

4.2.2. Compressors

Compressors are used for providing enough pressure for gas to transport through transmission and distribution systems.

The two major types of compressors are; positive displacement or intermitted flow compressors, and continuous flow compressors. Positive displacement units are those in which successive volumes of gas are confined within some type of enclosure (compression chamber) and elevated to higher pressure. Continuous flow compressors accelerate a continually flowing gas stream and subsequently convert the velocity head into pressure.

In literature, the following equation is usually used to model a compressor,

$$q_{sc} = \frac{HP}{C_1\left(\frac{P_d}{P_u}\right)^{c_2} - C_3} \tag{4.08}$$

where HP is horsepower used by the compressor, and the constants C_1, C_2 and C_3 are determined to fit data for the compressors, while P_d and P_u refer to the downstream (discharge) and upstream (suction) pressures, respectively. The derivation of this equation is given in Appendix B.

From energy point of view, energy balance equation for compressor shown in Figure 4.3 can be written as follows;

$$H_{out} = H_{in} + W_{comp} \tag{4.09}$$

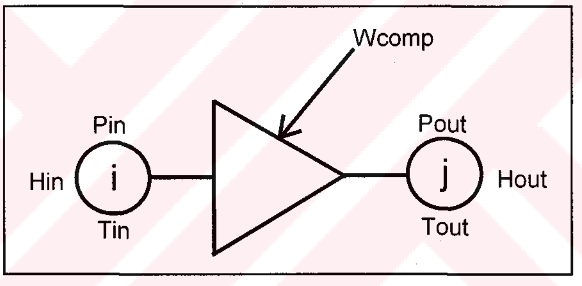

Figure 4.3. Sketch of a Compressor between Nodes i and j

W_{comp} represents work done by the compressor on the gas. It is;

$$W_{comp} = (C)(HP) \tag{4.10}$$

where C is a combination constant for conversion and efficiency factor of compressor.

4.2.3 Pressure Control Valves or Regulators

There are several locations in the gas transportation and distribution systems where the gas must pass through relatively short restrictions.

The flow through restrictions may be either subcritical of critical. In subcritical flow, the velocity of gas through the restriction is below the speed of sound. The flow rate will depend on both the upstream and downstream pressure. In critical flow, the velocity of gas through the restriction is equal to the speed of sound in the gas. Since pressure disturbances travel at the speed of sound, a disturbance downstream of the restriction in critical flow will not affect the upstream pressure of flow rate. The flow rate depends only on the upstream pressure in critical flow.

Gas flow through a restriction can be calculated for subcritical flow using the following equation:

$$q_{sc} = 27.608 C_d d_{ch}^2 \left(\frac{T_{cs}}{P_{sc}}\right)\left[\frac{1}{\gamma_{sc}T_1}\frac{k}{k-1}\left(\left(\frac{P_2}{P_1}\right)^{2/k} - \left(\frac{P_2}{P_1}\right)^{(k+1)/k}\right)\right]^{0.5} \tag{4.11}$$

if pressure *ratio* is less than critical value, $(P_2/P_1)_C$, Eq. 4.11 is not valid. The following equation represents critical flow through a restriction

$$q_{sc} = 27.608 C_d d_{ch}^2 \left(\frac{T_{cs}}{P_{sc}}\right)\left[\frac{1}{\gamma_{sc}T_1}\frac{k}{k-1}\left(\left(\frac{2}{k+1}\right)^{2/(k-1)} - \left(\frac{2}{k+1}\right)^{(k+1)/(k-1)}\right)\right]^{0.5} \tag{4.12}$$

If these devices are studied with energy balance concept, then flow through restriction will be an isoenthalpic process [10]. Thus, the steady state energy relation Eq. 4.4 reduces to

$$dH = 0 \tag{4.13}$$

by assuming that the device is well insulated from the surroundings and no shaft work is produced, these devices can assumed to be operating under isoenthalpic conditions. As a result, for a pressure regulator shown in Figure 4.4, Eq. 4.13 states

$$H_{in} = H_{out} \tag{4.14}$$

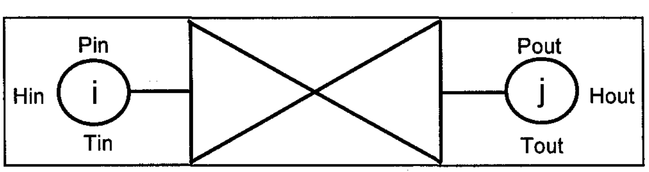

Figure 4.4. Sketch of a Regulator between Nodes i and j

CHAPTER V

NATURAL GAS DISTRIBUTION NETWORKS

Although the fundamental relationships of gas flow in a pipeline are stated in Chapter III the actual gas transmission systems often form connected nets, in which flow is governed by more complicated relations rather than those referring to single line. Pipe nets may be high-pressure, with pressure changes entailing significant changes in specific volume, and low-pressure, with such changes negligible. The first type includes transmission systems of regional supply, community utilities and households.

Flow in transmission systems is almost invariably transient, but numerous design and operation control problems may be solved notwithstanding by assuming flow to be steady state. Network models based on the assumption of steady flow permit the establishment of pressure contour maps of both tree structured and looped networks for periods of peak demand. This map permits us to pinpoint the critical segments of the network, where consumer demand cannot be fully met in peak demand periods. The pressure map is useful in designing new systems, and in explaining or checking the operation of existing ones.

The simulation of such systems, i.e., transmission lines and distribution networks, has been an interesting subject in engineering disciplines related with natural gas since 1930's. The earliest studies were confined to the basic flow characteristics and simple systems. The growth of natural gas systems in size and complexity has demanded more sophisticated computer programs to be developed.

Before constructing the model of natural gas networks it is necessary to define the basic elements of networks. They are nodes and node connecting elements,NCE's. Nodes are defined as the points where a NCE ends, or where two or more NCE's join, or where there is an intake-injection or offtake-delivery of gas. The NCE's include all possible elements (pipelines, compressors, pressure regulators, etc.) as a part of the whole system. They are usually described by a mathematical equation.

5.1 Steady State Isothermal Analysis of Networks

There are two major aspects regarding distribution of natural gas:

1. **Network Design**
2. **Network Analysis**

Network design starts with calculation of average consumption rate of region plus consideration for future gas demand and the measures to secure the supply pressure at all times all around the network. In fact, adequacy of a network is measured by its ability to meet the peak demand with the pressure available at the system's input point. This stage is followed by a selection of pipes, decision of pipe size which is usually a trial and error method followed by configuration of network.

Network analysis is essential to evaluate the system's performance under different conditions of loads, piping sizes, pipe lengths and operating pressures. Also it has the objective to ensure the safe and efficient performance of the designed network at a lesser cost. Under steady state operations two laws govern gas network systems:

Node Law: This law applies to any node. The algebraic sum of gas flows entering the node is equal to the algebraic sum of gas flows of those leaving that particular node. In other words the algebraic sum of the gas flows entering and leaving each node is zero.

Loop Law: For any loop, the algebraic sum of pressure drops around the loop is zero.

Basically the methods reported in the literature to analyze a gas network under steady state operations, are ;

1. Hardey Cross Method
2. Stoner's Method1.5.1.1. Hardey Cross Method [5, 8]

5.1.1. Hardey Cross Method

This method which is of trial and error nature, is straightforward and simple. Mathematically the method uses the "Loop law" as follows:

$$\sum_{j-1}^{nNCEI} K_J (q_J + \Delta q)\left|q_j + \Delta q\right| = 0 \qquad (5.01)$$

or

$$\Delta q = \frac{-\sum_{J-1}^{nNCEI} K_J q_J |q_J|}{2\sum_{J-1}^{nNCEI} K_J |q_J|} \tag{5.02}$$

and then

$$q^{new} = q^{old} + \Delta q \tag{5.03}$$

However, due to slowness of convergence the method is not feasible and time wasting in many practical applications. To increase the rate of convergence, variants of this method were developed by Renouard and Pernelle [8]. Both techniques aim at increasing the convergence rate by obtaining better throughput corrections needed in Hardy Cross method of solution. However, for complicated networks they both become slow as well.

5.1.2. Stoner's Method [8]

This method is based on the "Node law" to analyze looped networks under steady state operations. For any node i, the continuity equation states that, sum of the inflows and out flows at each node must be equal to zero.

$$F_i = \sum_{k=1}^{m(i)} s_{i,node(i,k)} Q_{i,node(i,k)} + Q_i \tag{5.04}$$

where

i = index for nodes, 1,...,number of nodes

$s(i, node(i, k))$ = term that accounts for the flow direction

$s(i, node(i, k))$ = $sign(p_i - p_j)$

=+1 for $p_i \geq p_j$

=-1 for $p_i < p_j$

k = index for NCE's attached to i^{th} node

$m(i)$ = number of NCE's connected to i^{th} node via k^{th} NCE attached to that node

q = flow from node (i) to node $(node(i, k))$

Flows into the node are considered positive, flows out of the node are negative. F_i, thus represents the flow imbalance at the node and will be equal to zero when system in balance.

For example consider node 2 shown below in Figure 5.1. Eq. 5.4 for node 2 can now be written as

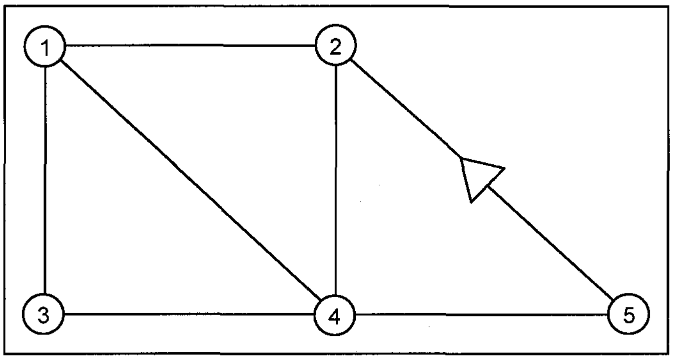

Figure 5.1. An Example Network

$$F_2 = s_{2,1}Q_{2,1} + s_{2,4}Q_{2,4} + s_{2,5}Q_{2,5} + Q_2 \tag{5.05}$$

With the substitution of the appropriate NCE equations (by using Eq. 3.28 and C.12), Eq. 5.5 becomes:

$$F_2 = s_{2,1}C_{2,1}\left(P_2^2 - P_1^2\right)^{0.5} + s_{2,4}C_{2,4}\left(P_2^2 - P_4^2\right)^{0.5} + s_{2,5}\frac{HP_{2,5}}{a_{2,5}\left(\frac{P_2}{P_5}\right)^{b_{2,5}} - c_{2,5}} + Q_2 \tag{5.06}$$

where $s_{i,}$'s represents flow direction from node *i* to *j*, c_j's are constants for corresponding pipelegs, *a*, *b* and *c* are compressor constants.

Similar equations are written for all the other nodes in the system. Consider a system of *n* nodes and *m* NCE's. Steady state flow through this system of *n* nodes is mathematically represented by a system of non-linear equations. There are a total of *(2n+m)* variables: for each node, there is one pressure and node flow rate variable, and for each NCE there is an adjustable parameter (for pipes "diameter", for pressure regulators "choke size", for compressors "horsepower"). Thus we can use this model consisting of *n* equations in *(2n+m)* variables to solve for any *n* variables, provided that the values of the remaining *(n+m)* variables are known.

Each of the node continuity equations, such as Eq. 5.6, can be expressed as follows:

$$F_1(x_1, x_2, \ldots, x_n) = 0; \quad i = 1, \ldots, n \tag{5.07}$$

Szilas proposed to solve this non-linear system of equations using Newton-Raphson iteration technique [8]. The values of the unknowns are computed repeatedly, until the values from any two successive steps converge. The values of any unknown at new iteration level is computed as follows:

$$x_i^{new} = x_i^{old} + \Delta x_i^{new} \tag{5.08}$$

where

$$\sum_{i=1}^{n} \frac{\delta F_i}{\delta x_k} \Delta x_k = -F_i; \quad i = 1,\ldots,n \tag{5.09}$$

The dF_i/dx_k are the values of the derivatives of the node continuity equations taken at the x_is calculated in foregoing step of iteration. The Newton-Raphson method requires that the initial values $x_i^{(1)}$ of the unknowns x_i be estimated. The convergence behavior of the iteration will depend on a significant degree on the goodness of these estimates, even in a fairly simple system. According to Stoner's proposition [8] a suitable acceleration factor ensuring a good rate of convergence, α_i, can be written in the form

$$x_i^{new} = x_i^{old} + \Delta x_i^{new} \alpha_i \tag{5.10}$$

The value of α_i can be expressed in terms of the actual and the foregoing corrections Δx_i as follows. Let

$$A_i = \frac{\Delta x_i^{new}}{\Delta x_i^{old}} \tag{5.11}$$

$a_i = 0.5|A_i|$, if $A_i \leq 1$,

$a_i = 1.0 - 0.5|Ai|$; if $-1 < A_i < 0$,

$a_i = 1.0 + 2.0|Ai|$; if $0 < A_i < 1$,

$a_i = 3$, if $A_i \geq 3$

To illustrate this method, let's apply it on a network shown in Figure 5.2 given with unknowns. In this example, pressures at nodes 1 and 4, nodal flows at nodes 1 and 5, and horsepower of compressor between node 2 and 5 are unknowns.

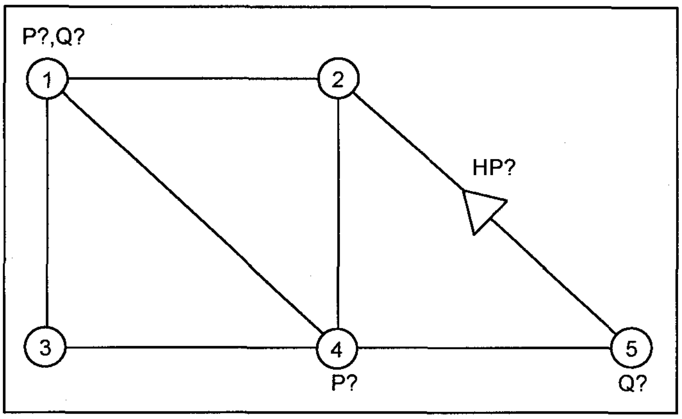

Figure 5.2 Example Network With Unknowns

This system is iteratively solved by using the following matrix which results from the linearization (in consideration of Newton-Raphson method) of non-linear continuity equations.

$$\begin{bmatrix} \frac{\partial F_1}{\partial Q_1} & \frac{\partial F_1}{\partial P_1} & \frac{\partial F_1}{\partial P_4} & & \\ & \frac{\partial F_2}{\partial P_1} & \frac{\partial F_2}{\partial P_4} & \frac{\partial F_2}{\partial HP} & \\ & \frac{\partial F_3}{\partial P_1} & \frac{\partial F_3}{\partial P_4} & & \\ & \frac{\partial F_4}{\partial P_1} & \frac{\partial F_4}{\partial P_4} & & \\ & & \frac{\partial F_5}{\partial F_4} & \frac{\partial F_5}{\partial HP} & \frac{\partial F_5}{\partial Q_5} \end{bmatrix} \begin{bmatrix} \Delta Q_1 \\ \Delta P_1 \\ \Delta P_4 \\ \Delta HP \\ \Delta Q_5 \end{bmatrix} = -\begin{bmatrix} F_1 \\ F_2 \\ F_3 \\ F_4 \\ F_5 \end{bmatrix}$$

Figure 5.3 Matrix form of the System Illustrated in Figure 5.2

In general Figure 5.3 can be shown in matrix notation as below:

$$[J][\Delta Y] = -[F] \tag{5.12}$$

Let y_j denote these those parameters whose changes we are interested in, after other m parameters of the system, denoted x_j in their turn, have been changed. In this notation, the non-linear system of equations resembling Eq. 5.6, constituting the model of the system, can be written in the form

$$F_J(y_1, y_2, \ldots, y_n; x_1, x_2, \ldots x_m) = 0 \quad j = 1, 2, \ldots, n. \tag{5.13}$$

The Taylor series expansion of the function F_j, with all but the linear terms dropped, is

$$\sum_{i=1}^{n} \frac{\partial F_j}{\partial y_i} dy_i + \sum_{i=1}^{m} \frac{\partial F_j}{\partial x_i} dx_i = 0; \; j = 1,2,\ldots,n \tag{5.14}$$

Each of the two sets of derivatives, $\partial F/\partial y_i$ and $\partial F/\partial x_i$, formally identical with the derivatives figuring in Eq. 5.9 can be rearranged as forming a matrix:

$$J = \begin{bmatrix} \frac{\partial F_1}{\partial y_1} & \cdots & \frac{\partial F_1}{\partial y_n} \\ \vdots & & \vdots \\ \frac{\partial F_n}{\partial y_1} & \cdots & \frac{\partial F_n}{\partial y_n} \end{bmatrix} \tag{5.15}$$

$$C = \begin{bmatrix} \frac{\partial F_1}{\partial x_1} & \cdots & \frac{\partial F_1}{\partial x_m} \\ \vdots & & \vdots \\ \frac{\partial F_n}{\partial x_1} & \cdots & \frac{\partial F_n}{\partial x_m} \end{bmatrix} \tag{5.16}$$

Using these identities, Eq. 5.14 may be rewritten in matrix notation as

$$Jdy + Cdx = 0 \tag{5.17}$$

which after rearranging becomes

$$dx = -J^{-1}Cdx \tag{5.18}$$

where J^{-1} is the inverse of J. The matrix resulting from the multiplication $-J^{-1}C$ is so-called sensitivity matrix of the system, to be denoted by the symbol $[d_y/d_x]$. It is a measure of change in the parameters y_i resulting from unity changes in the parameters x_i, provided that the node continuity equations, Eq. 5.5, is satisfied for every node. It suffices to determine by a simple matrix multiplication the change in the parameters y_j of the system, resulting from any change in the parameters x_i, represented by the vector Δx:

$$\Delta y = \left[\frac{dy}{dx}\right]\Delta x \tag{5.19}$$

In spite of the fact that Stoner's method can handle all kinds of node connecting elements, solution of the system of non-linear equations resulted in the application of it is rather complicated.

CHAPTER VI

NETWORK SIMULATION

In many cases distribution companies which deliver the gas commit a minimum pressure value and a certain flow rate to the user. Since all the facility and equipment used by the customers designated to work with that pressure it is important to keep the pressure and the flow rate at the user-end within a certain range. In cases where gas is supplied via a network there exist many customers with different flow rates and minimum - maximum pressure requirements.

Throughout this chapter finite differences equations for isothermal steady state horizontal flow have been introduced. By using these equations a simple simulation program that calculates the pressures for given flow rates has been developed.

6.1. Design Fundamentals in Natural Gas Distribution Networks

The characteristic equation that gives pressure drop in pipes as follows:

$$p_1^2 - p_2^2 = k_1 q^2 \tag{6.01}$$

or

$$q = \left[\frac{p_1^2 - p_2^2}{k_1}\right]^{0.5} \tag{6.02}$$

6.1.1. Low Pressure Networks

In a low pressure pipe leg, with pressure close to atmospheric, we have $z_{av}=1$ and

$$p_1^2 - p_2^2 = (p_1 + p_2)(p_1 - p_2) \cong 2p_{sc}(p_1 - p_2) \tag{6.03}$$

accordingly above equations can be modified to

$$p_1 - p_2 = k_2 q^2 \tag{6.04}$$

and

$$q = \left[\frac{p_1 - p_2}{k_2}\right]^{0.5} \tag{6.05}$$

where

$$k_2 = \frac{k_1}{2p_{sc}} \tag{6.06}$$

The coefficients of k_1 and k_2 vary depending on the unit systems employed. In SI units k_1 and k_2 are given by the following equations,

$$k_1 = 1.95x10^{-4}\left(\frac{p_n}{T_n}\right)^2 \frac{MT_{av}z_{av}fl}{d^5} \tag{6.07}$$

$$k_2 = 0.975x10^{-4}\,\frac{p_{sc}T_{av}Mf}{T_{sc}^2}\,\frac{l}{d^5} \tag{6.08}$$

where

P= Pressure, Pa (N/m^2)

T= Absolute temperature, °K

l= Length of pipe, m

M= molar weight of the gas mixture, kg/kg mole

d= diameter of pipe, m.

In Field units k_1 and k_2 are

$$k_1 = 0.031489\left(\frac{p_{sc}}{T_{sc}}\right)^2 \frac{T_{av} z_{av} \gamma_g fl}{d^5} \tag{6.09}$$

$$k_2 = 0.015744 \frac{p_{sc} T_{av} \gamma_g f}{T_{sc}^2} \frac{l}{d^5} \tag{6.10}$$

where

P= pressure, psia

T= Absolute temperature, °R

g= Specific gravity, (air = 1 basis)

L= Length of pipe, ft

d= diameter of pipe, ft.

In computer programs NETLOW and NETHIGH SI units are employed for the simplicity of comparison with the references.

Weymouth [4] defined friction factor in terms of pipe diameter as follows:

$$f = \frac{0.009407}{d^{1/3}} \tag{6.11}$$

Eq. 6.11 gives rather accurate results for pipes with small to medium size diameters. Substituting Eq. 6.11 in Eq. 6.8, we have in SI units,

$$k_2 = 917.1825x10^{-9} \frac{p_{sc} M T_{av}}{T_{sc}^2} \frac{l}{d^{16/3}} \tag{6.12}$$

Under isothermal flow regime the product, $917.1825x10^{-9} P_{SC} MT_{av} / T_{SC}^2$ can be assumed constant. Letting c denote such product, we obtain

$$k_1 = c \frac{l}{d^{16/3}} \tag{6.13}$$

Let $k_{ij} = c\, P_{ij} / D_{ij}^{16/3}$, where the subscripts ij now emphasize that we are concerned with the pipe joining nodes i and j. The flow rate Q_{ij} between nodes i and j is then given by

$$(p_i - p_j) = k_{ij} Q_{ij}^2 \tag{6.14}$$

Above Equation can be solved for Q_{ij} as follows

$$Q_{ij} = \sqrt{\frac{(p_i - p_j)}{k_{ij}}} \tag{6.15}$$

in which Q_{ij} is positive or negative for flow from *i* to *j* or vice versa. In the following version, computer program will yield the correct sign for Q_{ij} whilst it does not produce any domain error because the difference $(P_i - P_j)$ is under absolute value security

$$Q_{ij} = (p_i - p_j)\sqrt{\frac{1}{k_{ij}\left|p_i - p_j\right|}} \tag{6.16}$$

at any free node *j*, where the pressure is not specified, the sum of flows from neighboring nodes *i* must be zero:

$$\sum_i Q_{ij} = \sum_i (p_i - p_j)\sqrt{\frac{1}{k_{ij}\left|p_i - p_j\right|}} = 0 \tag{6.17}$$

In case of intake or offtake, Q_j in node *j* that must be included with consistent sign in above equation.

$$Q_{ij} = -Q_j \tag{6.18}$$

When applied at all free nodes, Eq. 6.17 yields a system of nonlinear simultaneous equations in the nodes with unknown pressures. This system can be solved by successive-substitution type of method. Eq. 6.17 can be solved to obtain P_j as follows

$$p_j = \frac{\sum_i a_{ij} p_i + Q_j}{\sum_i a_{ij}} \tag{6.19}$$

in which

$$a_{ij} = \left(k_{ij}\left|p_i - p_j\right|\right)^{-1/2} \tag{6.20}$$

Eq. 6.19. is applied repeatedly at all free nodes until either each computed pressure P_j does not change by more than a small amount of iterations to the next, or a preassigned number of iterations has been exceeded. The most recently estimated values of P_j will always be used in the right-hand side of Eq. 6.19.

6.1.2. High Pressure Networks

In a high pressure pipe leg, pressure drops and flow rate in pipe can be calculated with Eqs. 6.1 and 6.2. For the flow rate Q_{ij} between nodes *i* and *j*, Eq. 6.2 can be rewritten as,

$$Q_{ij} = \sqrt{\frac{(p_i^2 - p_j^2)}{k_{ij}}} \tag{6.21}$$

where k_{ij} equals, in SI units,

$$k_{ij} = 0.975x10^{-4}\,\frac{p_{sc}T_{av}Mf}{T_{sc}^2}\,\frac{l_{ij}}{d_{ij}^5} \tag{6.22}$$

and in field units,

$$k_{ij} = 0.015744\,\frac{p_{sc}T_{av}\gamma_g f}{T_{sc}^2}\,\frac{l}{d_{ij}^5} \tag{6.23}$$

Eq. 6.21 can be rearranged as

$$Q_{ij} = \left(p_i^2 - p_j^2\right)\sqrt{\frac{1}{k_{ij}\left|p_i^2 - p_j^2\right|}} \tag{6.24}$$

Letting *aij* denote $1/(k_{ij}\,|p_i^2 - p_j^2|)^{0.5}$, we have

$$Q_{ij} = \left(p_i^2 - p_j^2\right)a_{ij} \tag{6.25}$$

We can solve Eq. 6.21 for P_j while taking into consideration the individual intake or offtake, Q_j, in node *j*

$$p_j = \sqrt{\frac{\sum_i a_{ij} p_i^2 + Q_j}{\sum_i a_{ij}}} \tag{6.26}$$

In order to avoid any domain error we multiply the nominator and denominator of the expression in the square root with the product $(P_i^2 a_{ij} + Q_j)$ while keeping the consistent sign of Eq. 6.26 unchanged.

$$p_j = \left(\sum_i a_{ij} p_i^2 + Q_j\right) \sqrt{\frac{1}{\sum_i a_{ij}\left(\sum_i a_{ij} p_i^2 + Q_j\right)}} \tag{6.27}$$

Eq. 6.27 is the final expression repeatedly applied all nodes until the difference between P_j^{new} and P_j^{old} meets the convergence criteria, *e*.

6.2. Simulators NETLOW and NETHIGH

Two computer programs, calculating the pressure distribution of a given network, have been developed in FORTRAN 77 computer programming language in the frame of the expressions given in sections 6.1.1. and 6.1.2. The results of such programs have been compared with the example network analysis given by Szilas [8]. NETLOW is based on the low pressure assumption (Eqs. 6.3-20), whereas NETHIGH have been developed for high pressure networks (Eqs. 6.21-27). Algorithm of NETLOW and NETHIGH is explained in the following sections.

6.2.1. Simulating Interconnected Nodes

In NETLOW and NETHIGH, interconnected nodes are defined by a logical variable, *"incid"*, which has two dimensions representing the i^{th} nodes and j^{th} nodes. Such information can be stored in a data file or declared in a data statement. The latter is the way preferred in NETLOW and NETHIGH. For interconnected nodes the value of *incid(i, j)* is "True" which means such nodes must be included in computation. If two node do not have no a direct connection, i.e., there is no any NCE's between them the value of *incid(i, j)* "False", and they are not included in the computation. For a network illustrated in Figure 6.1, values of *incid(i, j)* that would be assigned by NETLOW or NETHIGH are listed in Table 6.1.

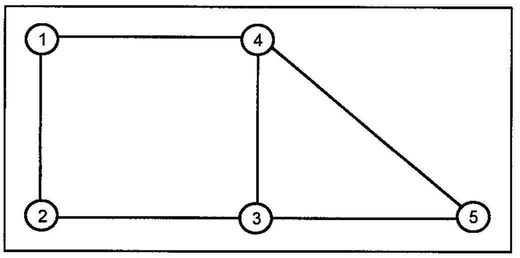

Figure 6.1. An example Network

Table 6.1. Values of Incid(i,j) for the Network given in Figure 6.1

Nodes i/j	1	2	3	4	5
1	FALSE	TRUE	FALSE	TRUE	FALSE
2	TRUE	FALSE	TRUE	FALSE	FALSE
3	FALSE	TRUE	FALSE	TRUE	TRUE
4	TRUE	FALSE	TRUE	FALSE	TRUE
5	FALSE	FALSE	TRUE	TRUE	FALSE

6.2.2. Calculation of Average Pressure, P_{av}

In high pressure networks where *Z*-factor is taken to be a function of pressure it is clear that for every infinitesimal part of the pipe it is possible to calculate a different *Z*-factor value due to the changing pressure profile in the pipe. In such cases an average *Z*-factor that is representative for whole pipe segment can be calculated using the average pressure, P_{av}. The derivation of P_{av} is as follows.

Considering the pipeline illustrated in Figure 6.2. we can rearrange Eq. 6.5. as

$$q = \left[\frac{p_1 - p_2}{k_3 Lx} \right]^{0.5} \tag{6.28}$$

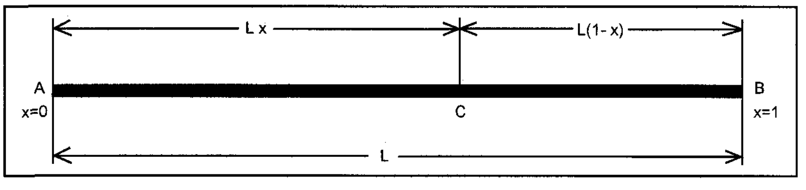

Figure 6.2. Pipeline of Length L

Using Eq. 6.28. for gas flow, we can calculate the pressure at any point *C* along the pipeline at a fractional distance *x* from the inlet end. For a flow rate *q* in the pipe, the following two relationships will give the same result.

$$q = \left[\frac{p_1 - p_x}{k_3 L x} \right]^{0.5} \tag{6.29}$$

$$q = \left[\frac{p_x - p_2}{k_3 L (1-x)} \right]^{0.5} \tag{6.30}$$

Equating Eq. 6.29. and Eq. 6.30. (with the assumption that the difference in Z_{av} for two pipe sections is negligible), we obtain:

$$\frac{p_1^2 - p_x^2}{x} = \frac{p_x^2 - p_2^2}{(1-x)} \tag{6.31}$$

Solving Eq. 6.31. for P_X:

$$p_x = \left[p_1^2 - x\left(p_1^2 - p_2^2\right) \right]^{0.5} \tag{6.32}$$

This suggests a pressure profile as shown in Figure 6.3. The mean pressure is given by:

$$p_{av} = \left(\frac{1}{1-0} \right) \int_0^1 p_x dx = \left(\frac{1}{1-0} \right) \int_0^1 \left[p_1^2 - x\left(p_1^2 - p_2^2\right)^{0.5} \right] dx \tag{6.33}$$

Integration in Eq. 6.33. equals

$$p_{av} = \frac{2}{3} \left(p_1 + \frac{p_2^2}{p_1 + p_2} \right) \tag{6.34}$$

or

$$p_{av} = \frac{2}{3} \left(\frac{p_1^3 - p_2^3}{p_1^2 - p_2^2} \right) \tag{6.35}$$

where

p_{av}= average pressure

p_1= upstream pressure

p_2= downstream pressure.

For a pipeline shown in Figure 6.2. pressure distributions along the line for different P_1/P_2's (Upstream / Downstream ratios) are shown in Figure 6.3.

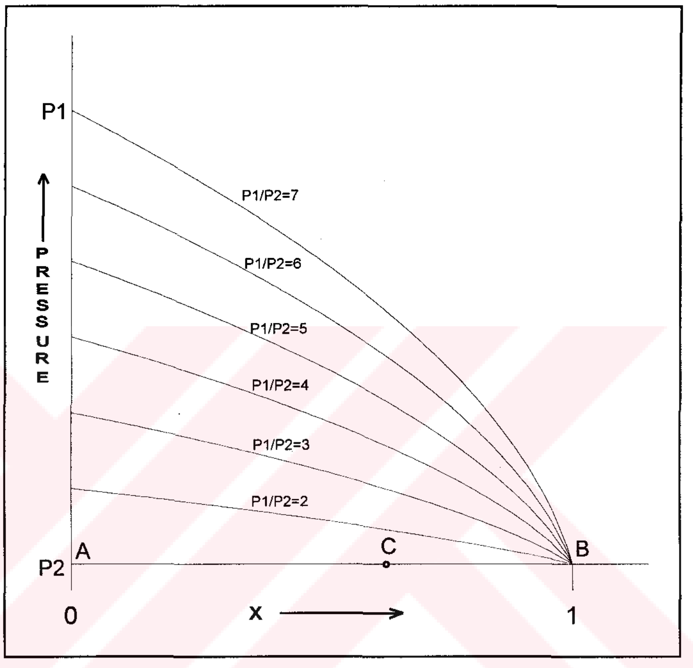

Figure 6.3. The Plot of pressure versus distance in a pipeline carrying gas.

6.2.3. A Sample Network Analysis

The layout of the low pressure network given in reference [8] is shown in Figure 6.4. In the network illustrated in Figure 6.4. flow rates for all nodes, pressure in node *1*, *P(1)*, are given and rest of the pressures, *P(2)* .. *P(9)*, are unknown.

Running NETLOW to analyze given network we obtain the following output:

====== INITIAL INFORMATION ABOUT NETWORK =======

# of Nodes 9

Max. iterations allowed 1000

Convergence Criteria .0010

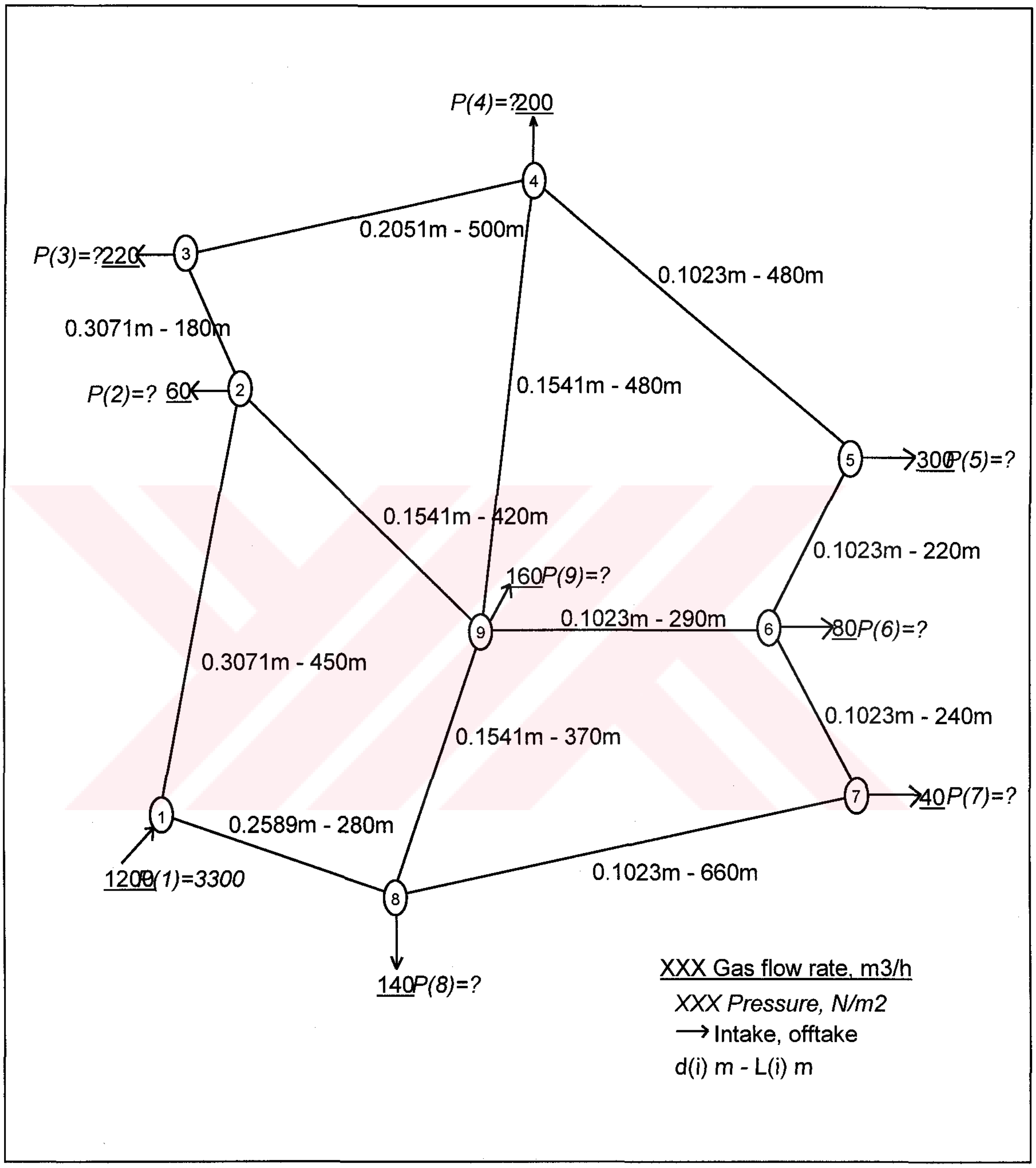

Figure 6.4. A Gas Network System with 9 nodes and 12 NCE's (Ref. [8])

I	P(I)	PGIVEN(I)
1	3300.00	T
2	2500.00	F
3	1000.00	F
4	1500.00	F
5	2000.00	F
6	2100.00	F
7	1600.00	F
8	1700.00	F
9	1800.00	F

INCID(1, 1)...INCID(1, 9) = F T F F F F F T F
INCID(2, 1)...INCID(2, 9) = T F T F F F F F T
INCID(3, 1)...INCID(3, 9) = F T F T F F F F F
INCID(4, 1)...INCID(4, 9) = F F T F T F F F T
INCID(5, 1)...INCID(5, 9) = F F F T F T F F F
INCID(6, 1)...INCID(6, 9) = F F F F T F T F T
INCID(7, 1)...INCID(7, 9) = F F F F F T F T F
INCID(8, 1)...INCID(8, 9) = T F F F F F T F T
INCID(9, 1)...INCID(9, 9) = F T F T F T F T F

D(1, 1)...D(1, 9) =	.0000	.3071	.0000	.0000	.0000	.0000	.0000	.2589	.0000
D(2, 1)...D(2, 9) =	.3071	.0000	.3071	.0000	.0000	.0000	.0000	.0000	.1541
D(3, 1)...D(3, 9) =	.0000	.3071	.0000	.2051	.0000	.0000	.0000	.0000	.0000
D(4, 1)...D(4, 9) =	.0000	.0000	.2051	.0000	.1023	.0000	.0000	.0000	.1541
D(5, 1)...D(5, 9) =	.0000	.0000	.0000	.1023	.0000	.1023	.0000	.0000	.0000
D(6, 1)...D(6, 9) =	.0000	.0000	.0000	.0000	.1023	.0000	.1023	.0000	.1023
D(7, 1)...D(7, 9) =	.0000	.0000	.0000	.0000	.0000	.1023	.0000	.1023	.0000
D(8, 1)...D(8, 9) =	.2589	.0000	.0000	.0000	.0000	.0000	.1023	.0000	.1541
D(9, 1)...D(9, 9) =	.0000	.1541	.0000	.1541	.0000	.1023	.0000	.1541	.0000

L(1, 1)...L(1, 9) =	.00	450.00	.00	.00	.00	.00	.00	280.00	.00
L(2, 1)...L(2, 9) =	450.00	.00	180.00	.00	.00	.00	.00	.00	420.00
L(3, 1)...L(3, 9) =	.00	180.00	.00	500.00	.00	.00	.00	.00	.00
L(4, 1)...L(4, 9) =	.00	.00	500.00	.00	480.00	.00	.00	.00	480.00
L(5, 1)...L(5, 9) =	.00	.00	.00	480.00	.00	220.00	.00	.00	.00
L(6, 1)...L(6, 9) =	.00	.00	.00	.00	220.00	.00	240.00	.00	290.00
L(7, 1)...L(7, 9) =	.00	.00	.00	.00	.00	240.00	.00	660.00	.00
L(8, 1)...L(8, 9) =	280.00	.00	.00	.00	.00	.00	660.00	.00	370.00
L(9, 1)...L(9, 9) =	.00	420.00	.00	480.00	.00	290.00	.00	370.00	.00

ITER PRESSURE AT NODE

	1	2	3	4	5	6	7	8	9
1	3300.0000	2040.1207	1883.2065	1795.6701	1741.1382	1649.6899	1638.1970	2444.7127	1844.3933
2	3300.0000	2117.1478	2021.0034	1866.6468	1496.0055	1617.3807	1668.1690	2903.4925	1970.0705
3	3300.0000	2197.1179	2123.0510	1966.4195	1391.3324	1608.8346	1723.5131	3067.4405	2021.5962

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179	3300.0000	3245.2373	3234.3412	3144.3525	2275.5933	2618.3792	2700.2440	3270.8992	3151.4836
180	3300.0000	3245.2379	3234.3419	3144.3532	2275.5944	2618.3802	2700.2449	3270.8993	3151.4843
181	3300.0000	3245.2384	3234.3425	3144.3539	2275.5954	2618.3812	2700.2457	3270.8994	3151.4849

PRESSURE AND INTER-NODAL FLOWS AFTER 181 ITERATIONS ARE

I	P(I) [Pa]	Q(I, 1)...Q(I, 9) [m3/h]								
1	3300.0000	.0000	756.5768	.0000	.0000	.0000	.0000	.0000	443.4843	.0000
2	3245.2384	-756.5768	.0000	533.6015	.0000	.0000	.0000	.0000	.0000	162.9425
3	3234.3425	.0000	-533.6015	.0000	313.5846	.0000	.0000	.0000	.0000	.0000
4	3144.3539	.0000	.0000	-313.5846	.0000	155.6152	.0000	.0000	.0000	-42.0358
5	2275.5954	.0000	.0000	.0000	-155.6152	.0000	-144.3853	.0000	.0000	.0000
6	2618.3812	.0000	.0000	.0000	.0000	144.3853	.0000	-67.5562	.0000	-156.8303
7	2700.2457	.0000	.0000	.0000	.0000	.0000	67.5562	.0000	-107.5567	.0000
8	3270.8994	-443.4843	.0000	.0000	.0000	.0000	.0000	107.5567	.0000	195.9264
9	3151.4849	.0000	-162.9425	.0000	42.0358	.0000	156.8303	.0000	-195.9264	.0000

6.2.4. Results and Conclusion

In Table 6.2. the resulting pressure distribution for the given network is shown. The differences between the pressure values calculated by Szilas and the ones calculated by NETLOW are so small that they are negligible. The highest difference value is 2 Pa. (0.039 psi.) This may arise from many reasons, such as, convergence criterion chosen, precision difference between manual and machine calculation.

Based on results obtained from NETLOW, it can be concluded that this computer program will produce accurate results for different network problems and it can be used to analyze larger networks involving more unknown variables.

However NETLOW and NETHIGH are far from being able to resolve every problem faced with while making the design of a distribution network. A complete network simulation program must be able to calculate the minimum and maximum pressure values with given flow rates or on the contrary it must be able to compute the flow rates with given pressures. It must also be capable to determine the optimum pipe diameter, calculate the required horse power for a given compressor, add or remove compressor stations and / or pressure control valves and regulators in accordance with the given data and requirements.

Table 6.2. Comparison of Network Analysis Results

			Ref: [8]		NETLOW	
NODE #	Q(i) (m3/sn)	p(i) (Pa)	Q(i) (m3/sn)	p(i) (Pa)	Q(i) (m3/sn)	p(i) (Pa)
1	1200	3300	1200	3300	1200	3300
2	-60	?	-60	3246	-60	3245
3	-220	?	-220	3235	-220	3234
4	-200	?	-200	3146	-200	3144
5	-300	?	-300	2278	-300	2276
6	-80	?	-80	2622	-80	2618
7	-40	?	-40	2702	-40	2700
8	-140	?	-140	3277	-140	3271
9	-160	?	-160	3152	-160	3152

PIPELEGS	Ref: [8]	NETLOW
NODE (ij)	Q(ij) (m2/sn)	Q(ij) (m2/sn)
1-2	0.20960	0.21020
2-1	-0.20960	-0.21020
2-3	0.14762	0.14820
3-2	-0.14762	-0.14820
3-4	0.08711	0.08651
4-3	-0.08711	-0.08651
4-5	0.04322	0.04315
5-4	-0.04322	-0.04315
5-6	0.04011	-0.04018
6-5	-0.04011	0.04018
6-7	0.01878	-0.01888
7-6	-0.01878	0.01888
1-8	-0.12320	-0.12373
8-1	0.12320	0.12373
7-8	-0.02988	-0.02999
8-7	0.02988	0.02999
2-9	0.04526	0.04532
9-2	-0.04526	-0.04532
4-9	-0.01168	-0.01220
9-4	0.01168	0.01220
6-9	-0.04356	-0.04353
9-6	0.04356	0.04353
8-9	0.05442	0.05486
9-8	-0.05442	-0.05486

CHAPTER VII

ECONOMIC EVALUATION METHODS

7.1. THE CONCEPT OF ECONOMIC EVALUATION

Alternatives producing the similar results, serving the same purposes or accomplishing the same functions should be compared insofar possible. Such comparisons can be done by reducing the alternatives to an equivalent basis that dependent on the;

1. Interest rate,
2. Amounts of money involved,
3. Timing of the monetary receipts and/or disbursements,
4. Manner in which the interest, or profit, on invested capital is repaid and the initial capital recovered.

In order to have a better understanding of the mechanics of interest let's take a simple case in which we should prefer one of the four plans of borrowing. In each of the options interest rate is 10% and the original amount borrowed is $ 8000, thus, differences among the items rest with the item (3) and (4) above.

In Plan (1) that $ 2000 of the loan principal is repaid at the end of each years 1 through 4. As a result, the interest we repay at the end of a particular year is affected by how much we still owe on the loan at the beginning of that year. Our end-of-year payment is just the sum of $ 2000 and interest paid on the beginning-of-year amount owed.

Plan 2 indicates that none of the loan principal is repaid until the end of fourth year. Interest that costs the same amount each year is repaid at the end of every year (years 1 through 4). Notice that in either of the above plans interest that has been accrued is being reimbursed, so compounding interest is not present.

Plan 3 requires that we repay equal end-of-year amounts of $ 2,524 each.

Finally in Plan 4 no interest and no principal are repaid for the first 3 years of the loan period. Then, at the end of the fourth year, the original loan principal plus accumulated interest for the four years is repaid in single lump-sump amount of $ 11,712.80. Both plans 3 and 4 involve compound interest.

The necessity of comparison of above mentioned four plans while choosing one of them brings us to the concept of economic equivalence.

If interest rates remain constant 10% for the plans shown in Table 7.1, all four plans are equivalent. This assumes one can freely borrow and lend at the 10% rate. Hence we would be indifferent about whether the principal is repaid early in the loan's life (e.g., plans 1 and 3) or repaid at the end of the year 4 (e.g., Plans 2 and 4). Economic equivalence is established, in general, when we are indifferent a future payment, or series of future payments, and a present sum of money.

To see why the four plans shown in Table 7.1 are equivalent at 10%, we can plot the amount owed at the beginning of each year (Column 2) versus the years. The area under the resultant curve represents the dollar-years that the money is owed.

When total dollar-years are calculated for each plan and divided into total interest paid over the four years (the sum of Column 3 in Table 7.1), the ratio is proved to be constant as shown in Table 7.2.

Since the ratio is constant at 0.1 for all plans, we can deduce that all repayment options considered in Table 7.2. are equivalent even though each involves a different total end-of-year payment in Column 6. Dissimilar dollar-years of borrowing, by itself, does not necessarily allow one to conclude that different loan repayment plans are equivalent or not equivalent. In summary, equivalence is established when total interest paid, divided by dollar-years of borrowing, is a constant ratio among financing plans.

7.2. METHODS FOR ASSESSING ECONOMIC WORTH

All evaluation procedures of capital projects should consider the return that a given project will or should produce. Project evaluation methods search whether a proposal capital investment and its associated investment expenditures can be recovered by revenues (or savings) over time in addition to a return on the capital that is sufficiently attractive in view of risks involved and potential alternative uses.

Table 7.1. Four Different Borrowing Scenarios

YEARS	AMOUNT OWED AT BEGINNING OF YEAR	INTEREST ACCRUED FOR YEAR	TOTAL MONEY OWED AT END OF YEAR	PRINCIPAL PAYMENT	TOTAL END-OF-YEAR PAYMENT
(I)	(II)	(III=10% x II)	(IV=II+V)	(V)	(VI=III+V)
Plan 1: At End of each Year Pay $ 2,000 Principal Plus Interest Due					
1	$8,000	$800	$8,800	$2,000	$2,800
2	6,000	600	6,600	2,000	2,600
3	4,000	400	4,400	2,000	2,400
4	2,000	200	2,200	2,000	2,200
	20,000 $-yr	$2,000 (total interest)		$8,000	$10,000 (total amount repaid)
Plan 2: Pay Interest Due at the End of Each Year and Principle at the End of Four Years					
1	$8,000	$800	$8,800	$0	$800
2	8,000	800	8,800	0	800
3	8,000	800	8,800	0	800
4	8,000	800	8,800	8,000	8,800
	32,000 $-yr	$3,200 (total interest)		$8,000	$11,200 (total amount repaid)
Plan 3: Pay In 4 Equal End-of-Year Payments					
1	$8,000	$800	$8,800	$1,724	$2,524
2	6,276	628	6,904	1,896	2,524
3	4,380	438	4,818	2,086	2,524
4	2,294	229	2,524	2,294	2,524
	20,951 $-yr	$2,095 (total interest)		$8,000	$10,095 (total amount repaid)
Plan 4: Pay Principle and Interest in One Payment at End of Four Year					
1	$8,000	$800	$8,800	$0	$0
2	8,800	880	9,680	0	0
3	9,680	968	10,648	0	0
4	10,648	1,065	11,713	8,000	11,713
	37,128 $-yr	$3,713 (total interest)		$8,000	$11,713 (total amount repaid)

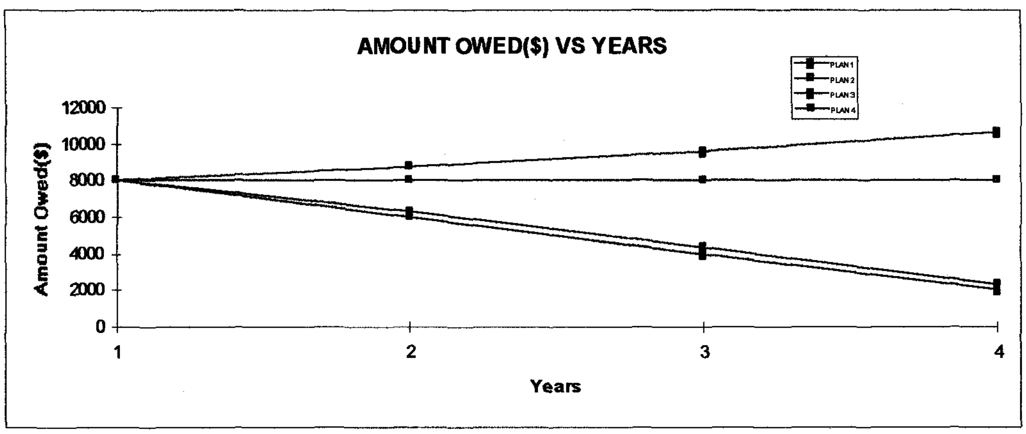

Figure 7.1. Amount Owed vs. Time for Four Different Borrowing Scenarios

Table 7.2. Ratio of Total Interest to be Paid for Four Different Borrowing Plans

PLAN #	AREA UNDER CURVE (dollar-years)	TOTAL INTEREST PAID	RATIO OF TOTAL INTEREST to DOLLAR-YEARS
1	$20,000	2000	0.10
2	$32,000	3200	0.10
3	$20,951	2095	0.10
4	$37,128	3713	0.10

Because patterns of capital investment, revenues (or savings), cash flows, and cost cash flows can be quite different in various projects, there is no single method for performing engineering economic analysis that is ideal for all cases. Consequently, several methods are commonly used in practice. All produce equally satisfactory results and lead to the same decision in cases where inherent assumptions of each method are applicable.

In practice commonly used evaluation methods can be classified in two groups;

1. Equivalent Worth Methods

1.1. Present Worth Method (PW)

1.2. Annual Worth Method (AW)

1.3. Future Worth Method (FW)

2. Rate of Return Methods

2.1. Internal Rate of Return (IRR)

2.2. External Rate of Return (ERR)

Equivalent rate methods convert all cash flows into equivalent worths at the same rate equal to the *minimum attractive rate of return* (MARR). Establishing the MARR as the interest rate to be used for discounting purposes within an organization is usually a policy issue resolved by management based on a number of considerations.

These considerations include (1) the number of potential projects (investment opportunities), (2) the availability, source, and cost of capital funds; and (3) the perceived risk associated with the investment opportunities. Also, the type of organization involved will affect the selection. In general, the minimum attractive rate of return rates used within government organizations are less than those used by private sector industry.

The MARR, should be chosen to maximize the economic well-being of an organization. However, in practice the MARR is a decision criterion which is provided to the analyst for purposes of evaluating the economic merits of alternative course of action. How explicitly and adeptly an organization specifies its MARR is seldom clear. Determination of the MARR is a critical policy issue that affects the strategic welfare of any enterprise.

The rate of return methods are various ways to calculate an annual rate of profit or savings resulting from an investment so that such annual rate can, in turn, be compared against MARR.

7.2.1. THE PRESENT WORTH METHOD

The present worth (PW) method is based on the concept of equivalent worth of all cash flows relative to some base, usually the beginning point, in time called the present. That is all cash inflows and outflows are discounted to the base point at an interest rate that is generally equals to the MARR [13]. It is also called Present value method.

The present worth of an alternative is a measure of how much money will have to be put aside now to provide for one or more future expenditures. It is assumed that such cash placed in reserve earns interest rate at a rate equal to firm's MARR.

To find the PW of a series of cash receipts and/or expenses, it is necessary to discount future amounts to the present by using an interest rate greater than or equal to MARR for appropriate study period (years, for example) in the following manner.

$$PW = F_0(1+I)^0 + F_1(1+I)^{-1} + F_2(1+I)^{-2} + \dots + F_k(1+I)^{-k} + \dots + F_N(1+I)^{-N} \quad (7.01)$$

where;

i = effective interest rate, or MARR, per compounding period,

k = index for each compounding period ($0 \le k \le N$)

F_k = future cash flow at the end of period k

N = number of compounding periods in the planning horizon.

The relationship given Eq. 7.1. is based on the assumption of a constant interest rate throughout the life of a particular project.

The higher the interest rate and the further into the future a cash flow occurs, the lower is its present worth. This is shown graphically in Figure 7.2. As long as the present worth, PW, (i.e., present equivalent of cash inflows minus cash outflows) is greater than or equal to zero, the project is economically justified, otherwise it is not acceptable.

Example:

An investment of $10,000 can be made in a project that will produce a uniform annual revenue of $5,310 for 5 years and then have a salvage value of $2,000. Annual expense will be $3,000 each year for operation and maintenance. The company is willing to accept any project that will earn an annual return of 10% or more, before income taxes, on all invested capital.

Is this an acceptable investment for the company?

Table 7.3. Present Worth of Investment

	PRESENT WORTH	
	Outflows	**Inflows**
Anual revenue		$20,125
Salvage Value		$1,245
Investment	($10,000)	
Annual Expenses	($11,370)	
Total	($21,370)	$21,370
Total PW		$0
* Since the total PW = $0, the project is marginally acceptable.		

7.2.2. THE ANNUAL WORTH METHOD

The annual worth method (AW) of a project is an uniform annual series of dollar amounts, for a given study period, that is equivalent to the cash inflows (receipts or savings) and/or cash outflows (expenses) under consideration [13]. In other words, the annual worth of a project is its annual equivalent receipts (or savings) ($\underline{R}$), less annual equivalent expenses ($\underline{E}$), less its annual equivalent capital recovery (CR) amount which is defined below. An annual equivalent value of $\underline{R}$, $\underline{E}$, and CR is computed as the MARR. The study period is denoted by N, which is usually years. In equation form the annual worth is

$$AW = \underline{R} - \underline{E} - CR \qquad (7.02)$$

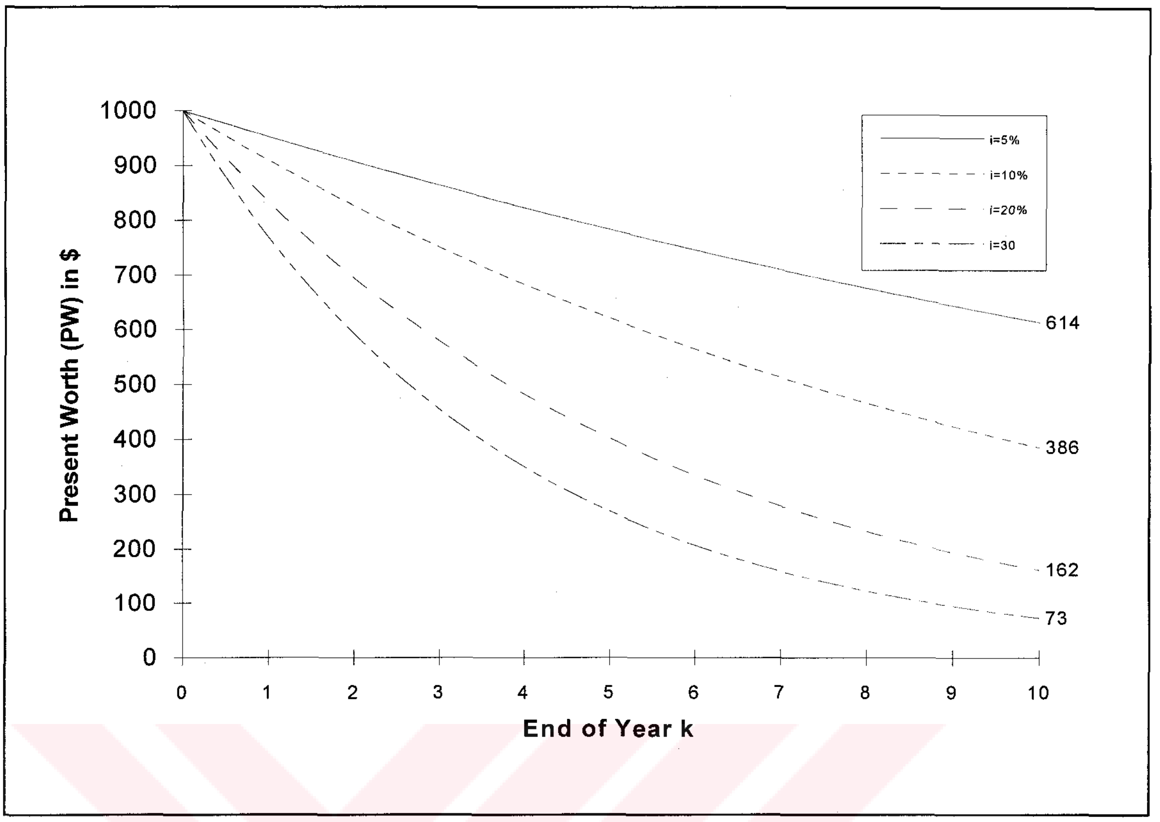

Figure 7.2. Present Worth of Investment for Different Interest Rates

As long as the annual worth is greater than or equal to zero the project is economically attractive; otherwise it is not. An annual worth of zero means that annual return equal to the MARR has been earned.

The capital recovery cost (CR) for a project is the equivalent uniform annual cost of the capital invested. It is an annual amount that covers the following two items:

1. Depreciation (loss in value of the assets).
2. Interest on invested capital (MARR).

Example:

Consider a machine or other asset that will cost $10,000, last 5 years, and have salvage value of $2,000. Further, the interest on invested capital is, i, is 10%. The decrease in asset's value is calculated by straight line depreciation method, the equivalent annual cost of recovery is calculated to be $2,310, as shown in Table 7.4.

There are several convenient formulas by which capital recovery cost may be calculated to obtain the same answer as above. Probably the easiest formula to understand involves finding the annual equivalent of initial investment and then subtracting the annual equivalent of the salvage value.

In some cases where project is spread over several periods, i is taken to be the PW of all investment amounts.

7.2.3. THE FUTURE WORTH METHOD

Because a primary objective of the all time value of money methods is to maximize the future wealth of the owners of the firm, the future worth (FW) criterion has become a widely used method. With this method, the future worth of an alternative can be calculated in view of MARR and compared with do-nothing option. If FW≥0, the alternative would be

Table 7.4. Present Worth of Capital at 10% discount rate

Year	Value of Investment at Beginnin of Year	Straight Line Depreciation	Interest on Beginning-of-Year Investment at i = 10%	Capital Recovery Cost Each Year	Present Worth of Capital Recovery Cost at i = 10%
1	$10,000	$1,600	$1,000	$2,600	$2,364
2	8,400	1,600	840	2,440	2,218
3	6,800	1,600	680	2,280	2,073
4	5,200	1,600	520	2,120	1,927
5	3,600	1,600	360	1,960	1,782
					$10,364
CR cost = $2,310					
				Annual Worth	
				Outflows	Inflows
Annual revenue:					$5,310
Annual Expenses				-$3,000	
CR cost				-2,310	
Total				-$5,310	$5,310
Total AW					$0

recommended. The future worth method is exactly comparable to the present worth method except that all cash inflows and outflows are compounded forward to a reference point in time called the future [13].

To this point the PW, AW, and FW methods have utilized a known constant MARR over the study period. Each method produces a measure of merit expressed in dollars and is equivalent to the other two. On the other hand rate of return methods, Internal Rate of Return and External Rate of Return, produce an interest rate as their measure of merit.

7.2.4. INTERNAL RATE OF RETURN

The internal rate of return, IRR, method is one of the most widely used rate of return method for performing economic analysis. It is commonly called by several other names, such as investor's method, discounted cash flow method, and profitability index.

This method solves for the interest rate that equates the equivalent worth of an alternative's cash inflows (receipts of savings) to the equivalent worth of cash outflows (expenditures, including investments) [13]. Equivalent worth may be computed with any of three methods discussed above. The resultant interest rate is termed the "internal rate of return" (IRR). For a single alternative, the IRR is not positive unless both receipts exceeds the sum of all cash outflows.

The equation for calculating internal rate of return is

$$\frac{R_1}{(1+i')^1}+\frac{R_2}{(1+i')^2}+...+\frac{R_N}{(1+i')^N}=\frac{E_1}{(1+i')^1}+\frac{E_2}{(1+i')^2}+...+\frac{E_N}{(1+i')^N}$$

$$\sum_{k=1}^{N}\frac{R_k}{(1+i')^k}=\sum_{k=1}^{N}\frac{E_k}{(1+i')^k} \qquad (7.03)$$

where ;

R_k = net receipts or savings for the k^{th} year

E_k = net expenditures including investments for k^{th} year

N = project life (study period)

i' = internal rate of return (IRR).

Once i' has been calculated, it is then compared with the MARR to assess whether the alternative in question is acceptable. If i'≥MARR the alternative is acceptable; otherwise, it is not.

A popular variation of Eq. 7.3. to compute the IRR for an alternative is to determine the i' at which its present worth is zero. In equation form' the IRR is the value of i' at which

$$\sum_{k=1}^{N}\frac{R_k}{(1+i')^k}-\sum_{k=1}^{N}\frac{E_k}{(1+i')^k}=0 \qquad (7.04)$$

Example :

The cost of introduction of a better lighting system to the plant is $1,500. System will not only improve most of the other operations but also provide the yearly energy savings respectively Year 1 to Year 5, $ 300, $450, $750, $750, $900. Decide if this investment is an acceptable one given MARR is 25%.

7.2.5. EXTERNAL RATE OF RETURN

It is also called the Modified rate of return (MIRR). The reinvestment assumption of the IRR method may not be valid in some of the investment analysis. For instance, if a firm's MARR is 20% per year and the IRR for a project is 42.2%, it may not be possible for the firm to

Table 7.5. IRR of the Investment

Year	Cash Flow	PV @10%		PV @20%		PV @25%		PV @25.4%	
0	-$1,500	1.000	-$1,500	1.000	-$1,500	1.000	-$1,500	1.000	-$1,500
1	300	0.909	273	0.833	250	0.800	240	0.797	239
2	450	0.826	372	0.694	313	0.640	288	0.636	286
3	750	0.751	563	0.579	434	0.512	384	0.507	380
4	750	0.683	512	0.482	362	0.410	307	0.404	303
5	900	0.621	559	0.402	362	0.328	295	0.322	290
	$1,650		$779		$220		$14		-$1
IRR	25.40%								
MARR	25.00%								
DIFFE	0.40%	Investment is acceptable with the given MARR							

reinvest net cash proceeds from the project at an interest rate much more than 20%. This situation, coupled with the computational demands and possible multiple interest rates associated with the IRR method, has given rise to other rate of return methods, such as the external rate of return (ERR) method, that can remedy some of the weakness.

The ERR method takes into account the external interest rate (ε) at which net cash flows generated (or required) by a project over its life can be reinvested (or borrowed) outside the firm. If this external reinvestment rate happens to equal the project's IRR, then the ERR method produces results identical to those of the IRR method.

In general, all cash outflows are discounted to period 0 (the present) at ε% per compounding period while all cash inflows are compounded to period N at ε%. The external rate of return is then the interest rate that establishes equivalence between the two quantities. In equation form, the ERR is,

$$I(1+i')^N = \sum_{k=1}^{N} R_k (1+\varepsilon)^k - \sum_{k=1}^{N} E_k (1+\varepsilon)^{-k} \quad (7.05)$$

where;

I= Investment amount,

R_k= Net cash inflow (excess of receipts over expenditures in period k)

E_k= Net cash outflow (excess of expenditures over receipts in period k)

N= project life or number of periods for the study

i'= internal rate of return

ε= external reinvestment rate per period

Graphical representation of external rate of return is shown in Figure 7.3.

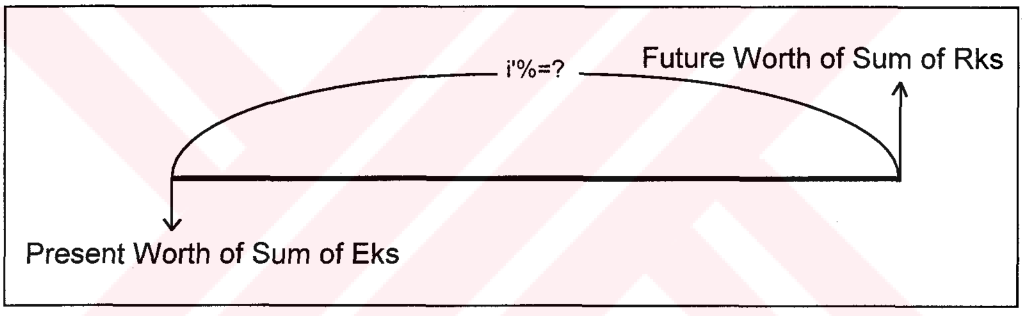

Figure 7.3. Graphical Representation of ERR

A project is acceptable when i'% of the ERR method is greater than or equal to the firm's MARR.

The external rate of return method has two basic advantages over the IRR:

1. It usually can be solved for directly rather than by trial and error.
2. It is not subject to possibility of multiple rates of return that can be resulted in any root finding procedure while solving i' in IRR method.

CHAPTER VIII

A SAMPLE PRE-FEASIBILITY STUDY FOR A CITY NATURAL GAS DISTRIBUTION NETWORK

The aim of this chapter is to present a sample pre-feasibility study that must be carried out by any company which is planning to invest in and run a natural gas distribution network. Data used herein belong to the several different studies made for different cities of Turkey. Therefore, the resulting figures do not correspond any of the cities of Turkey even though they may be the correct values individually. But using the systematic presented here, one can make his own study for a given city.

Study consisted of tables that have been linked to each other. Thus a random modification made in one of the tables would affect all the tables that have a direct or indirect link to that table. The results have been supported by graphs for better understanding.

Many different runs performed using the model prepared in Excel 5.0 for different scenarios and the results displayed in Tables 8.11, 8.12., 8.13., also in Figures 8.6., 8.7., 8.8., 8.9.

8.1. Market definition

The target market can be classified in two groups, residences and industry.

8.1.1. Residences

The population of City X, according to the records of State Planning Department's reports, will be 500,000 individuals living in 125,000 residences in the year 2000. All physical investment assumptions have been based on population figures foreseen by State Planning Department. According to the State Planning Department's projections mentioned population figures will grow to 925,000 individuals accommodated and 240,000 residences in 2010.

The distribution network will not cover the whole city but only the regions where the city suffers from higher rates of air pollution because of high population density and industrialization. Also the number of buildings per unit area and the consumption potential of a region are the key factors in providing the facility to a specific region. The flexibility of demand on the contrary the allocation of limited amount of gas by BOTAS, the wholesaler, are the other points which prevent the project from covering the whole city.

8.1.2. Average consumption of a residence

Since all the revenues and some of the expense items are based on average consumption amount for a residence, this figure must be determined with high accuracy. Calculation of an accurate average yearly consumption figure for a residence is the initial point of this study.

Satman provided an equation that relates the annual fuel load need of a residence to the summation of degree-day product for a year as follows [14];

$$Q_T = \overline{UA}\sum_{n=1}^{365}(T_0 - T_h)_n = \overline{UA}(DG)_y \qquad (8.01)$$

where;

$\overline{UA}$ = Average heat loss coefficient of the residence, kcal / (day - °C)

Q_T = Annual fuel load, kcal

T_o = Lowest temperature that do not need heating, 18.7 °C

T_h = Daily average temperature, °C

$(DG)_y$ = Degree - day product summation for one year, °C - day

The monthly distribution of Degree - day values for the City X are given in Table 8.1.

Table 8.1. Monthly temperature distribution of City X

MONTH	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Degree - Day	389	360	342	206	70	0	0	0	0	89	147	235
Monthly heat requirement, GJ	9.3	8.6	8.2	4.9	1.7	0.0	0.0	0.0	0.0	2.1	3.5	5.6
UA, kJ / day - °C	24000											
Q_T, GJ	44.1											

Assuming 65% overall burning efficiency (η_b), i.e., 10-12% heat loss in the burner plus 20% heat loss in the chimney plus 2-5% in pipes etc. and 9200 kcal / m^3 average heating value of natural gas annual gas consumption of a residence can be calculated as follows;

$$Q_g = 44.1\ (GJ) / 4.168\ (J / cal) * 10^6\ (kcal / Gcal) / 0.65\ (\eta_b) / 9200\ (kcal / m^3) = 1769\ m^3$$

Q_g, in the rest of the study is taken to be 1750 m^3/year. Calculated amount had been compared with actual consumption figures of neighboring cities utilizing natural gas and its accuracy was confirmed.

8.2. Industry

All industrial establishments in City X have been visited during the market survey and their consumption potentials examined and the equivalent consumption amount found to be $65x10^6$ m^3/yr. The resulting consumption figures reflect the current equivalent natural gas consumption potential of the industry without taking into consideration of the future developments that are not likely to happen very soon. To have switched industry from its current fuel to the natural gas depends on competitive pricing. Pricing strategy is explained in detail in revenues section, Section 8.5.7.

8.3. Planned Investment

The initial investment was planned to be completed in 3 years period and consists of the following items;

- **High pressure system:** 15 km, 12" steel lines and 30 line valves.
- **City gate station:** Reduces the pressure from delivery pressure to a level at which high pressure system designated to work (From 70 bars, approximately, to 25 bars.)
- **District regulators:** There are 24 district regulators in the network, reducing the pressure from 25 bars to a level at which low pressure system designated to work (From 25 bars, approximately, to 4 bars.)
- **Low pressure system:** Designated to work at 4 bars, consists of 266 km, 110,63 mm and 40 mm PE pipes.
- **Service lines:** Consists of 86.5 km service line and service regulators, all to be installed within the initial investment period.
- **Gas meters**
- **Inside installations:** Includes 15 m piping for each building. A flexible trunk, ventilation and gas heater's and oven's conversion for each residence.

In the Investment Sheet, Table 8.3., yearly distribution of initial investment and additional investment figures are shown in detail. Additional investment items cover installation of low pressure system, service lines and inside installation to reach new customers.

8.4. Financing

Financing of the project will be realized through two items, owner's equity and a Credit package. No other possible financing instruments such as compensation credits foreseen during operation period. Project credits according to the conditions of bidding will be provided by the Supplier which is going to be a Consortium formed by a Foreign and a Turkish Company.

Credit Package will be a blend of export and commercial credits financing the different parts of the project.

- **Export Credit:** This credit will finance a certain percentage of the material and equipment of foreign origin. Mentioned percentage, i.e., Credit / Project ratio, may change from 70% to 100% depending on many factors, such as nature of the project, credibility of the State and Contracting Companies, profitability of the project. In the tables presented here Credit / Project ratio is 85% of the physical investment.

  Overall cost of this credit assumed to be 7% including all the fees and commissions payable to the Banks. Utilization period of the Export Credit is 3 years. During the utilization period accrued interest will be reimbursed in every six months. Repayment period is 8.5 years and the first principal repayment installment will be paid 6 months after the last date for utilization. Export Credit is a low cost credit partly supported by the Government of Foreign Contractor in the frame of developing the export and evaluating the idle funds that the Country has.

- **Commercial Credit:** This portion will be utilized for the financing of local works, materials and equipment in consistent with the determined Credit / Project ratio.

  Commercial Credit has a 8% of overall cost, 3 years utilization period and 4 years repayment period.

8.5. Financial Tables

8.5.1. Parameters and Assumptions Sheet

Parameters & Assumptions Sheet, Table 8.2., is the control panel of system. It contains the parameters and general assumptions affecting all the tables. Modifying the parameters shown in this table one can create his own study in consistent with his own conditions.

8.5.2. Investment Sheet

In Investment sheet the activities to be performed throughout the project life is shown in item base. Items divided into two groups Local, L, and Foreign, F. Total of Local and Foreign activities placed on the top of the row of the corresponding investment item. The reason for grouping investment activities is that they are to be financed through different credit portions.

Investment activities placed in export rows of the Investment Sheet cover materials, to be imported in the frame of the project and the works to be performed by the foreign partner of the Contractor. The figures placed in the local rows of the Investment Sheet belong to the works to be performed by the local partner of the Contractor, a Turkish Company. In such projects materials to be supplied from the domestic market, by the local partner do not have a considerable percentage compared with the whole investment.

Sub Total I, represents the total of the physical investment. In the scenario shown here the 85% of physical investment is being financed through the credits. Sub Total II is the total of Sub Total I and the Contingency item. Contingency represents the additional investment that may be realize during the initial investment period and the price adjustments. Financing this item in the scope of the Credits might be optional depending on the nature of the project and credibility of the Borrower (Investor). Rest of the items placed in investment in order to show the final amount of the investment. The final amount being subjected to depreciation will affect the net earnings of the company before interest and tax, therefore is one of the parameters forming the tax assessment while still not being a cash movement.

Table 8.2. Parameters and Assumptions

PARAMETERS & ASSUMPTIONS				
1 UNIT DISTRIBUTION PRICE (RESIDENTIALS) ($/1000)		70.00		
2 UNIT DISTRIBUTION PRICE (INDUSTRY) ($/1000)		25.00		
3 YEARLY AVERAGE GAS CONSUMPTION OF A RESIDENTIAL (m^3/year)		1750		
4 CONSUMPTION OF A CUSTOMER SUBSCRIBED DURING THE YEAR (m^3/year)		875		
5 CONTINGENCY/PHYSICAL INVESTMENT RATIO		5%		
6 ADVANCE PAYMENT / PHYSICAL INVESTMENT RATIO		15%		
7 EQUITY/INVESTMENT RATIO		15%		
8 CREDIT/INVESTMENT RATIO		85%		
9 EXPORT CREDIT				
9-A INTEREST RATE		7%		
9-B UTILIZATION PERIOD, yrs		3		
10-C REPAYMENT PERIOD, yrs		4		
10 COMMERCIAL CREDIT				
10-A INTEREST RATE		8%		
10-B UTILIZATION PERIOD, yrs		3		
10-C REPAYMENT PERIOD, yrs		8.5		
11 WORKING CAPITAL REQUIREMENT/YEARLY INVESTMENT RATIO				
11-A 1st YEAR		10%		
11-B 2nd YEAR		2%		
11-C 3rd YEAR		2%		
12 MAINTENANCE				
12-A	2001-2003	0.5%	OF ACCUMULATED INVESTMENT	
12-B	2004-	1.8%	OF ACCUMULATED INVESTMENT	
13 INSURANCE		0.4%	OF ACCUMULATED INVESTMENT	
14 ENGINEERING & CONSULTANCY		3.0%	OF ANNUAL INVESTMENT	
15 PERSONNEL		# OF PERSONNEL	ANNUAL COST ($)	
15-A	2001	25		15000
15-B	2002	50		15000
15-C	2003	100		15000
15-D	2004-2020	2		15000
16 VEHICLES		# OF CARS	EACH CAR'S PRICE ($)	
16-A	2001	20		10000
16-B	2002	20		10000
16-C	2003	5		10000
16-D	2004-2020	1		10000
17 VEHICLES (MAINTENANCE + GASOLINE)		20%	OF EACH CAR'S PRICE	
18 BUILDINGS (RESTORATION + etc.)		2.5%	OF BUILDING INVESTMENT	
19 OTHERS		0.5%	OF OPERATIONAL COSTS (SUB TOTAL I)	
20 SYSTEM LOSS		2%	OF GAS SALES	
21 STRAIGHT LINE DEPRECIATION PERIOD, yrs		20		
22 FIXED SERVICE REVENUE		6	$/year-subscriber	
23 DEPOSIT		1	YEAR CONSUMPTION OF EACH SUBSCRIBER	
24 METER RENTAL REVENUE		9	$/year-subscriber	
25 TAX EXEMPTION PERIOD		3	yrs.	
26 CORPORATE TAX		50%	OF NET PROFIT	
27 MARR (MINIMUM ATTRACTIVE RATE OF RETURN)		10%		
28 REINVESTMENT RATE		6%		

Table 8.3. Planned Investment

INVESTMENT SHEET													
(000 $)		2000	2001	2002	2003	TOT. INV.	2004	2005	2006	2007	2008	2009	2010
	T	0	300	0	0	300	0	0	0	0	0	0	0
DESIGN & ENGINEERING	L		75			75							
	F		225			225							
	T	0	800	0	0	800	0	0	0	0	0	0	0
CITY GATE STATION	L		400			400							
	F		400			400							
	T	0	2,560	464	0	3,024	0	0	0	0	0	0	0
HIGH PRESSURE SYSTEM	L		1,090	464		1,554							
	F		1,470			1,470							
	T	0	574	574	0	1,148	0	0	0	0	0	0	0
DISTRICT REGULATOR	L		46	46		92							
	F		528	528		1,056							
	T	0	5,351	5,136	2,353	12,840	200	200	200	200	200	200	200
LOW PRESSURE SYSTEM	L		3,294	3,765	2,353	9,412	150	150	150	150	150	150	150
	F		2,057	1,371		3,428	50	50	50	50	50	50	50
	T	0	360	1,943	2,916	5,219	108	108	108	108	108	108	108
SERVICE LINES	L		14	75	113	202	4	4	4	4	4	4	4
	F		346	1,868	2,803	5,017	104	104	104	104	104	104	104
	T	0	200	2,160	3,240	5,600	120	120	120	120	120	120	120
METERS	L		200	2,160	3,240	5,600	120	120	120	120	120	120	120
	F					0		0	0	0	0	0	0
	T	0	375	2,025	3,038	5,438	225	225	225	225	225	225	225
INHOUSE DISTRIBUTION	L		375	2,025	3,038	5,438	225	225	225	225	225	225	225
	F					0		0	0	0	0	0	0
	T	**0**	**10,520**	**12,302**	**11,547**	**34,369**	**653**	**653**	**653**	**653**	**653**	**653**	**653**
SUB TOTAL I	**L**	**0**	**5,494**	**8,535**	**8,744**	**22,773**	**499**	**499**	**499**	**499**	**499**	**499**	**499**
	F	**0**	**5,026**	**3,767**	**2,803**	**11,596**	**154**	**154**	**154**	**154**	**154**	**154**	**154**
	T	0	526	615	577	1,718	33	33	33	33	33	33	33
CONTINGENCY	L		275	427	437	1,139	25	25	25	25	25	25	25
	F		251	188	140	580	8	8	8	8	8	8	8
	T	**0**	**11,046**	**12,917**	**12,124**	**36,087**	**686**	**686**	**686**	**686**	**686**	**686**	**686**
SUB TOTAL II	**L**	**0**	**5,769**	**8,962**	**9,181**	**23,912**	**524**	**524**	**524**	**524**	**524**	**524**	**524**
	F	**0**	**5,277**	**3,955**	**2,943**	**12,176**	**162**	**162**	**162**	**162**	**162**	**162**	**162**

Table 8.3. (Continued)

INVESTMENT SHEET													
(000 $)		2000	2001	2002	2003	TOT. INV.	2004	2005	2006	2007	2008	2009	2010
	T	0	518	625	638	1,781	0	0	0	0	0	0	0
INTEREST	L		431	398	432	1,261		0	0	0	0	0	0
	F		87	226	206	520		0	0	0	0	0	0
	T	0	225	300	225	750	0	0	0	0	0	0	0
CONSULTANCY	L		75	100	75	250		0	0	0	0	0	0
	F		150	200	150	500		0	0	0	0	0	0
	T	0	200	500	200	900	0	0	0	0	0	0	0
ADMINISTRATION BUILDINGS	L		200	500	200	900		0	0	0	0	0	0
	F					0		0	0	0	0	0	0
	T	0	200	200	50	450	10	10	10	10	10	10	10
VEHICLES	L		100	100	50	250	10	10	10	10	10	10	10
	F		100	100		200		0	0	0	0	0	0
	T	0	250	100	0	350	0	0	0	0	0	0	0
GENERAL EXPENSES	L		250	100		350		0	0	0	0	0	0
	F					0		0	0	0	0	0	0
	T	0	12,439	14,642	13,238	40,319	696	696	696	696	696	696	696
TOTAL	L	0	6,824	10,160	9,938	26,923	534	534	534	534	534	534	534
	F	0	5,615	4,482	3,300	13,396	162	162	162	162	162	162	162
	T	**0**	**12,439**	**27,081**	**40,319**		**41,014**	**41,710**	**42,406**	**43,101**	**43,797**	**44,493**	**45,188**
ACCUMULATED INVESTMENT	**L**	**0**	**6,824**	**16,984**	**26,923**		**27,457**	**27,991**	**28,524**	**29,058**	**29,592**	**30,126**	**30,660**
	F	**0**	**5,615**	**10,097**	**13,396**		**13,558**	**13,719**	**13,881**	**14,043**	**14,205**	**14,366**	**14,528**

Table 8.3. (Continued)

INVESTMENT SHEET											
(000 $)		2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
	T	0	0	0	0	0	0	0	0	0	0
DESIGN & ENGINEERING	L										
	F										
	T	0	0	0	0	0	0	0	0	0	0
CITY GATE STATION	L										
	F										
	T	0	0	0	0	0	0	0	0	0	0
HIGH PRESSURE SYSTEM	L										
	F										
	T	0	0	0	0	0	0	0	0	0	0
DISTRICT REGULATOR	L										
	F										
	T	200	200	200	200	200	200	200	200	200	200
LOW PRESSURE SYSTEM	L	150	150	150	150	150	150	150	150	150	150
	F	50	50	50	50	50	50	50	50	50	50
	T	108	108	108	108	108	108	108	108	108	108
SERVICE LINES	L	4	4	4	4	4	4	4	4	4	4
	F	104	104	104	104	104	104	104	104	104	104
	T	120	120	120	120	120	120	120	120	120	120
METERS	L	120	120	120	120	120	120	120	120	120	120
	F	0	0	0	0	0	0	0	0	0	0
	T	225	225	225	225	225	225	225	225	225	225
INHOUSE DISTRIBUTION	L	225	225	225	225	225	225	225	225	225	225
	F	0	0	0	0	0	0	0	0	0	0
	T	**653**	**653**	**653**	**653**	**653**	**653**	**653**	**653**	**653**	**653**
SUB TOTAL I	**L**	**499**	**499**	**499**	**499**	**499**	**499**	**499**	**499**	**499**	**499**
	F	**154**	**154**	**154**	**154**	**154**	**154**	**154**	**154**	**154**	**154**
	T	33	33	33	33	33	33	33	33	33	33
CONTINGENCY	L	25	25	25	25	25	25	25	25	25	25
	F	8	8	8	8	8	8	8	8	8	8
	T	**686**	**686**	**686**	**686**	**686**	**686**	**686**	**686**	**686**	**686**
SUB TOTAL II	**L**	**524**	**524**	**524**	**524**	**524**	**524**	**524**	**524**	**524**	**524**
	F	**162**	**162**	**162**	**162**	**162**	**162**	**162**	**162**	**162**	**162**

Table 8.3. (Continued)

INVESTMENT SHEET											
(000 $)		2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
	T	0	0	0	0	0	0	0	0	0	0
INTEREST	L	0	0	0	0	0	0	0	0	0	0
	F	0	0	0	0	0	0	0	0	0	0
	T	0	0	0	0	0	0	0	0	0	0
CONSULTANCY	L	0	0	0	0	0	0	0	0	0	0
	F	0	0	0	0	0	0	0	0	0	0
	T	0	0	0	0	0	0	0	0	0	0
ADMINISTRATION BUILDINGS	L	0	0	0	0	0	0	0	0	0	0
	F	0	0	0	0	0	0	0	0	0	0
	T	10	10	10	10	10	10	10	10	10	10
VEHICLES	L	10	10	10	10	10	10	10	10	10	10
	F	0	0	0	0	0	0	0	0	0	0
	T	0	0	0	0	0	0	0	0	0	0
GENERAL EXPENSES	L	0	0	0	0	0	0	0	0	0	0
	F	0	0	0	0	0	0	0	0	0	0
	T	696	696	696	696	696	696	696	696	696	696
TOTAL	L	534	534	534	534	534	534	534	534	534	534
	F	162	162	162	162	162	162	162	162	162	162
	T	**45,597**	**46,292**	**46,988**	**47,684**	**48,379**	**49,075**	**49,771**	**50,466**	**51,162**	**51,858**
ACCUMULATED INVESTMENT	**L**	**30,907**	**31,441**	**31,975**	**32,509**	**33,043**	**33,577**	**34,111**	**34,645**	**35,179**	**35,713**
	F	**14,690**	**14,851**	**15,013**	**15,175**	**15,336**	**15,498**	**15,660**	**15,822**	**15,983**	**16,145**

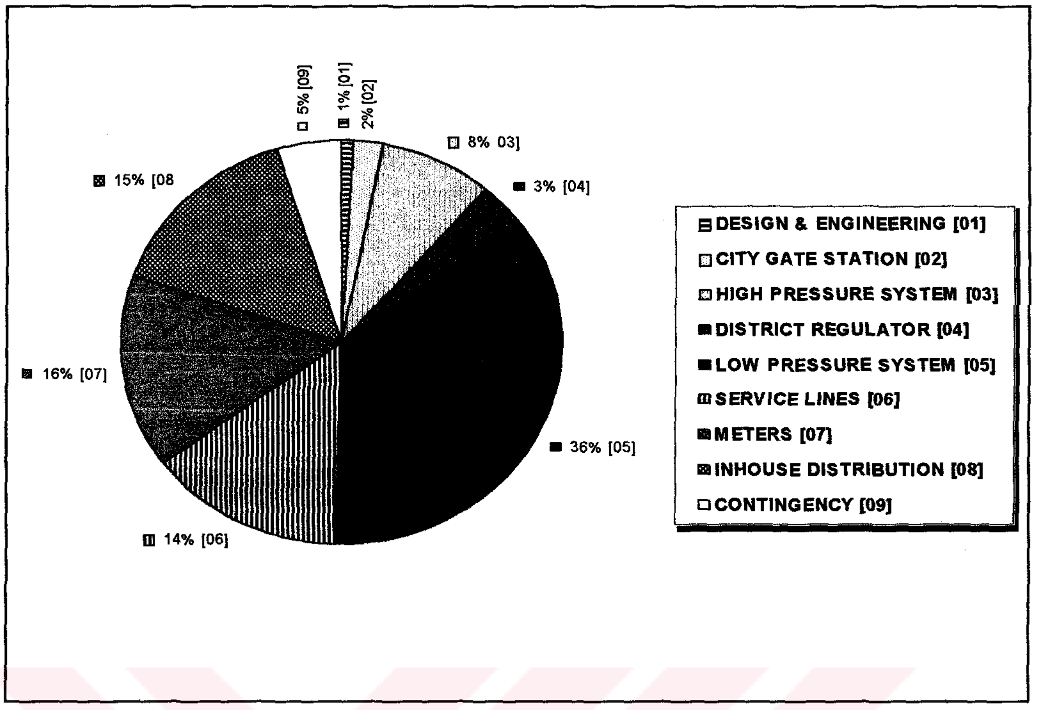

Figure 8.1. Distribution of Physical Investment

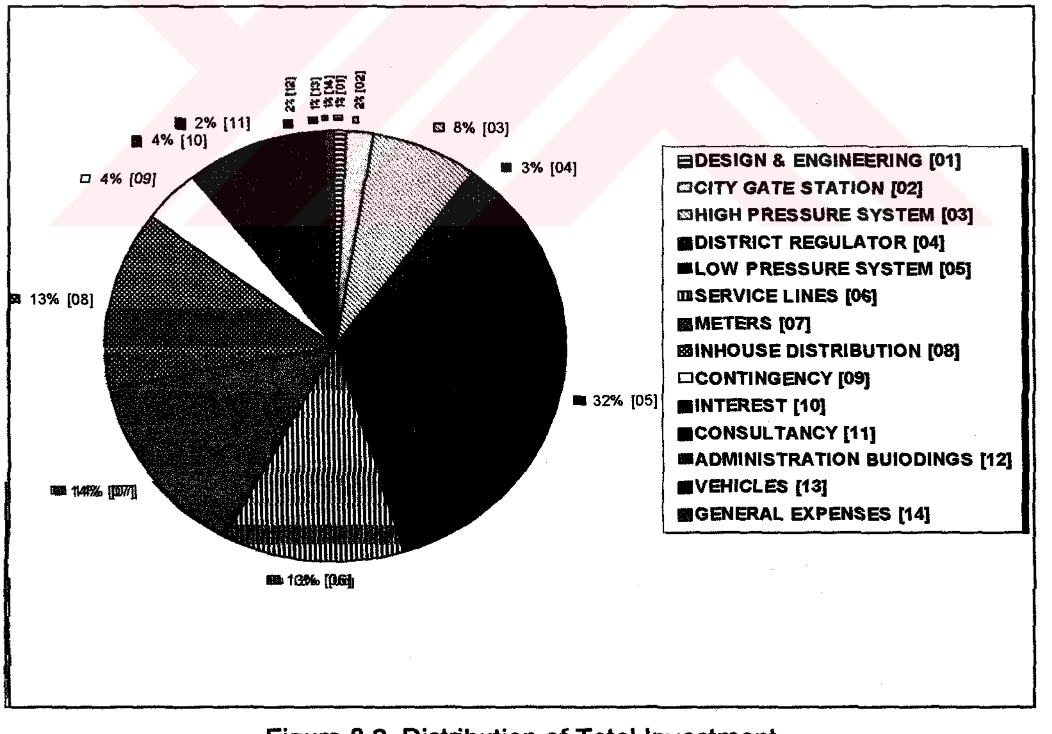

Figure 8.2. Distribution of Total Investment

8.5.3. Gas Sales

In the gas sales table the natural gas consumption figures are listed on yearly base. The average consumption of a residence is taken to be 1750 m^3/year as calculated in section 8.1.2. Since all the customers do not apply at the beginning of the year, annual residential sales or consumptions are not simply the product of number of customers of the year with the average consumption of a residence. Instead, the average consumption of a subscriber applied in the current year is assumed to be 875 m^3/year, which is the half of the full year utilization. The calculation of residential consumption (base scenario) for the years 2001 and 2002 is as follows;

- Year 2001: Number of Customers * Average Yearly consumption / 2
  3000 * 1750 m^3 / 2 = **2,625, 000 m^3**
- Year 2002: Number of Customers of Previous Year * Average Yearly Consumption + Increase of the Customers in the Current Year * Average Yearly Consumption / 2
  3000 * 1750 + (24000 - 3000) * 1750 m^3 / 2 = **23,625,000 m^3**

Industrial consumption is not defined as a function of number of industrial establishments because it varies a lot from one to another. The sales projection to industry based on market surveys performed visiting all the plants and large scope commercial establishments one by one.

Unit distribution price will be the markup of the company to the purchasing price of gas from wholesaler. In the study it is assumed that whatever will be the purchasing price the company is capable to save its markup. The profitability results shown in display sheet depend on the assumption of saving the same markup throughout the project life. There are two different markups applied two different kinds of customers groups. They have almost the same constraints showing below:

1. They must be able to compete with the other fuels' prices.
2. They must be able to yield a certain percentage of return while fulfilling the above condition.

While making such projections it is more safe to rely on not only one case but considering more pessimistic and optimistic situations. Therefore, three scenarios, a base scenario believed most likely to happen, a pessimistic scenario based on 15 % less realization of sales higher realization than base scenario separately evaluated and results are shown in display sheet.

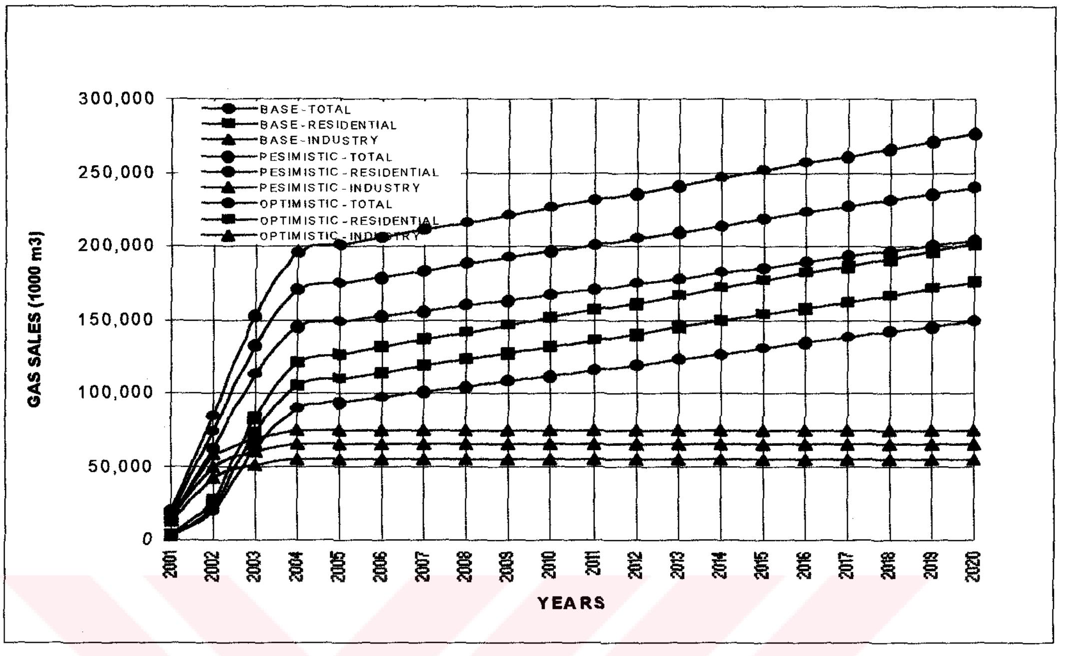

Figure 8.3. Gas Sales (1000 m3) vs. Years for three different scenarios

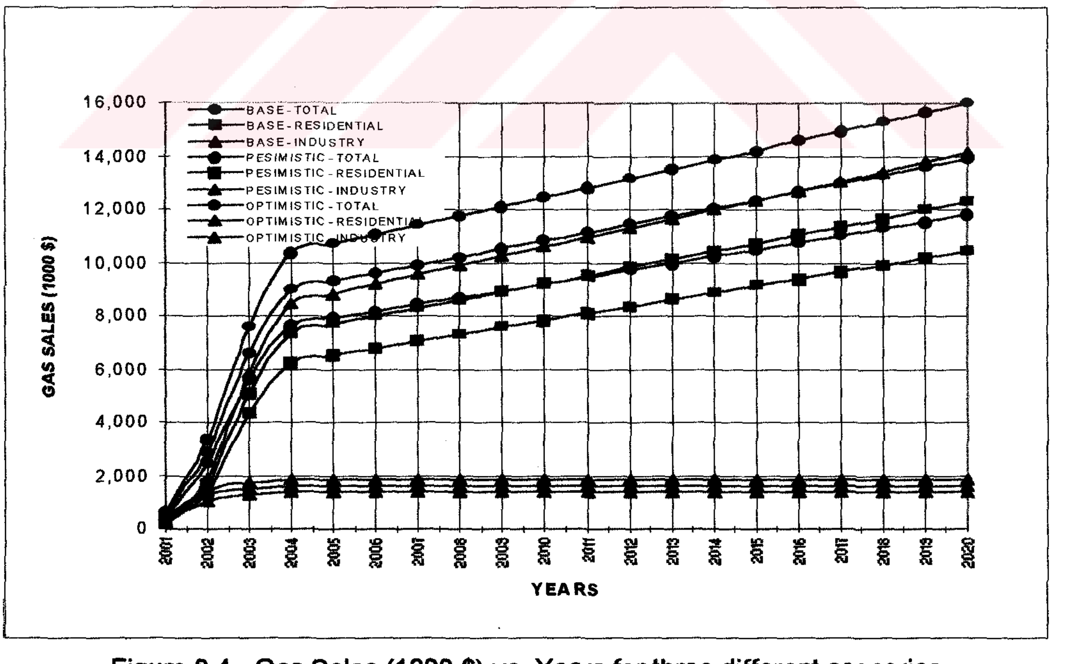

Figure 8.4. Gas Sales (1000 $) vs. Years for three different scenarios

Table 8.4. Gas Sales "Base Scenario"

NATURAL GAS SALES (BASE SCENARIO)										
(000 $)	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
NUMBER OF RESIDENTIAL CUSTOMERS	3,000	24,000	59,000	61,500	64,000	66,500	69,000	71,500	74,000	76,500
TOTAL SALES (1000 m^3)	17,625	73,625	132,625	170,438	174,813	179,188	183,563	187,938	192,313	196,688
RESIDENTIAL SALES (1000 m^3)	2,625	23,625	72,625	105,438	109,813	114,188	118,563	122,938	127,313	131,688
INDUSTRIAL SALES (1000 m^3)	15,000	50,000	60,000	65,000	65,000	65,000	65,000	65,000	65,000	65,000
TOTAL SALES	559	2,904	6,584	9,006	9,312	9,618	9,924	10,231	10,537	10,843
RESIDENTIAL SALES	184	1,654	5,084	7,381	7,687	7,993	8,299	8,606	8,912	9,218
INDUSTRIAL SALES	375	1,250	1,500	1,625	1,625	1,625	1,625	1,625	1,625	1,625
UNIT DISTRIBUTION PRICE (RESIDENTIALS) ($/1000)	70									
UNIT DISTRIBUTION PRICE (INDUSTRY) ($/1000)	25									
YEARLY AVERAGE GAS CONSUMPTION OF A RESIDENTIAL (m^3/year)	1,750									

Table 8.4. (Continued)

NATURAL GAS SALES (BASE SCENARIO)										
(000 $)	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
NUMBER OF RESIDENTIAL CUSTOMERS	79,000	81,500	84,000	86,500	89,000	91,500	94,000	96,500	99,000	101,500
TOTAL SALES (1000 m^3)	201,063	205,438	209,813	214,188	218,563	222,938	227,313	231,688	236,063	240,438
RESIDENTIAL SALES (1000 m^3)	136,063	140,438	144,813	149,188	153,563	157,938	162,313	166,688	171,063	175,438
INDUSTRIAL SALES (1000 m^3)	65,000	65,000	65,000	65,000	65,000	65,000	65,000	65,000	65,000	65,000
TOTAL SALES	11,149	11,456	11,762	12,068	12,374	12,681	12,987	13,293	13,599	13,906
RESIDENTIAL SALES	9,524	9,831	10,137	10,443	10,749	11,056	11,362	11,668	11,974	12,281
INDUSTRIAL SALES	1,625	1,625	1,625	1,625	1,625	1,625	1,625	1,625	1,625	1,625
UNIT DISTRIBUTION PRICE (RESIDENTIALS) ($/1000)	70									
UNIT DISTRIBUTION PRICE (INDUSTRY) ($/1000)	25									
YEARLY AVERAGE GAS CONSUMPTION OF A RESIDENTIAL (m^3/year)	1,750									

8.5.4. Credit Sheet

In Credit Sheet drawdowns from the Credits both Commercial and Export Credit, interest accrued balance of the credit and the repayment of principal are shown in parallel with the investment programme shown in Investment Sheet. As explained earlier Commercial Credit finances the 85% of local Investment activities. Foreign investment activities is financed through Export Credit.

The relationship between the invested amounts and the drawdowns through the credits, also the calculation of interest and repayments are shown below for both credits.

- **Drawdowns :**

  The whole year is divided into two and drawdowns are shown for two different intervals, for the first half and second half of the year. The calculation of drawdowns are as follows;

  Year 2001:

  01/01 - 30/06 Interval: (Total Physical Investment Amount " Sub Total I") * (Credit / Physical Investment Ratio)* (Advance Payment / Investment Ratio) + Investment Realized in 01/01 - 30/06 Interval * (Credit / Physical Investment Ratio)* (1 - Advance Payment / Investment Ratio).

  01/07 - 31/12 Interval: (Investment Realized in 01/07 - 31/12 Interval * (Credit / Physical Investment Ratio)* (1 - Advance Payment / Investment Ratio).

  Yrs. 2002-2003:

  Both Intervals: (Investment Realized in the interval * (Credit / Physical Investment Ratio)* (1 - Advance Payment / Investment Ratio).

1. **Commercial Credit:** (Local Investment figures only.)

   Year 2001:

   01/01 - 30/06 Interval: $ 22,773,000 * 85% * 15% + 5,494,000 / 2 * 85% * (1 - 15%) = $ 4,888,265

   01/07 - 31/12 Interval: 5,494,000 / 2 * 85% * (1 - 15%) = $ 1,984,708

   Yrs. 2002-2003:

   Both Intervals: $ 17,279,000 * 85% * (1 - 15%) = $ 12,484,078

2. **Export Credit:** (Foreign Investment figures only.)

   Year 2001:

   01/01 - 30/06 Interval: $ 11,596,000 * 85% * 15% + 5,026,000 / 2 * 85% * (1 - 15%) = $ 3,294,133

01/07 - 31/12 Interval: 5,026,000 / 2 * 85% * (1 - 15%) = $ 1,815,643

Yrs. 2002-2003:

01/01 - 30/06 Both Intervals: $ 6,570,000 * 85% * (1 - 15%) = $ 4,746,825

- **Interest:**

For the first drawing: Drawdown made in the interval * 1/2 year * Interest Rate

For the rest of the drawings: Balance of the Credit * 1/2 year * Interest Rate + Drawdown made in the interval * 1/4 year * Interest Rate

For the repayment period: Balance of the Credit * 1/2 year * Interest Rate

1. **Commercial Credit:**

Year 2001:

01/01 - 30/06 Interval: $ 4,888,000 * 1/2 * 8% = $ 196,000

01/07 - 31/12 Interval: $ 4,888,000 * 1/2 * 8% + $ 1,985,000 * 1/4 * 8% = $ 235,220

Year 2005:

01/01 - 30/06 Interval: $ 19,357,000 * 1/2 * 8% = $ 774,280

01/07 - 31/12 Interval: $ 16,937,000 * 1/2 * 8% = $677,480

2 **Export Credit:**

Year 2001:

01/01 - 30/06 Interval: $ 3,294,000 * 1/2 * 7% = $ 115,290

01/07 - 31/12 Interval: $ 3,294,000 * 1/2 * 7% + $ 1,816,000 * 1/4 * 8% = $ 147,070

Year 2005:

01/01 - 30/06 Interval: $ 9,857,000 * 1/2 * 7% = $ 344,995

01/07 - 31/12 Interval: $ 9,277,000 * 1/2 * 7% = $ 324,695

- **Repayment (Principal):**

For Commercial Credit: Installment Amount = (Balance of the Credit on 31.12.2003) / 8

For Export Credit: Installment Amount = (Balance of the Credit on 31.12.2003) / 17

- **Balance of The Credit:**

For both Credits: Balance of Previous Interval + Drawdowns made in the current Interval - Repayment (Principal.)

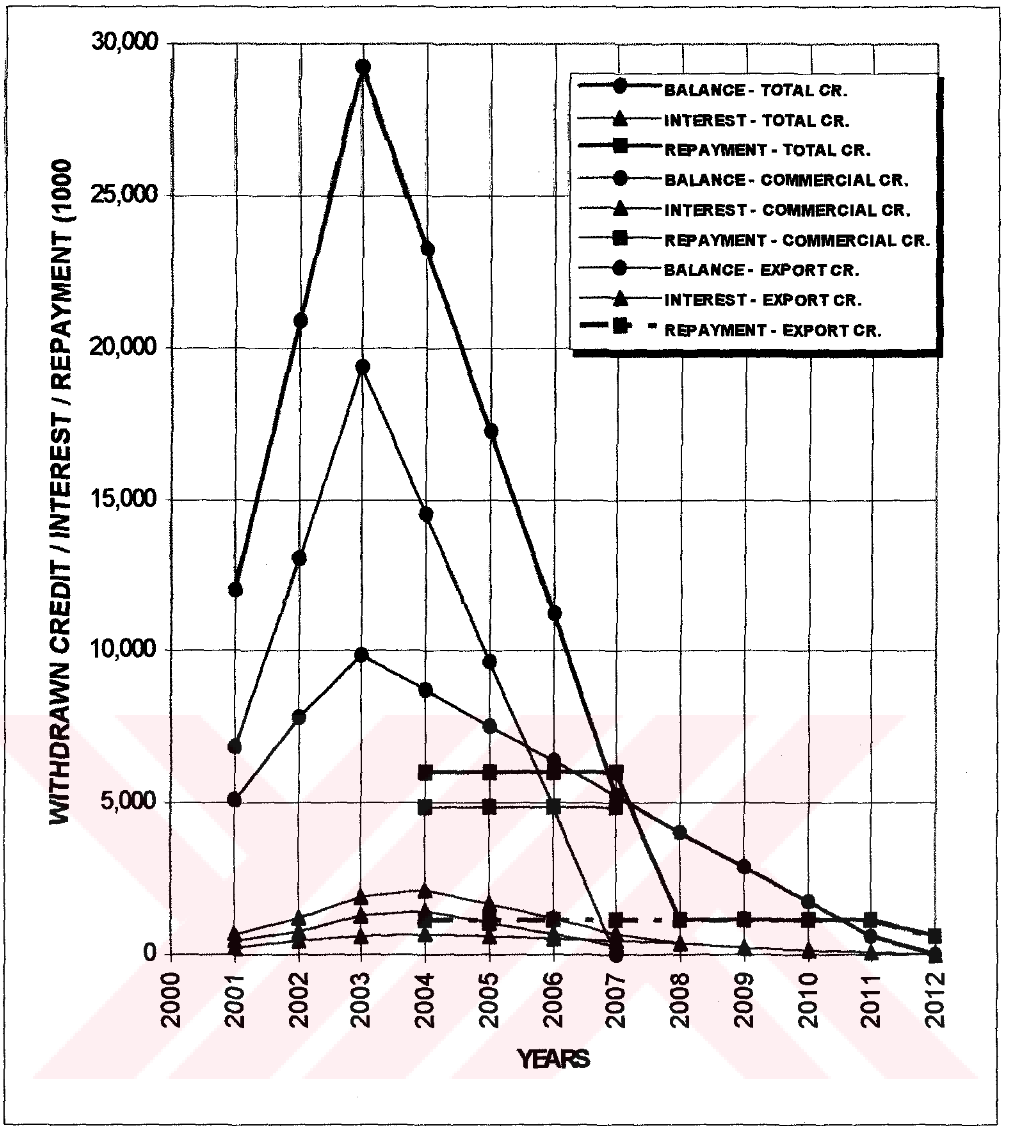

Figure 8.5. Utilization - Repayment of Project Credits "Base Scenario"

Table 8.5. Credit Utilizations - Interest - Repayments "Base Scenario"

		CREDIT SHEET												
	(000 $)	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
TOTAL CREDIT														
ACCUMULATED DRAWDOWN			**11,983**	**20,871**	**29,214**									
DRAWDOWN	**TOTAL**		**11,983**	**8,888**	**8,343**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
	01/01-30/06		8,182	4,444	4,171	0	0	0	0	0	0	0	0	0
	01/07-31/12		3,800	4,444	4,171	0	0	0	0	0	0	0	0	0
INTEREST	**TOTAL**		**693**	**1,249**	**1,915**	**2,121**	**1,653**	**1,185**	**717**	**345**	**264**	**183**	**101**	**20**
	01/01-30/06		311	539	877	1,119	885	651	417	183	142	101	61	20
	01/07-31/12		382	710	1,038	1,002	768	534	300	162	122	81	41	0
REPAYMENT (PRINCIPAL)	**TOTAL**		**0**	**0**	**0**	**5,999**	**5,999**	**5,999**	**5,999**	**1,160**	**1,160**	**1,160**	**1,160**	**580**
	01/01-30/06		0	0	0	2,999	2,999	2,999	2,999	580	580	580	580	580
	01/07-31/12		0	0	0	2,999	2,999	2,999	2,999	580	580	580	580	0
BALANCE	01/01-30/06		8,182	16,427	25,042	26,214	20,215	14,216	8,218	4,638	3,479	2,319	1,160	0
	01/07-31/12		11,983	20,871	29,214	23,215	17,216	11,217	5,218	4,059	2,899	1,739	580	0
COMMERCIAL CREDIT														
ACCUMULATED DRAWDOWN			**6,873**	**13,040**	**19,357**									
DRAWDOWN	**TOTAL**		**6,873**	**6,167**	**6,318**									
	01/01-30/06		4,888	3,083	3,159									
	01/07-31/12		1,985	3,083	3,159									
INTEREST	**TOTAL**		**431**	**796**	**1,296**	**1,452**	**1,065**	**677**	**290**					
	01/01-30/06		196	337	585	774	581	387	194					
	01/07-31/12		235	460	711	677	484	290	97					
REPAYMENT (PRINCIPAL)	**TOTAL**		**0**	**0**	**0**	**4,839**	**4,839**	**4,839**	**4,839**					
	01/01-30/06					2,420	2,420	2,420	2,420					
	01/07-31/12					2,420	2,420	2,420	2,420					
BALANCE	01/01-30/06		4,888	9,956	16,198	16,937	12,098	7,259	2,420	0	0	0	0	0
	01/07-31/12		6,873	13,040	19,357	14,518	9,679	4,839	0	0	0	0	0	0
EXPORT CREDIT														
ACCUMULATED DRAWDOWN			**5,110**	**7,831**	**9,857**									
DRAWDOWN	**TOTAL**		**5,110**	**2,722**	**2,025**									
	01/01-30/06		3,294	1,361	1,013									
	01/07-31/12		1,816	1,361	1,013									
INTEREST	**TOTAL**		**262**	**453**	**619**	**670**	**588**	**507**	**426**	**345**	**264**	**183**	**101**	**20**
	01/01-30/06		115	203	292	345	304	264	223	183	142	101	61	20
	01/07-31/12		147	250	327	325	284	244	203	162	122	81	41	
REPAYMENT (PRINCIPAL)	**TOTAL**		**0**	**0**	**0**	**1,160**	**1,160**	**1,160**	**1,160**	**1,160**	**1,160**	**1,160**	**1,160**	**580**
	01/01-30/06					580	580	580	580	580	580	580	580	580
	01/07-31/12					580	580	580	580	580	580	580	580	
BALANCE	01/01-30/06		3,294	6,471	8,844	9,277	8,117	6,958	5,798	4,638	3,479	2,319	1,160	0
	01/07-31/12		5,110	7,831	9,857	8,697	7,537	6,378	5,218	4,059	2,899	1,739	580	0

8.5.5. Cash Flow - Sources and Funds Sheet

In this study, Cash Flow - Sources & Funds Statement is not arranged in traditional way. Instead of placing all the revenues top and all the expenses bottom, every fund and corresponding financing source shown separately for clearer understanding. The explanations of the items formed the statement are as follows;

- **Revenues:**
  Total revenue figures are carried from revenues sheet. Detailed explanation about each revenue item is given in section 8.5.7.

- **Payments to the Contractors under Project Credits Scope:**
  This item represents all the payments made for physical investment. Physical investment financed through two sources, Equity I and Project Credits.

- **Payments to the Contractors under Project Credits Scope:**
  This item also covers the investment period's interest and full financed through Owner's Equity, Equity II.

- **Operational Costs:**
  Operational Cost figures carried from Operational Costs Sheet. Depreciation is excluded since its not a cash flow.

- **Interest and Principal Payments:**
  Carried from Credit Sheet.

- **Corporate Tax:**
- Carried from Income Statement.

- **Working Capital:**
  Net working capital, by definition, is the numerical difference between total current assets and total current liabilities. Working capital is necessary for the firm to make its initial payments before business yields some cash inflows. Such initial payments can be firs gas purchases, personnel salaries, etc.

- **Net Funds - Accumulated Net Funds:**
  Placed to show the difference between the cash inflows and outflows, If Net funds for any of the year is negative than firm must refer to some another source. Most likely to

be referred would be the firm's collections, accumulated net funds. If the accumulated net funds are not capable to compensate the deficit firm can optionally refer two different sources. Owner's Equity, Equity IV or financial markets that are ready to compensate the deficit in return a cost, so called interest charge.

- **Adjusted Funds & Accumulated Adjusted Funds:**
  They are the last two rows in the statement showing the firm's situation after any compensating activity performed. Accumulated adjusted fund cannot have a negative balance, otherwise firm goes bankrupt.

8.5.6. Income Statement

Income Statement provides a financial summary of the firm's operating results during a specified period. It also forms *EBIT*, earnings before interest and tax, to form the tax assessment. Corporate to be paid is calculated over tax assessment.

Depreciation, decrease in the value of the assest resulting from operation, shown here as an expense to reduce the *EBIT*.

8.5.7. Revenues Sheet

In Revenues Sheet each revenue item is shown separately in terms of years. Company will have two types of operational revenues: gas sales, direct operational revenues and fees to be charged to the subscribers, indirect operational revenues.

1. **Residential Sales**
   This item is explained in section 8.1.1. Residential selling price of natural gas is taken to be 70 $ / 1000 m^3 for residences in base scenario.

2. **Industrial Sales**
   Industrial Sales have a great importance in regulating the fluctuation of residential consumption. Industrial establishments have the tendency of consuming large amount of gas regularly throughout the year as can be seen from the Figures 8.3. and 8.4. But being able sell gas to the industry is closely depends on having competitive price compared with the ones that other fuels have. Industrial selling price is taken to be 25 $ / 1000 m^3 in base scenario. All the tables presented here are based on above mentioned two selling prices.

Table 8.6. Cash Flow - Sources & Funds Statement "Base Scenario"

	CASH FLOW - SOURCES & FUNDS ($ 000)	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
I	REVENUES		634	3,478	7,826	9,954	10,297	10,641	10,985	11,329	11,672	12,016
	PAYMENTS TO THE CONTRACTORS UNDER CREDIT SCOPE		14,097	10,457	9,815							
	SOURCES		14,097	10,457	9,815							
	PROJECT CREDITS		11,983	8,888	8,343							
	EQUITY I		2,115	1,569	1,472							
II	PAYMENTS TO THE CONTRACTORS OUT OF CREDIT SCOPE (INVESTMENT PERIOD'S INTERESET INCLUDED)		2,524	1,989	1,437	696	696	696	696	696	696	696
	SOURCE: EQUITY II		2,524	1,989	1,437							
III	OPERATIONAL COSTS (DEPRECIATION EXCLUDED)		931	1,606	2,534	2,791	2,857	2,923	2,989	3,056	3,122	3,188
IV	INTEREST (OPERATION PERIOD)		175	625	1,277	2,121	1,653	1,185	717	345	264	183
	REPAYMENT (PRINCIPAL)		0	0	0	5,999	5,999	5,999	5,999	1,160	1,160	1,160
V	CORPORATE TAX			0	0	0	0	0	0	2,572	2,694	2,815
VI	WORKING CAPITAL		1,244	293	265							
	SOURCE: EQUITY III		1,715	0	0							
VII	NET FUNDS		0	954	3,751	-1,653	-907	-161	584	3,500	3,738	3,975
	ACCUMULATED NET FUNDS		0	954	4,705	3,052	2,145	1,984	2,568	6,068	9,806	13,781
IX	EQUITY IV		0	0	0	0	0	0	0	0	0	0
X	ADJUSTED FUNDS		0	954	4,705	3,052	2,145	1,984	2,568	6,068	9,806	13,781
XI	ACCUMULATED ADJUSTED COMPANY FUNDS		0	954	5,660	8,712	10,857	12,841	15,409	21,478	31,284	45,065

Table 8.6. (Continued)

	CASH FLOW - SOURCES & FUNDS										
	($ 000)	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
I	REVENUES	12,360	12,704	13,047	13,391	13,735	14,079	14,422	14,766	15,110	15,454
	PAYMENTS TO THE CONTRACTORS UNDER CREDIT SCOPE										
	SOURCES										
	PROJECT CREDITS										
	EQUITY I										
II	PAYMENTS TO THE CONTRACTORS OUT OF CREDIT SCOPE (INVESTMENT PERIOD'S INTERESET INCLUDED)	696	696	696	696	696	696	696	696	696	696
	SOURCE: EQUITY II										
III	OPERATIONAL COSTS (DEPRECIATION EXCLUDED)	3,254	3,321	3,387	3,453	3,519	3,586	3,652	3,718	3,784	3,850
IV	INTEREST (OPERATION PERIOD)	101	20	0	0	0	0	0	0	0	0
	REPAYMENT (PRINCIPAL)	1,160	580	0							
V	CORPORATE TAX	2,936	3,058	3,179	3,301	3,422	3,543	3,665	3,786	3,907	4,029
VI	WORKING CAPITAL										
	SOURCE: EQUITY III										
VII	NET FUNDS	4,212	5,029	5,786	5,942	6,098	6,254	6,410	6,566	6,723	6,879
	ACCUMULATED NET FUNDS	17,993	23,023	28,809	34,750	40,848	47,103	53,513	60,079	66,802	73,681
IX	EQUITY IV	0	0	0	0	0	0	0	0	0	0
X	ADJUSTED FUNDS	17,993	23,023	28,809	34,750	40,848	47,103	53,513	60,079	66,802	73,681
XI	ACCUMULATED ADJUSTED COMPANY FUNDS	63,058	86,081	114,890	149,640	190,489	237,591	291,104	351,184	417,986	491,666

Table 8.7. Income Statement "Base Scenario"

	INCOME STATEMENT											
	($ 000)	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
I	REVENUES		634	3,478	7,826	9,954	10,297	10,641	10,985	11,329	11,672	12,016
	EXPENSES		13,992	17,602	17,787	5,537	5,638	5,739	5,840	5,941	6,042	6,143
II	INVESTMENT		12,439	14,642	13,238	696	696	696	696	696	696	696
1	FIXED INVESTMENT		11,921	14,017	12,599	696	696	696	696	696	696	696
2	INTEREST (INVESTMENT PERIOD)		518	625	638							
III	OPERATIONAL COSTS		1,553	2,960	4,550	4,841	4,942	5,044	5,145	5,246	5,347	5,448
IV	INTEREST (OPERATION PERIOD)		175	625	1,277	2,121	1,653	1,185	717	345	264	183
V	NET PROFIT BEFORE TAX		-13,358	-14,124	-9,961	4,417	4,659	4,902	5,145	5,387	5,630	5,873
VI	CUMILATIVE LOSS DEDUCTABLE FROM NEXT YEAR'S PROFIT		-13,358	-27,482	-37,443	-33,026	-28,367	-23,465				
VII	TAX ASSESMENT		0	0	0	0	0	0	5,145	5,387	5,630	5,873
VIII	TAX		0	0	0	0	0	0	2,572	2,694	2,815	2,936
IX	PROFIT AFTER TAX		0	0	0	0	0	0	2,572	2,694	2,815	2,936

Table 8.7. (Continued)

	INCOME STATEMENT										
	($ 000)	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
I	REVENUES	12,360	12,704	13,047	13,391	13,735	14,079	14,422	14,766	15,110	15,454
	EXPENSES	6,244	6,345	6,446	6,547	6,648	6,749	6,850	6,951	7,052	7,153
II	INVESTMENT	696	696	696	696	696	696	696	696	696	696
1	FIXED INVESTMENT	696	696	696	696	696	696	696	696	696	696
2	INTEREST (INVESTMENT PERIOD)										
III	OPERATIONAL COSTS	5,549	5,650	5,751	5,852	5,953	6,054	6,155	6,256	6,357	6,458
IV	INTEREST (OPERATION PERIOD)	101	20								
V	NET PROFIT BEFORE TAX	6,116	6,358	6,601	6,844	7,087	7,329	7,572	7,815	8,058	8,300
VI	CUMILATIVE LOSS DEDUCTABLE FROM NEXT YEAR'S PROFIT										
VII	TAX ASSESMENT	6,116	6,358	6,601	6,844	7,087	7,329	7,572	7,815	8,058	8,300
VIII	TAX	3,058	3,179	3,301	3,422	3,543	3,665	3,786	3,907	4,029	4,150
IX	PROFIT AFTER TAX	3,058	3,179	3,301	3,422	3,543	3,665	3,786	3,907	4,029	4,150

3. Meter Rental Revenue

It is assumed to be 9 $ / year - gas meter.

4. Fixed Service Fee

It is charged to the residences and represents the permanent efforts of the Company in order to keep the gas available to use any time along the year whether or not dense consumption exist. For example during the summer time. It is taken to be 6 $ / year - subscriber.

5. Deposit

Deposit is a security fee charged to the subscriber for gas meters. Actually it is a long term debt of the Company to be returned to any customer who decides not to use gas anymore. But in the short run, it is a revenue item which contributes to the cash flow of the Company. Deposit will be equal the consumption of a residence for one month.

8.5.8. Operational Costs Sheet

Operational costs or expenses by definition are the expenses directly related to operating activities. Nonoperating expenses are the ones that are not directly related to the operating expenses, such as interest expense. The definitions of operating expenses listed in the table are as follows;

1. Maintenance

Maintenance is taken to be 0.5% of the accumulated investment for the years 2001 - 2003, initial investment period, and 1.8% of the accumulated investment for the following years. The percentage, 1.8%, is a relatively high ratio arising from the idea based on purchasing all maintenance services from outside instead of holding permanent staff for such services.

2. Insurance

System will be insured against all risks. Insurance premiums assumed to be 0.4% of the total investment.

Table 8.8. Revenues Sheet "Base Scenario"

REVENUES											
($ 000)	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**
RESIDENTIAL SALES	184	1,654	5,084	7,381	7,687	7,993	8,299	8,606	8,912	9,218	9,524
INDUSTRIAL SALES	375	1,250	1,500	1,625	1,625	1,625	1,625	1,625	1,625	1,625	1,625
SUB TOTAL I	**559**	**2,904**	**6,584**	**9,006**	**9,312**	**9,618**	**9,924**	**10,231**	**10,537**	**10,843**	**11,149**
METER RENTAL REVENUE	27	216	531	554	576	599	621	644	666	689	711
FIXED SERVICE REVENUE	18	144	354	369	384	399	414	429	444	459	474
DEPOSIT	31	214	357	26	26	26	26	26	26	26	26
TOTAL	**634**	**3,478**	**7,826**	**9,954**	**10,297**	**10,641**	**10,985**	**11,329**	**11,672**	**12,016**	**12,360**

Table 8.8. (Continued)

REVENUES										
($ 000)	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**
RESIDENTIAL SALES	9,831	10,137	10,443	10,749	11,056	11,362	11,668	11,974	12,281	12,587
INDUSTRIAL SALES	1,625	1,625	1,625	1,625	1,625	1,625	1,625	1,625	1,625	1,625
SUB TOTAL I	**11,456**	**11,762**	**12,068**	**12,374**	**12,681**	**12,987**	**13,293**	**13,599**	**13,906**	**14,212**
METER RENTAL REVENUE	734	756	779	801	824	846	869	891	914	936
FIXED SERVICE REVENUE	489	504	519	534	549	564	579	594	609	624
DEPOSIT	26	26	26	26	26	26	26	26	26	26
TOTAL	**12,704**	**13,047**	**13,391**	**13,735**	**14,079**	**14,422**	**14,766**	**15,110**	**15,454**	**15,797**

3. Engineering & Consultancy

Engineering services cover the design studies made in feasibility study before opening the bid. During construction period an another firm will consult the realization of the Project. Design & Engineering expenses taken to be 3% of the annual investment.

4. Personnel

Number of personnel is kept at the minimum level for cost minimization. Number of personnel is 25, 50, 100 respectively for the years 2001, 2002, 2003. For each following year two personnel will be added to the staff. The cost of one personnel is assumed to be 15,000 $/year.

5. Buildings

Includes the restoration, cleaning services and fuel expenses of the buildings and taken to be 2.5% of the buildings item in the Investment Sheet.

6. Others

Represent all the expenses which are covered by the above items and is 0.5% of the total of above items.

7. System loss

Represents the network losses and is taken to be the 2% of the gas sales.

8. Depreciation

To depreciate the assets, straight line depreciation method is used. Straight line depreciation is the simplest and most widely used method in accounting. This method by definition is the systematic allocation of the same portion of the cost of an asset to expense during the periods of its useful time [15.] All assest shown in Investment Sheet depreciated in 20 years and the salvage or residual value of the whole system is ignored since otherwise not realistic.

8.5.9. Table of Results (Display Sheet)

In the display sheet the results of more than 300 runs made for three different scenarios and many different unit selling prices (both Residential and Industrial) are shown. The reason for trying so many different prices is that the Company must be

Table 8.9. Operational Costs "Base Scenario"

OPERATIONAL COSTS											
($ 000)	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**
MAINTANANCE		62	135	202	738	751	763	776	788	801	813
INSURANCE		50	108	161	164	167	170	172	175	178	181
ENGINEERING & CONSULTANCY		373	439	397	21	21	21	21	21	21	21
PERSONNEL		375	750	1,500	1,530	1,560	1,590	1,620	1,650	1,680	1,710
VEHICLES		40	80	90	92	94	96	98	100	102	104
BUILDINGS		5	18	30	43	55	68	80	93	105	118
OTHERS		15	18	22	23	23	24	24	24	24	25
SYSTEM LOSS		11	58	132	180	186	192	198	205	211	217
SUB TOTAL		**931**	**1,606**	**2,534**	**2,791**	**2,857**	**2,923**	**2,989**	**3,056**	**3,122**	**3,188**
DEPRECIATION		622	1,354	2,016	2,051	2,085	2,120	2,155	2,190	2,225	2,259
TOTAL		**1,553**	**2,960**	**4,550**	**4,841**	**4,942**	**5,044**	**5,145**	**5,246**	**5,347**	**5,448**

Table 8.9. (Continued)

OPERATIONAL COSTS										
($ 000)	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**
MAINTANANCE	826	838	851	863	876	889	901	914	926	939
INSURANCE	184	186	189	192	195	197	200	203	206	209
ENGINEERING & CONSULTANCY	21	21	21	21	21	21	21	21	21	21
PERSONNEL	1,740	1,770	1,800	1,830	1,860	1,890	1,920	1,950	1,980	2,010
VEHICLES	106	108	110	112	114	116	118	120	122	124
BUILDINGS	130	143	155	168	180	193	205	218	230	243
OTHERS	25	25	26	26	26	27	27	27	28	28
SYSTEM LOSS	223	229	235	241	247	254	260	266	272	278
SUB TOTAL	**3,254**	**3,321**	**3,387**	**3,453**	**3,519**	**3,586**	**3,652**	**3,718**	**3,784**	**3,850**
DEPRECIATION	2,294	2,329	2,364	2,399	2,433	2,468	2,503	2,538	2,572	2,607
TOTAL	**5,549**	**5,650**	**5,751**	**5,852**	**5,953**	**6,054**	**6,155**	**6,256**	**6,357**	**6,458**

Table 8.10. Financial Rantability "Base Scenario"

FINANCIAL RANTABILITY												
	($ 000)	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
I	CASH IN		12,617	12,366	16,169	9,954	10,297	10,641	10,985	11,329	11,672	12,016
1	REVENUES		634	3,478	7,826	9,954	10,297	10,641	10,985	11,329	11,672	12,016
2	CREDITS		11,983	8,888	8,343	0	0	0	0	0	0	0
II	CASH OUT		18,971	14,969	15,327	11,607	11,205	10,803	10,400	7,828	7,935	8,041
1	PAYMENTS TO THE CONTRACTORS (PROJECT CREDITS + EQUITY I)		14,097	10,457	9,815							
2	PAYMENTS TO THE CONTRACTORS (EQUITY II)		2,524	1,989	1,437	696	696	696	696	696	696	696
3	INTEREST (OPERATION PERIOD)		175	625	1,277	2,121	1,653	1,185	717	345	264	183
4	REPAYMENT		0	0	0	5,999	5,999	5,999	5,999	1,160	1,160	1,160
5	OPERATIONAL COSTS		931	1,606	2,534	2,791	2,857	2,923	2,989	3,056	3,122	3,188
6	CORPORATE TAX		0	0	0	0	0	0	0	2,572	2,694	2,815
7	WORKING CAPITAL		1,244	293	265	0	0	0	0	0	0	0
I - II	DIFFERENCE		-6,354	-2,603	842	-1,653	-907	-161	584	3,500	3,738	3,975
	NET PRESENT VALUE (BASE YEAR: 2000)		9,683									
	IRR		17%									
	MIRR		13%									

Table 8.10. (Continued)

FINANCIAL RANTABILITY											
	($ 000)	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
I	**CASH IN**	**12,360**	**12,704**	**13,047**	**13,391**	**13,735**	**14,079**	**14,422**	**14,766**	**15,110**	**15,454**
1	REVENUES	12,360	12,704	13,047	13,391	13,735	14,079	14,422	14,766	15,110	15,454
2	CREDITS	0	0	0	0	0	0	0	0	0	0
II	**CASH OUT**	**8,148**	**7,674**	**7,262**	**7,449**	**7,637**	**7,825**	**8,012**	**8,200**	**8,387**	**8,575**
1	PAYMENTS TO THE CONTRACTORS (PROJECT CREDITS + EQUITY I)										
2	PAYMENTS TO THE CONTRACTORS (EQUITY II)	696	696	696	696	696	696	696	696	696	696
3	INTEREST (OPERATION PERIOD)	101	20	0	0	0	0	0	0	0	0
4	REPAYMENT	1,160	580	0	0	0	0	0	0	0	0
5	OPERATIONAL COSTS	3,254	3,321	3,387	3,453	3,519	3,586	3,652	3,718	3,784	3,850
6	CORPORATE TAX	2,936	3,058	3,179	3,301	3,422	3,543	3,665	3,786	3,907	4,029
7	WORKING CAPITAL	0	0	0	0	0	0	0	0	0	0
I - II	**DIFFERENCE**	**4,212**	**5,029**	**5,786**	**5,942**	**6,098**	**6,254**	**6,410**	**6,566**	**6,723**	**6,879**
	NET PRESENT VALUE (BASE YEAR: 2000)	**9,683**									
	IRR	**17%**									
	MIRR	**13%**									

able to know the price range in which it can make profit from its operations. The results enlisted were illustrated in Figures 8.6., 8.7., 8.8., 8.9. for better understanding.

8.6. Results and Conclusion

8.6.1. Base Scenario

In the base scenario the worst situation is that where residential unit selling price (RUSP) is 60 $/1000m^3$ and industrial unit selling price (IUSP) is 21 $/1000m^3$. Even in this combination, system is capable to reach its target with a net present value (NPV) of $ 2,025,000. This price pair gives an internal rate of return (IRR) of 11.45 % and an external rate of return (ERR or MIRR) of 9.5% (with 5% reinvestment rate.) These figures are satisfactory for the accepted minimum attractive rate of return, 10%. The best returns obtained are 17,069,000 NPV, 23.97% IRR and 17.71% ERR where RUSP is 80 and IUSP is 29 $ / 1000m^3$.

If the company catches the base scenario sales level it is obvious that the investment will be a profitable one within any point in the rage of RUSP, 60-80 $/1000 m^3$ IUSP, 22-29 $/1000 m^3$.

8.6.2. Pessimistic Scenario

In the pessimistic scenario based on 15% less realization of gas sales the RUSP, 70 $/1000 m^3$, IUSP, 23 $/1000 m^3$ price pair is the break even point. Below this level company loses with the given criterion, but above these prices even in the pessimistic scenario, system is capable to generate the expected rate of return. For example with the average price pair of RUSP, 70 $ / 1000 m^3$, IUSP, 25 $ / 1000 m^3$, system will have a NPV of $ 1,082,000, IRR of 10.76%, ERR of 9.13%.

8.6.3. Optimistic Scenario

In optimistic scenario based of 15% higher realization of gas sales the lowest price pair RUSP of 60, IUSP of 21 $ / 1000 m^3$ gives a NPV of 9,615,000. With this price pair the IRR is 17.25% and the ERR is 12.58%.

Since the sales level foreseen in optimistic scenario is not so far from reality in case company can sale at this level natural gas prices will be very competitive and this competitiveness in pricing will have an exponential effect in penetrating the fuel market This will result in excessive demand but limited supply.

In general, it was observed that the profitibility of the project had been a weak function of the industrial unit selling price (Figures: 8.6., 8.7., 8.8., 8.9.) This is due to the small weigth of industrial sales in the total sales since the main target is residential market.

An overall evaluation of the project is that investing in proposed system will generate a lot higher return than any other investment alternatives; such as investing in financial assets and this project is a viable investment opportunity with the given criterion.

Table 8.11. Results of Base Scenario

BASE SCENARIO

RESIDENTIAL SELLING PRICE ($/1000 m^3)	INDUSTRAL SELLING PRICE ($/1000 m^3)	EQUITY/PROJECT RATIO	EQUITY REQUIREMENT	NET PRESENT VALUE ($ 1000)	IRR	MIRR
60.00	21.00	15%	24,200	2,025	11.45%	9.50%
61.00	21.00	15%	22,308	2,631	11.89%	9.75%
62.00	21.00	15%	20,416	3,237	12.33%	10.00%
63.00	21.00	15%	18,775	3,843	12.77%	10.25%
64.00	21.00	15%	17,489	4,449	13.22%	10.49%
65.00	21.00	15%	16,202	5,055	13.68%	10.74%
66.00	21.00	15%	14,915	5,660	14.13%	10.98%
67.00	21.00	15%	13,891	6,266	14.59%	11.23%
68.00	21.00	15%	12,950	6,872	15.06%	11.47%
69.00	21.00	15%	12,882	7,478	15.52%	11.71%
70.00	21.00	15%	12,879	8,084	15.99%	11.95%
71.00	21.00	15%	12,876	8,690	16.47%	12.19%
72.00	21.00	15%	12,873	9,295	16.95%	12.43%
73.00	21.00	15%	12,870	9,901	17.43%	12.67%
74.00	21.00	15%	12,867	10,507	17.92%	12.90%
75.00	21.00	15%	12,864	11,113	18.42%	13.12%
76.00	21.00	15%	12,861	11,719	18.91%	13.34%
77.00	21.00	15%	12,858	12,325	19.41%	13.56%
78.00	21.00	15%	12,855	12,930	19.92%	13.78%
79.00	21.00	15%	12,852	13,536	20.43%	14.00%
80.00	21.00	15%	12,849	14,142	20.95%	14.22%
60.00	23.00	15%	21,588	2,757	11.99%	9.81%
61.00	23.00	15%	19,696	3,363	12.44%	10.06%
62.00	23.00	15%	18,239	3,969	12.89%	10.30%
63.00	23.00	15%	16,952	4,575	13.34%	10.55%
64.00	23.00	15%	15,666	5,180	13.80%	10.79%
65.00	23.00	15%	14,483	5,786	14.26%	11.04%
66.00	23.00	15%	13,511	6,392	14.72%	11.30%
67.00	23.00	15%	12,859	6,998	15.19%	11.53%
68.00	23.00	15%	12,856	7,604	15.66%	11.77%
69.00	23.00	15%	12,853	8,210	16.14%	12.01%
70.00	23.00	15%	12,850	8,815	16.62%	12.25%
71.00	23.00	15%	12,847	9,421	17.10%	12.50%
72.00	23.00	15%	12,844	10,027	17.59%	12.74%
73.00	23.00	15%	12,841	10,633	18.09%	12.97%
74.00	23.00	15%	12,838	11,239	18.58%	13.20%
75.00	23.00	15%	12,835	11,845	19.09%	13.42%
76.00	23.00	15%	12,832	12,450	19.60%	13.64%
77.00	23.00	15%	12,829	13,056	20.11%	13.86%
78.00	23.00	15%	12,826	13,662	20.62%	14.08%
79.00	23.00	15%	12,823	14,268	21.15%	14.30%
80.00	23.00	15%	12,820	14,874	21.67%	14.51%
60.00	25.00	15%	18,989	3,489	12.55%	10.11%
61.00	25.00	15%	17,703	4,095	13.00%	10.36%
62.00	25.00	15%	16,416	4,700	13.46%	10.60%
63.00	25.00	15%	15,130	5,306	13.92%	10.85%
64.00	25.00	15%	14,103	5,912	14.39%	11.10%
65.00	25.00	15%	13,131	6,518	14.86%	11.36%
66.00	25.00	15%	12,832	7,124	15.33%	11.60%
67.00	25.00	15%	12,829	7,730	15.81%	11.84%
68.00	25.00	15%	12,826	8,335	16.29%	12.08%
69.00	25.00	15%	12,823	8,941	16.77%	12.32%
70.00	25.00	15%	12,820	9,547	17.26%	12.57%
71.00	25.00	15%	12,817	10,153	17.76%	12.81%
72.00	25.00	15%	12,814	10,759	18.25%	13.04%
73.00	25.00	15%	12,811	11,365	18.76%	13.27%
74.00	25.00	15%	12,808	11,970	19.27%	13.49%
75.00	25.00	15%	12,805	12,576	19.78%	13.71%
76.00	25.00	15%	12,802	13,182	20.30%	13.93%
77.00	25.00	15%	12,799	13,788	20.82%	14.16%
78.00	25.00	15%	12,796	14,394	21.35%	14.38%
79.00	25.00	15%	12,793	15,000	21.88%	14.58%
80.00	25.00	15%	12,790	15,605	22.42%	14.77%

Table 8.11. (Continued)

BASE SCENARIO

RESIDENTIAL SELLING PRICE ($/1000 m^3)	INDUSTRAL SELLING PRICE ($/1000 m^3)	EQUITY/PROJECT RATIO	EQUITY REQUIREMENT	NET PRESENT VALUE ($ 1000)	IRR	MIRR
60.00	27.00	15%	17,167	4,220	13.12%	10.41%
61.00	27.00	15%	15,880	4,826	13.58%	10.66%
62.00	27.00	15%	14,696	5,432	14.05%	10.91%
63.00	27.00	15%	13,723	6,038	14.52%	11.17%
64.00	27.00	15%	12,809	6,644	14.99%	11.42%
65.00	27.00	15%	12,806	7,250	15.47%	11.66%
66.00	27.00	15%	12,803	7,855	15.95%	11.90%
67.00	27.00	15%	12,800	8,461	16.44%	12.15%
68.00	27.00	15%	12,797	9,067	16.93%	12.39%
69.00	27.00	15%	12,794	9,673	17.42%	12.64%
70.00	27.00	15%	12,791	10,279	17.92%	12.88%
71.00	27.00	15%	12,788	10,885	18.42%	13.12%
72.00	27.00	15%	12,785	11,490	18.93%	13.34%
73.00	27.00	15%	12,782	12,096	19.45%	13.56%
74.00	27.00	15%	12,779	12,702	19.97%	13.79%
75.00	27.00	15%	12,776	13,308	20.49%	14.01%
76.00	27.00	15%	12,773	13,914	21.02%	14.24%
77.00	27.00	15%	12,770	14,520	21.55%	14.46%
78.00	27.00	15%	12,767	15,125	22.09%	14.66%
79.00	27.00	15%	12,764	15,731	22.64%	14.85%
80.00	27.00	15%	12,761	16,337	23.18%	15.04%
60.00	29.00	15%	15,344	4,952	13.71%	10.72%
61.00	29.00	15%	14,316	5,558	14.18%	10.97%
62.00	29.00	15%	13,343	6,164	14.65%	11.23%
63.00	29.00	15%	12,783	6,770	15.13%	11.48%
64.00	29.00	15%	12,780	7,375	15.61%	11.73%
65.00	29.00	15%	12,777	7,981	16.10%	11.97%
66.00	29.00	15%	12,774	8,587	16.59%	12.21%
67.00	29.00	15%	12,771	9,193	17.08%	12.46%
68.00	29.00	15%	12,768	9,799	17.58%	12.71%
69.00	29.00	15%	12,765	10,405	18.09%	12.96%
70.00	29.00	15%	12,762	11,010	18.60%	13.19%
71.00	29.00	15%	12,759	11,616	19.11%	13.41%
72.00	29.00	15%	12,756	12,222	19.63%	13.64%
73.00	29.00	15%	12,753	12,828	20.16%	13.86%
74.00	29.00	15%	12,749	13,434	20.69%	14.09%
75.00	29.00	15%	12,746	14,040	21.22%	14.32%
76.00	29.00	15%	12,743	14,645	21.76%	14.54%
77.00	29.00	15%	12,740	15,251	22.31%	14.74%
78.00	29.00	15%	12,737	15,857	22.86%	14.93%
79.00	29.00	15%	12,734	16,463	23.41%	15.11%
80.00	29.00	15%	12,731	17,069	23.97%	15.30%

Table 8.12. Results of Pessimistic Scenario

PESIMISTIC SCENARIO

RESIDENTIAL SELLING PRICE ($/1000 m^3)	INDUSTRAL SELLING PRICE ($/1000 m^3)	EQUITY/PROJECT RATIO	EQUITY REQUIREMENT	NET PRESENT VALUE ($ 1000)	IRR	MIRR
60.00	21.00	15%	63,887	-5,326	6.38%	6.68%
61.00	21.00	15%	60,222	-4,809	6.73%	6.87%
62.00	21.00	15%	56,557	-4,293	7.08%	7.06%
63.00	21.00	15%	52,998	-3,777	7.42%	7.26%
64.00	21.00	15%	50,018	-3,260	7.77%	7.45%
65.00	21.00	15%	47,038	-2,744	8.12%	7.65%
66.00	21.00	15%	44,058	-2,227	8.47%	7.84%
67.00	21.00	15%	41,078	-1,711	8.82%	8.04%
68.00	21.00	15%	38,579	-1,194	9.18%	8.24%
69.00	21.00	15%	36,226	-678	9.53%	8.44%
70.00	21.00	15%	33,872	-162	9.89%	8.64%
71.00	21.00	15%	31,519	355	10.25%	8.84%
72.00	21.00	15%	29,166	871	10.61%	9.04%
73.00	21.00	15%	27,298	1,388	10.97%	9.25%
74.00	21.00	15%	25,552	1,904	11.33%	9.45%
75.00	21.00	15%	23,944	2,420	11.70%	9.66%
76.00	21.00	15%	22,335	2,937	12.07%	9.87%
77.00	21.00	15%	20,727	3,453	12.44%	10.08%
78.00	21.00	15%	19,269	3,970	12.81%	10.29%
79.00	21.00	15%	18,175	4,486	13.19%	10.50%
80.00	21.00	15%	17,082	5,002	13.56%	10.71%
60.00	23.00	15%	59,039	-4,704	6.78%	6.90%
61.00	23.00	15%	55,374	-4,187	7.13%	7.10%
62.00	23.00	15%	51,963	-3,671	7.48%	7.29%
63.00	23.00	15%	48,983	-3,155	7.83%	7.49%
64.00	23.00	15%	46,003	-2,638	8.18%	7.68%
65.00	23.00	15%	43,023	-2,122	8.53%	7.88%
66.00	23.00	15%	40,049	-1,605	8.89%	8.08%
67.00	23.00	15%	37,696	-1,089	9.24%	8.28%
68.00	23.00	15%	35,343	-573	9.60%	8.48%
69.00	23.00	15%	32,989	-56	9.96%	8.68%
70.00	23.00	15%	30,636	460	10.32%	8.88%
71.00	23.00	15%	28,354	977	10.68%	9.08%
72.00	23.00	15%	26,571	1,493	11.05%	9.29%
73.00	23.00	15%	24,940	2,010	11.42%	9.50%
74.00	23.00	15%	23,332	2,526	11.78%	9.71%
75.00	23.00	15%	21,724	3,042	12.16%	9.92%
76.00	23.00	15%	20,115	3,559	12.53%	10.13%
77.00	23.00	15%	18,813	4,075	12.90%	10.34%
78.00	23.00	15%	17,720	4,592	13.28%	10.55%
79.00	23.00	15%	16,626	5,108	13.66%	10.75%
80.00	23.00	15%	15,532	5,624	14.05%	10.96%
60.00	25.00	15%	54,191	-4,082	7.18%	7.13%
61.00	25.00	15%	50,927	-3,565	7.54%	7.32%
62.00	25.00	15%	47,948	-3,049	7.89%	7.52%
63.00	25.00	15%	44,968	-2,533	8.24%	7.72%
64.00	25.00	15%	41,988	-2,016	8.60%	7.92%
65.00	25.00	15%	39,166	-1,500	8.95%	8.11%
66.00	25.00	15%	36,813	-983	9.31%	8.31%
67.00	25.00	15%	34,460	-467	9.67%	8.52%
68.00	25.00	15%	32,106	49	10.03%	8.72%
69.00	25.00	15%	29,753	566	10.40%	8.92%
70.00	25.00	15%	27,626	1,082	10.76%	9.13%
71.00	25.00	15%	25,937	1,599	11.13%	9.33%
72.00	25.00	15%	24,329	2,115	11.50%	9.54%
73.00	25.00	15%	22,720	2,631	11.87%	9.75%
74.00	25.00	15%	21,112	3,148	12.25%	9.97%
75.00	25.00	15%	19,504	3,664	12.62%	10.18%
76.00	25.00	15%	18,357	4,181	13.00%	10.39%
77.00	25.00	15%	17,264	4,697	13.38%	10.59%
78.00	25.00	15%	16,170	5,214	13.76%	10.80%
79.00	25.00	15%	15,077	5,730	14.15%	11.01%
80.00	25.00	15%	14,149	6,246	14.54%	11.23%

Table 8.12. (Continued)

PESIMISTIC SCENARIO

RESIDENTIAL SELLING PRICE ($/1000 m^3)	INDUSTRAL SELLING PRICE ($/1000 m^3)	EQUITY/PROJECT RATIO	EQUITY REQUIREMENT	NET PRESENT VALUE ($ 1000)	IRR	MIRR
60.00	27.00	15%	49,892	-3,460	7.59%	7.36%
61.00	27.00	15%	46,912	-2,944	7.95%	7.55%
62.00	27.00	15%	43,932	-2,427	8.30%	7.75%
63.00	27.00	15%	40,953	-1,911	8.66%	7.95%
64.00	27.00	15%	38,283	-1,394	9.02%	8.15%
65.00	27.00	15%	35,930	-878	9.38%	8.35%
66.00	27.00	15%	33,577	-362	9.75%	8.56%
67.00	27.00	15%	31,224	155	10.11%	8.76%
68.00	27.00	15%	28,870	671	10.48%	8.96%
69.00	27.00	15%	26,934	1,188	10.84%	9.17%
70.00	27.00	15%	25,325	1,704	11.21%	9.38%
71.00	27.00	15%	23,717	2,221	11.59%	9.59%
72.00	27.00	15%	22,109	2,737	11.96%	9.80%
73.00	27.00	15%	20,500	3,253	12.34%	10.02%
74.00	27.00	15%	18,995	3,770	12.72%	10.23%
75.00	27.00	15%	17,902	4,286	13.10%	10.43%
76.00	27.00	15%	16,808	4,803	13.48%	10.64%
77.00	27.00	15%	15,714	5,319	13.87%	10.85%
78.00	27.00	15%	14,652	5,835	14.26%	11.06%
79.00	27.00	15%	13,826	6,352	14.65%	11.28%
80.00	27.00	15%	12,999	6,868	15.04%	11.48%
60.00	29.00	15%	45,877	-2,838	8.01%	7.59%
61.00	29.00	15%	42,897	-2,322	8.37%	7.79%
62.00	29.00	15%	39,917	-1,805	8.73%	7.99%
63.00	29.00	15%	37,401	-1,289	9.09%	8.19%
64.00	29.00	15%	35,047	-772	9.45%	8.39%
65.00	29.00	15%	32,694	-256	9.82%	8.60%
66.00	29.00	15%	30,341	260	10.19%	8.80%
67.00	29.00	15%	27,987	777	10.55%	9.01%
68.00	29.00	15%	26,322	1,293	10.92%	9.22%
69.00	29.00	15%	24,714	1,810	11.30%	9.43%
70.00	29.00	15%	23,105	2,326	11.67%	9.64%
71.00	29.00	15%	21,497	2,842	12.05%	9.85%
72.00	29.00	15%	19,889	3,359	12.43%	10.07%
73.00	29.00	15%	18,540	3,875	12.81%	10.27%
74.00	29.00	15%	17,446	4,392	13.20%	10.48%
75.00	29.00	15%	16,352	4,908	13.58%	10.69%
76.00	29.00	15%	15,259	5,425	13.97%	10.90%
77.00	29.00	15%	14,329	5,941	14.36%	11.12%
78.00	29.00	15%	13,503	6,457	14.76%	11.33%
79.00	29.00	15%	12,841	6,974	15.16%	11.54%
80.00	29.00	15%	12,838	7,490	15.56%	11.74%

Table 8.13. Results of Optimistic Scenario

OPTIMISTIC SCENARIO

RESIDENTIAL SELLING PRICE ($/1000 m^3)	INDUSTRAL SELLING PRICE ($/1000 m^3)	EQUITY/PROJECT RATIO	EQUITY REQUIREMENT	NET PRESENT VALUE ($ 1000)	IRR	MIRR
60.00	21.00	15%	12,829	9,615	17.25%	12.58%
61.00	21.00	15%	12,826	10,314	17.82%	12.86%
62.00	21.00	15%	12,822	11,013	18.39%	13.13%
63.00	21.00	15%	12,819	11,711	18.97%	13.38%
64.00	21.00	15%	12,815	12,410	19.55%	13.64%
65.00	21.00	15%	12,812	13,109	20.14%	13.89%
66.00	21.00	15%	12,808	13,807	20.74%	14.15%
67.00	21.00	15%	12,805	14,506	21.34%	14.40%
68.00	21.00	15%	12,801	15,205	21.95%	14.64%
69.00	21.00	15%	12,798	15,903	22.57%	14.85%
70.00	21.00	15%	12,794	16,602	23.19%	15.07%
71.00	21.00	15%	12,791	17,301	23.82%	15.28%
72.00	21.00	15%	12,788	17,999	24.46%	15.49%
73.00	21.00	15%	12,784	18,698	25.11%	15.70%
74.00	21.00	15%	12,781	19,397	25.76%	15.91%
75.00	21.00	15%	12,777	20,095	26.42%	16.07%
76.00	21.00	15%	12,774	20,794	27.08%	16.22%
77.00	21.00	15%	12,770	21,493	27.75%	16.37%
78.00	21.00	15%	12,767	22,191	28.43%	16.52%
79.00	21.00	15%	12,763	22,890	29.12%	16.66%
80.00	21.00	15%	12,760	23,589	29.81%	16.81%
60.00	23.00	15%	12,795	10,457	18.01%	12.94%
61.00	23.00	15%	12,792	11,155	18.58%	13.21%
62.00	23.00	15%	12,788	11,854	19.17%	13.47%
63.00	23.00	15%	12,785	12,553	19.76%	13.72%
64.00	23.00	15%	12,781	13,251	20.36%	13.98%
65.00	23.00	15%	12,778	13,950	20.96%	14.24%
66.00	23.00	15%	12,775	14,649	21.58%	14.50%
67.00	23.00	15%	12,771	15,347	22.19%	14.72%
68.00	23.00	15%	12,768	16,046	22.82%	14.94%
69.00	23.00	15%	12,764	16,745	23.45%	15.16%
70.00	23.00	15%	12,761	17,443	24.09%	15.37%
71.00	23.00	15%	12,757	18,142	24.74%	15.58%
72.00	23.00	15%	12,754	18,841	25.39%	15.79%
73.00	23.00	15%	12,750	19,539	26.05%	15.99%
74.00	23.00	15%	12,747	20,238	26.72%	16.15%
75.00	23.00	15%	12,743	20,937	27.39%	16.30%
76.00	23.00	15%	12,740	21,635	28.07%	16.45%
77.00	23.00	15%	12,736	22,334	28.76%	16.60%
78.00	23.00	15%	12,733	23,033	29.45%	16.75%
79.00	23.00	15%	12,730	23,731	30.16%	16.89%
80.00	23.00	15%	12,726	24,430	30.86%	17.03%
60.00	25.00	15%	12,761	11,298	18.78%	13.29%
61.00	25.00	15%	12,758	11,997	19.38%	13.55%
62.00	25.00	15%	12,755	12,695	19.98%	13.81%
63.00	25.00	15%	12,751	13,394	20.58%	14.07%
64.00	25.00	15%	12,748	14,093	21.20%	14.33%
65.00	25.00	15%	12,744	14,791	21.81%	14.59%
66.00	25.00	15%	12,741	15,490	22.44%	14.81%
67.00	25.00	15%	12,737	16,189	23.08%	15.03%
68.00	25.00	15%	12,734	16,887	23.72%	15.25%
69.00	25.00	15%	12,730	17,586	24.36%	15.46%
70.00	25.00	15%	12,727	18,285	25.02%	15.67%
71.00	25.00	15%	12,723	18,983	25.68%	15.89%
72.00	25.00	15%	12,720	19,682	26.35%	16.08%
73.00	25.00	15%	12,716	20,381	27.03%	16.23%
74.00	25.00	15%	12,713	21,079	27.71%	16.39%
75.00	25.00	15%	12,710	21,778	28.40%	16.54%
76.00	25.00	15%	12,706	22,477	29.10%	16.69%
77.00	25.00	15%	12,703	23,175	29.80%	16.83%
78.00	25.00	15%	12,699	23,874	30.51%	16.98%
79.00	25.00	15%	12,696	24,573	31.23%	17.12%
80.00	25.00	15%	12,692	25,272	31.95%	17.26%

Table 8.13. (Continued)

OPTIMISTIC SCENARIO

RESIDENTIAL SELLING PRICE ($/1000 m^3)	INDUSTRAL SELLING PRICE ($/1000 m^3)	EQUITY/PROJECT RATIO	EQUITY REQUIREMENT	NET PRESENT VALUE ($ 1000)	IRR	MIRR
60.00	27.00	15%	12,728	12,139	19.59%	13.64%
61.00	27.00	15%	12,724	12,838	20.20%	13.90%
62.00	27.00	15%	12,721	13,537	20.81%	14.16%
63.00	27.00	15%	12,717	14,235	21.43%	14.42%
64.00	27.00	15%	12,714	14,934	22.06%	14.68%
65.00	27.00	15%	12,710	15,633	22.69%	14.90%
66.00	27.00	15%	12,707	16,332	23.34%	15.12%
67.00	27.00	15%	12,703	17,030	23.99%	15.34%
68.00	27.00	15%	12,700	17,729	24.64%	15.55%
69.00	27.00	15%	12,697	18,428	25.31%	15.77%
70.00	27.00	15%	12,693	19,126	25.98%	15.98%
71.00	27.00	15%	12,690	19,825	26.66%	16.16%
72.00	27.00	15%	12,686	20,524	27.34%	16.32%
73.00	27.00	15%	12,683	21,222	28.04%	16.47%
74.00	27.00	15%	12,679	21,921	28.74%	16.62%
75.00	27.00	15%	12,676	22,620	29.44%	16.77%
76.00	27.00	15%	12,672	23,318	30.16%	16.92%
77.00	27.00	15%	12,669	24,017	30.88%	17.06%
78.00	27.00	15%	12,665	24,716	31.61%	17.20%
79.00	27.00	15%	12,662	25,414	32.34%	17.35%
80.00	27.00	15%	12,658	26,113	33.08%	17.48%
60.00	29.00	15%	12,694	12,981	20.42%	13.99%
61.00	29.00	15%	12,690	13,680	21.04%	14.25%
62.00	29.00	15%	12,687	14,378	21.67%	14.52%
63.00	29.00	15%	12,683	15,077	22.31%	14.77%
64.00	29.00	15%	12,680	15,776	22.95%	14.99%
65.00	29.00	15%	12,677	16,474	23.60%	15.21%
66.00	29.00	15%	12,673	17,173	24.26%	15.43%
67.00	29.00	15%	12,670	17,872	24.93%	15.65%
68.00	29.00	15%	12,666	18,570	25.60%	15.86%
69.00	29.00	15%	12,663	19,269	26.28%	16.08%
70.00	29.00	15%	12,659	19,968	26.97%	16.25%
71.00	29.00	15%	12,656	20,666	27.67%	16.40%
72.00	29.00	15%	12,652	21,365	28.37%	16.56%
73.00	29.00	15%	12,649	22,064	29.08%	16.71%
74.00	29.00	15%	12,645	22,762	29.80%	16.86%
75.00	29.00	15%	12,642	23,461	30.52%	17.01%
76.00	29.00	15%	12,638	24,160	31.25%	17.15%
77.00	29.00	15%	12,635	24,858	31.99%	17.29%
78.00	29.00	15%	12,632	25,557	32.73%	17.43%
79.00	29.00	15%	12,628	26,256	33.48%	17.57%
80.00	29.00	15%	12,625	26,954	34.24%	17.71%

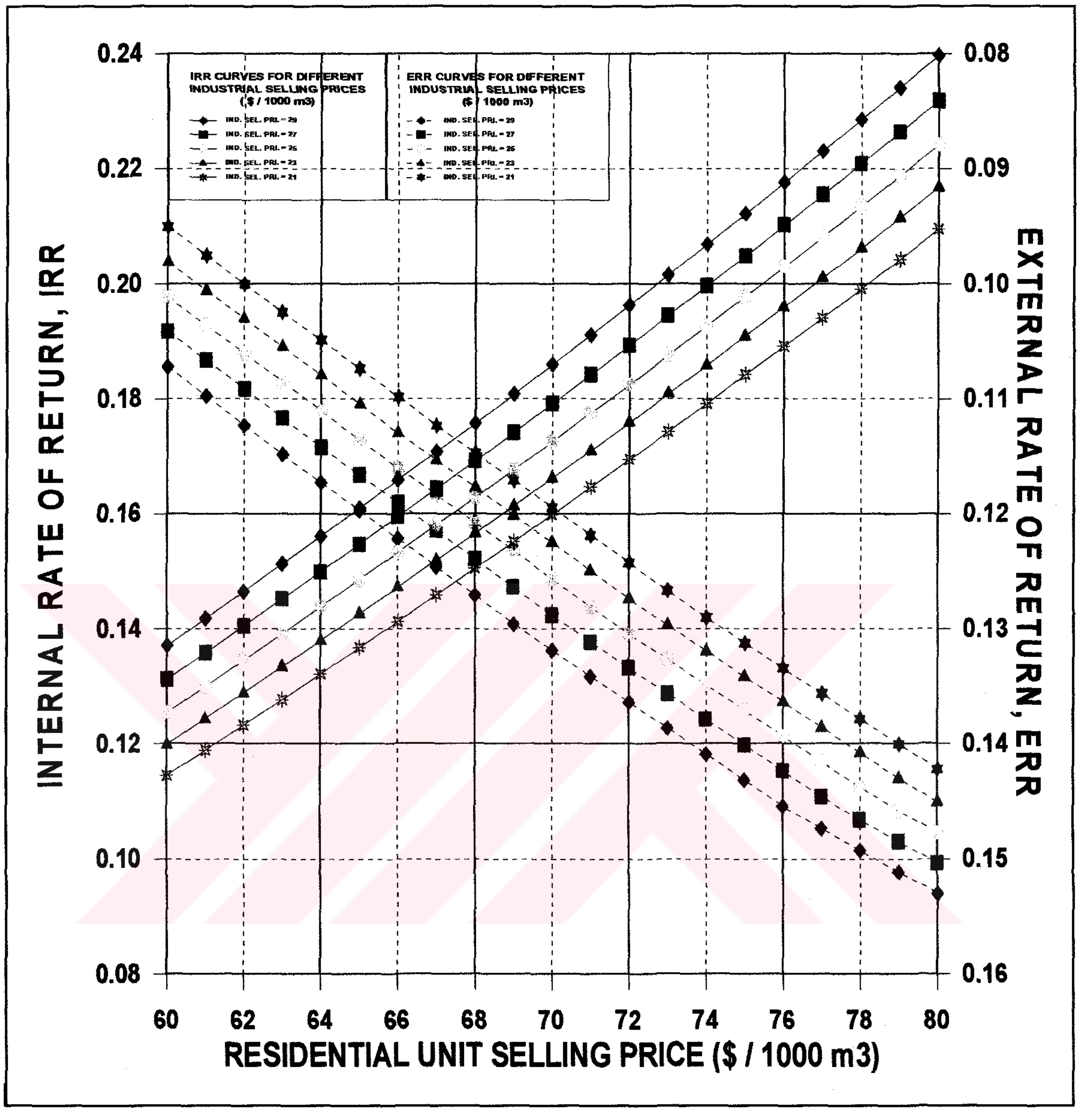

Figure 8.6. IRR & ERR values for different
Residential & Industrial Unit Selling Prices
" Base Scenario"

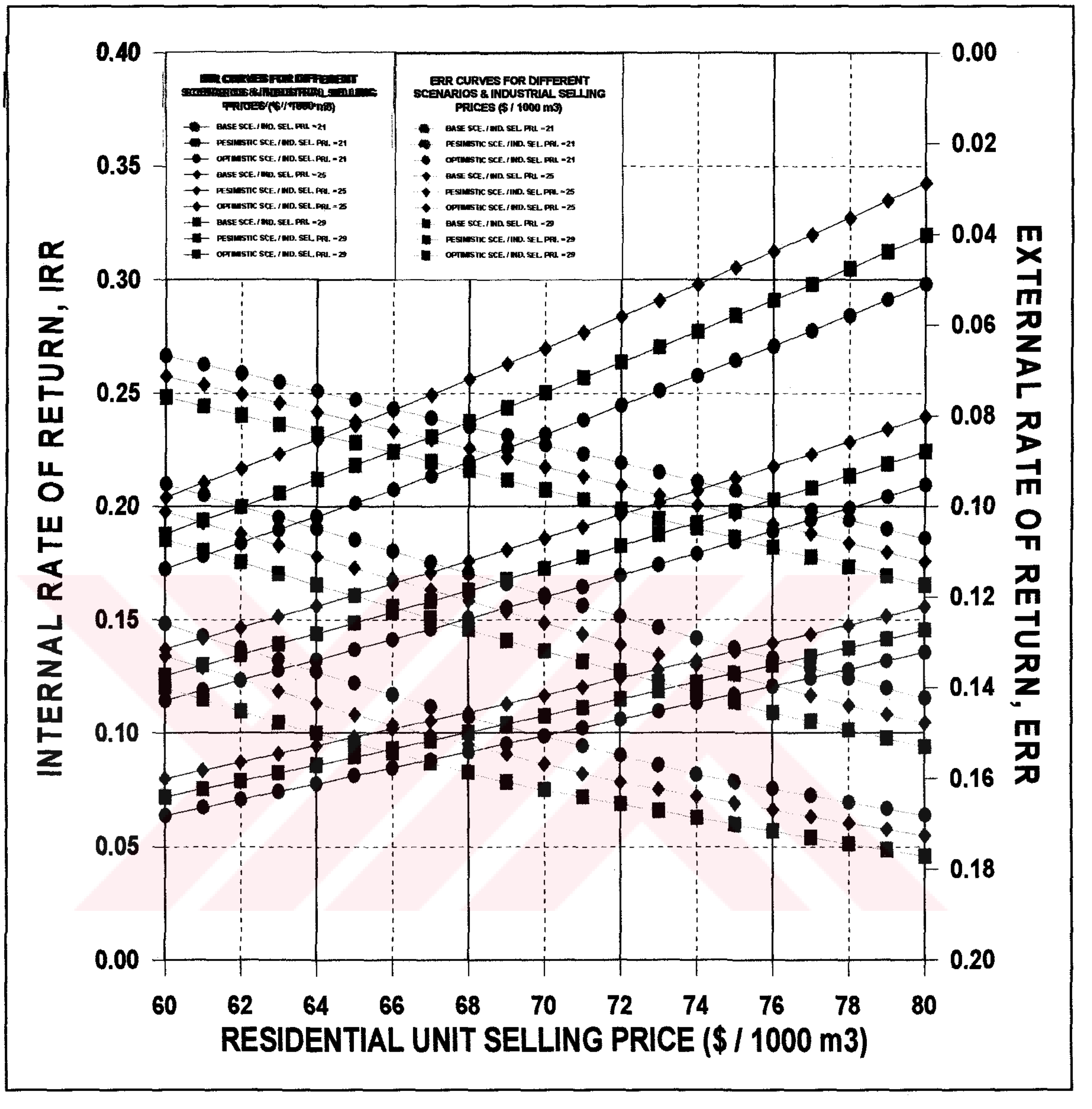

Figure 8.7. IRR & ERR values for different Residential & Industrial Unit Selling Prices for three different scenarios

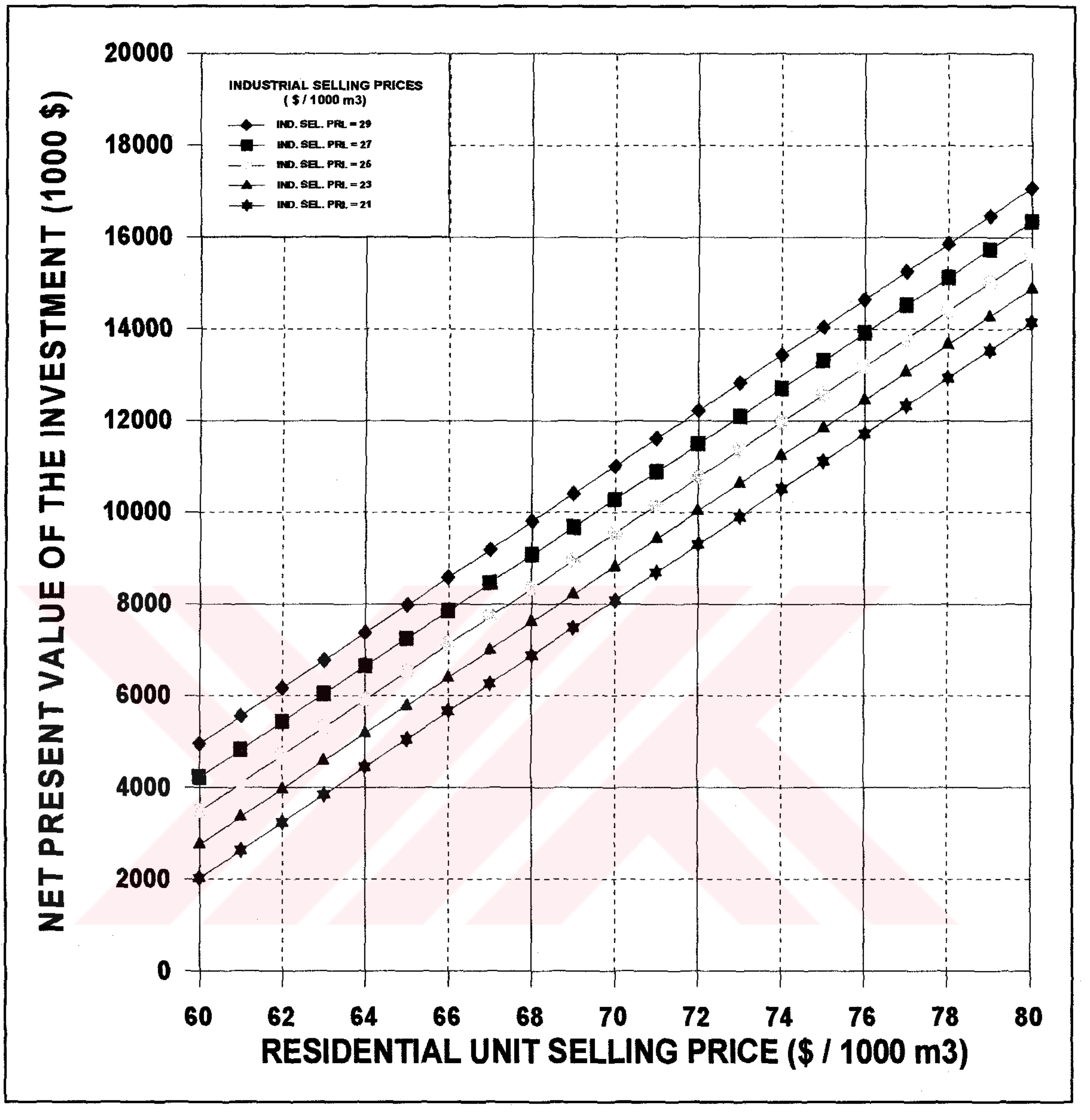

Figure 8.8. Net Present Value of the Investment vs. Residential Unit Selling Price "Base Scenario"

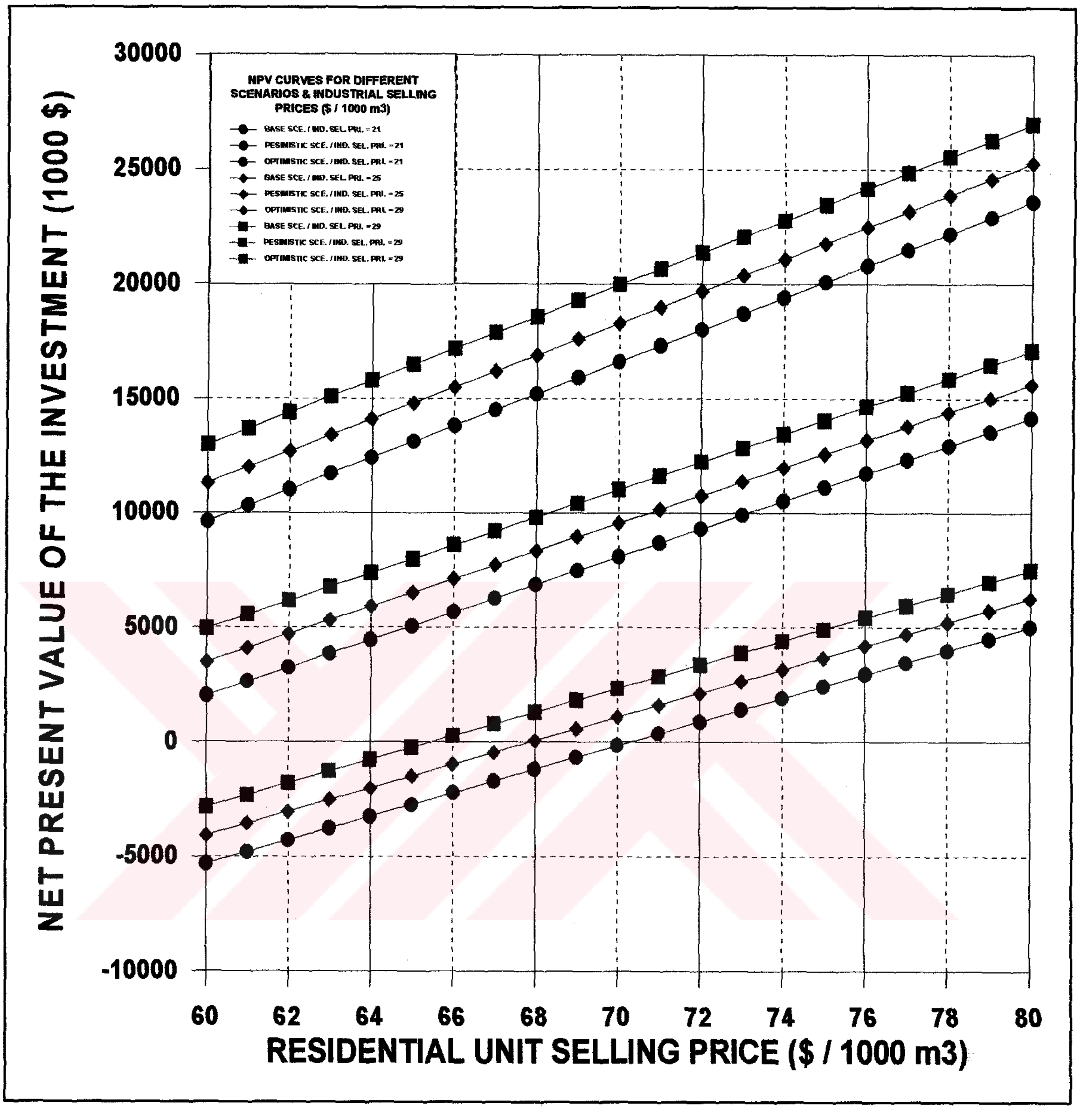

Figure 8.9. Net Present Value of the Investment vs. Residential Unit Selling Price (For different Industrial Selling Prices and three different scenarios)

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APPENDIX A
LISTING OF PROGRAMS AND DATA FILES

A.1. Listing of Netlow

```
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
C                                                                     C
C  Netlow                                                             C
C  Fatih CAN                                                          C
C  April, 1994                                                        C
C                                                                     C
C  = Calculates the pressure map both tree structured and looped low pressure networks =  C
C                                                                     C
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC


        implicit real*8 (a-h, o-z)
        real*8 l

C       i, j: Node indices
C       itmax: # of iterations allowed
C       iter: counter for iterations made

        integer i, j, n, iter, itmax

C       conv: indicator of convergence

        logical conv

        logical incid (99,99), pgiven(99)
        dimension p(99), q(99), d(99,99), l(99,99),
     &            co(99, 99), a(99, 99), ql(99, 99)

C       eps: convergence criteria

        parameter (co1=917.1825e-9, eps=10e-4, itmax=1000)
        open (unit=5, file='result.dat')

C============== DATA SECTION ==========================================

C        N: # of Nodes

        data n /9/

C       PSC: Pressure at standard conditions [N/m2 (Pa)]
C       TSC: Temperature at standard conditions [°K]
C       TAV: Temperature at standard conditions [°K]

        data psc, tsc, tav /1.014e5, 288.2d0, 283d0/

C       YM: Molecular Weight of the gas mixture

        data ym /16.03d0/

C       PGIVEN [Pa] : is true if pressure is specified at node i,
C       false if pressure is not specified at node i.


        data (pgiven(i), i=1, 9) /1, 0, 0, 0, 0, 0, 0, 0, 0/

C       Start-up pressures [Pa]
```

```
      data (p(i), i=1, 9) /3300, 2500, 1000, 1500, 2000, 2100,
     &              1600, 1700, 1800/

C           Flow rates at nodes [m3/h]

      data (q(i), i=1, 9) /1200,-60, -220, -200, -300, -80,
     & 40, -140, -160/

C            Data representing the interconnected nodes

      data ((incid(i,j), j=1,1), i=1,1) /0/
      data ((incid(i,j), j=1,2), i=2,2) /1, 0/
      data ((incid(i,j), j=1,3), i=3,3) /0, 1, 0/
      data ((incid(i,j), j=1,4), i=4,4) /0, 0, 1, 0/
      data ((incid(i,j), j=1,5), i=5,5) /0, 0, 0, 1, 0/
      data ((incid(i,j), j=1,6), i=6,6) /0, 0, 0, 0, 1, 0/
      data ((incid(i,j), j=1,7), i=7,7) /0, 0, 0, 0, 0, 1, 0/
      data ((incid(i,j), j=1,8), i=8,8) /1, 0, 0, 0, 0, 0, 1, 0/
      data ((incid(i,j), j=1,9), i=9,9) /0, 1, 0, 1, 0, 1, 0, 1, 0/

C           Pipe diameters (d) [m] and lengths (L) [m]. {Follows the order of
C           incid (i,j) }.

      data ((d(i,j), l(i,j), j=1,1), i=1,1) /0, 0/
      data ((d(i,j), l(i,j), j=1,2), i=2,2) /0.3071d0, 450d0, 0, 0/
      data ((d(i,j), l(i,j), j=1,3), i=3,3) /0, 0, 0.3071d0, 180d0,0,0/
      data ((d(i,j), l(i,j), j=1,4), i=4,4) /0, 0, 0, 0,0.2051d0,500d0,
     &                          0, 0/
     &data ((d(i,j), l(i,j), j=1,5), i=5,5) /0, 0, 0, 0, 0, 0,
     &                         0.1023d0, 480d0, 0d0, 0d0/
      data ((d(i,j), l(i,j), j=1,6), i=6,6) /0, 0, 0, 0, 0, 0, 0, 0,
     &                          0.1023d0, 220d0, 0, 0/
      data ((d(i,j), l(i,j), j=1,7), i=7,7) /0, 0, 0, 0, 0, 0, 0, 0,
     &                          0, 0, 0.1023d0, 240d0,0,0/
      data ((d(i,j), l(i,j), j=1,8), i=8,8) /0.2589d0, 280d0, 0, 0,0,0,
     &                          0, 0, 0, 0, 0, 0,
     &                          0.1023d0, 660d0, 0, 0/
      data ((d(i,j), l(i,j), j=1,9), i=9,9) /0, 0, 0.1541d0, 420d0,0,0,
     &                          0.1541d0, 480d0, 0, 0,
     &                          0.1023d0, 290d0, 0, 0,
     &                          0.1541d0, 370d0, 0, 0/
C============== End of Data section ======================================

C==============  MAIN PROGRAM     =========================================

      do 5 i=1, 9
      q(i)= q(i)/3600d0
00005 continue

      do 10 i=1, 9
      do 10 j=1, i

      if (i.eq.j) go to 10
      if ( incid(i,j)) co(i,j)= co1* psc* ym* tav/ tsc**2d0*
     &l(i,j)/d(i,j)**(5.333d0)
      incid(j, i)= incid(i, j)
      d(j,i)= d(i,j)
      l(j,i)= l(i,j)
      co(j,i)= co(i,j)

00010 continue


C==============  PRINT OUT INITIAL INFIRMATION ABOUT NETWORK     ===========
      write (5,*)
      write (5,*) '====== INITIAL INFORMATION ABOUT NETWORK =======' ==============
      write (5,*)
      write (5,100) n
      write (5,101) itmax
      write (5,102) eps
      write (5,103) (i,p(i),pgiven(i), i=1,n)
      write (5,*)
      do 15 i=1, n
      00015 write (5,104) i, i, n, (incid(i,j), j=1,n)
      write (5,*)
      do 16 i=1, n
00016 write (5,105) i, i, n, (d(i,j), j=1,n)
      write (5,*)
      do 17 i=1, n
00017 write (5,106) i, i, n, (l(i,j), j=1,n)
      write (5,107)
      write (5,108) (i, i=1,n)

      do 40 iter=1, itmax
```

```
         conv=.true.
         do 30 j=1, 9
         if ( pgiven(j) ) goto 30
         dnumer= 0d0
         denom= 0d0
         do 20 i=1, 9
                  if ( .not. incid(i,j)) goto 20
                           a(i,j)= 1d0/dsqrt(co(i,j)*dabs(p(i)-p(j)))
                           dnumer= dnumer+ a(i,j)*p(i)
                           denom= denom+ a(i,j)
00020    continue
         savep= p(j)
         p(j)=  (dnumer- q(j)/dabs(q(j))*q(j))/ denom
         if (dabs(savep- p(j)) .ge. eps) conv= .false.
00030    continue
         write (5,109) iter, (p(i), i=1,n)
         if ( conv) goto 50
00040    continue


00050    do 60 i=1, n
         do 60 j=1, i
         ql(i,j)= 0d0
         ql(j,i)= 0d0
         if ( .not. incid(i,j) ) goto 60
         ql(i,j) = (p(i)- p(j))/dsqrt(co(i,j)* dabs(p(i)- p(j)))*3600d0
         ql(j,i)= -ql(i,j)
00060 continue

C--->    Print Final Pressures and Inter-Nodal Flows

         write (5,110) iter
         write (5,111) n

         do 70 i=1,n
00070    write (5, 112) i, p(i), (ql(i,j), j=1,n)
         stop

C==============  Format Statements ========================================

         00100 format (' # of Nodes ', I3)
         00101 format (' Max. iterations allowed ', I5)
         00102 format (' Convergence Criteria ', f8.4)
         00103 format (//2x,'  I',2x,'  P(I) ',4x,'PGIVEN(I)'/
        &2x,'---',2x,'-------',4x,'---------'/
        &(2x,i3,2x,f8.2,7x,l2))
00104    format (2x,'INCID(',i2,',',' 1)','...','INCID(',i2,',',i2,')'
        &,' =',25(l2)/)
00105    format (2x,'D(',i2,',',' 1)','...','D(',i2,',',i2,')'
        &,' =',25(f10.4)/)
00106    format (2x,'L(',i2,',',' 1)','...','L(',i2,',',i2,')'
        &              ,' =',25(f10.2)/)
00107    format (//2x,'ITER',4x,'PRESSURE AT NODE')
00108    format (/14x,25(i2,10x))
00109    format (2x,i4,4x,25(f10.4,2x))
00110    format (//2x,'PRESSURE AND INTER-NODAL FLOWS AFTER  '
        &              ,I3,' ITERATIONS ARE ')
00111    format (/2x,' I',4x,'P(I) [Pa]',4x,'Q(I, 1)...Q(I,',I2,')
        &              ,' [m3/h]'/)
00112    format (2x,i2,4x,25(f10.4,2x)/)

C========= End of Format Statements  ====================================

C---> end main program
      end
```

A.2. Listing of Nethigh

```
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
C                                                                     C
C  Nethigh                                                            C
C  Fatih CAN                                                          C
C  April, 1994                                                        C
C                                                                     C
C  = Calculates the pressure map both tree structured and looped high pressure networks =   C
C                                                                     C
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC

      implicit real*8 (a-h, o-z)
      real*8 l

C     i, j: Node indicis
C     itmax: # of iterations allowed
C     iter: counter for iterations made

      integer i, j, n, iter, itmax

C     conv: indicator of convergence

      logical conv

      logical incid(99,99), pgiven(99)
      dimension p(99), q(99), d(99,99), l(99,99),
     &          co(99,99), a(99,99), ql(99,99)

C     eps: convergence criteria

      parameter (co1=1.834365e-6, eps=10e-3, itmax=1000)
      open (unit=5, file='result.dat')

C=============  DATA SECTION   ======================================

C     N: # of Nodes

      data n /9/

C     PSC: Pressure at standard conditions [N/m2 (Pa)]
C     TSC: Temperature at standard conditions [°K]
C     TAV: Average Temperature [°K]

      data psc, tsc, tav /1.014e5, 288.2, 283d0/

C     PGIVEN [Pa] : is true if pressure is specified at node i,
C     false if pressure is not specified at node i.

      data (pgiven(i), i=1, 9) /1, 0, 0, 0, 0, 0, 0, 0, 0/

C     Start-up pressures  [Pa]

      data (p(i), i=1, 9) /3300d0, 2500d0, 1000d0, 1500d0, 2000d0,
     & 2100d0, 1600d0, 1700d0, 1800d0/

C     Flow rates at nodes [m3/h]

      data (q(i), i=1, 9) /1200d0, -60d0, -220d0, -200d0, -300d0,
     &                     80d0, -40d0, -140d0, -160d0/

C      Data representing the interconnected nodes

      data ((incid(i,j), j=1,1), i=1,1) /0/
      data ((incid(i,j), j=1,2), i=2,2) /1, 0/
      data ((incid(i,j), j=1,3), i=3,3) /0, 1, 0/
      data ((incid(i,j), j=1,4), i=4,4) /0, 0, 1, 0/
      data ((incid(i,j), j=1,5), i=5,5) /0, 0, 0, 1, 0/
      data ((incid(i,j), j=1,6), i=6,6) /0, 0, 0, 0, 1, 0/
      data ((incid(i,j), j=1,7), i=7,7) /0, 0, 0, 0, 0, 1, 0/
      data ((incid(i,j), j=1,8), i=8,8) /1, 0, 0, 0, 0, 0, 1, 0/
      data ((incid(i,j), j=1,9), i=9,9) /0, 1, 0, 1, 0, 1, 0, 1, 0/

C     Pipe diameters (d) [m] and lengths (L) [m]. {Follows the order of
C     incid (i,j)}.

      data ((d(i,j), l(i,j), j=1,1), i=1,1) /0, 0/
      data ((d(i,j), l(i,j), j=1,2), i=2,2) /0.3071d0, 450d0, 0, 0/
      data ((d(i,j), l(i,j), j=1,3), i=3,3) /0, 0, 0.3071d0, 180d0, 0,0/
      data ((d(i,j), l(i,j), j=1,4), i=4,4) /0, 0, 0, 0, 0.2051d0,500d0,
```

```
          &                                   0, 0/
           data ((d(i,j), l(i,j), j=1,5), i=5,5) /0, 0, 0, 0, 0, 0,
          &                                   0.1023d0, 480, 0, 0/
           data ((d(i,j), l(i,j), j=1,6), i=6,6) /0, 0, 0, 0, 0, 0, 0, 0,
          &                                   0.1023d0, 220, 0, 0/
           data ((d(i,j), l(i,j), j=1,7), i=7,7) /0, 0, 0, 0, 0, 0, 0, 0,
          &                                   0, 0, 0.1023d0, 240, 0, 0/
           data ((d(i,j), l(i,j), j=1,8), i=8,8) /0.2589d0, 280, 0, 0, 0, 0,
          &                                   0, 0, 0, 0, 0, 0,
          &                                   0.1023d0, 660, 0, 0/
           data ((d(i,j), l(i,j), j=1,9), i=9,9) /0, 0, 0.1541d0, 420d0, 0,0,
          &                                   0.1541d0, 480d0, 0, 0,
          &                                   0.1023d0, 290d0, 0, 0,
          &                                   0.1541d0, 370d0, 0, 0/

C==============  End of Data section    =================================

C==============  MAIN PROGRAM    =====================================

C--->      Calculate Pseudo Critical Pressure
C          Pseudo Critical Temperature
C          Molecular Weight of the Gas Mixture


           call ppctpc(ypc, ytc, ym)
           tpr= (1.8d0*(tav-273.15d0)+492d0)/ ytc


           do 10 i=1, n
           p(i)= p(i)+ psc
           q(i)= q(i)/3600d0

           do 10 j=1, i

           if (i.eq.j) go to 10
           if ( incid(i,j)) co(i,j)= co1* (psc/tsc)**2*ym*
          &          tav*l(i,j)/d(i,j)**(16d0/3d0)
           incid(j,i)= incid(i,j)
           d(j,i)= d(i,j)
           l(j,i)= l(i,j)
           co(j,i)= co(i,j)

00010      continue


           do 40 iter=1, itmax
           conv=.true.
           do 30 j=1, n
           if ( pgiven(j) ) goto 30
           dnumer= 0d0
           denom= 0d0
           do 20 i=1, n

           if ( .not. incid(i,j)) goto 20

C--------------------->    Calculate Average Pressure
                           pav= pave(p(i),p(j))
                           ppr= pav*1.45038e-4/ ypc

C--------------------->    Calculate Compressibility factor
                           call compress (zav, ppr, tpr)
                           a(i,j)=1d0/dsqrt(co(i,j)*zav*
                         &          dabs(p(i)**2d0-p(j)**2d0))
                           dnumer= dnumer+ a(i,j)*p(i)**2d0
                           denom= denom+ a(i,j)

00020      continue

           savep= p(j)
           p(j)= (q(j)+ dnumer)*
          &1d0/dsqrt((denom* dabs(q(j)+dnumer)))
           write (5,*) 'i',i,'j','p(',j,')',p(j)
C--------->  Compare p(j) with previous p(j)
C          Check for convergence criteria, Eps.

           if (dabs(savep- p(j)) .ge. eps) conv= .false.

00030      continue

           if ( conv) goto 50

00040      continue

00050      do 60 i=1, n
```

```
        do 60 j=1, i

        ql(i,j)= 0d0
        ql(j,i)= 0d0

        if (i .eq. j .or. .not. incid(i,j)) goto 60

        ql(i,j) = (p(i)- p(j))/dsqrt(co(i,j)* dabs(p(i)- p(j)))
        ql(j,i)= -ql(i,j)
        write (5,*) i, j, ql(i,j), ql(j,i)

00060   continue

        do 70 i=1, n
        write (5, *) i, p(i)-psc
00070   continue

        write (5, *) iter
        write (5, *) conv
        end

C--->   End of Main program

CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
C                                                                              C
C   Subroutine compress (zav, ppr, tpr)                                        C
C   Calculates the Z-Factor                                                    C
C                                                                              C
C   Input  : Ppr: Pseudo reduced pressure                                      C
C            Tpr: Pseudo reduced temperature                                   C
C   Output : Zav: Average Compressibility Factor                                C
C                                                                              C
C   Method : Hall-Yarborough z-factor Correlation                              C
C                                                                              C
C                                                                              C
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC

        subroutine compress (zav, ppr, tpr)
        implicit real*8 (a-h, o-z)

        tre=tpr**(-1)
        x1=0d0
        x2=.5d0

C--->   Bracket the root (Zav) before bisection.
        call bracket (ppr, tre, x1, x2)

C--->   Find the root (Zav) with Bisection Method.
        call rootbis (ppr, tre, x1, x2, y)

        zav= 0.06125d0*ppr*tre*dexp(-1.2d0*(1d0-tre)**2)/y
        return
        end

C--->   end of subroutine compress
```

```
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
C                                                                         C
C    Calculates the Pseudo Critic Pressure, Pseudo Critic Temperature    C
C              Molecular Weight                                           C
C                                                                         C
C    Output : ypc: Pseudo Critic Pressure                                 C
C          ytc: Pseudo Critic Temperature                                 C
C          ym : Molecular weight                                          C
C                                                                         C
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
          subroutine ppctpc (ypc, tpc, ym)

          implicit real*8 (a-h, o-z)
          real*8 m
          integer i
          dimension m(15), y(15), pc(15), tc(15)
          parameter (ma= 28.97)

C--->      Read Critical Pressure, Critical Temperature for each component,
C          from the file that contains the composition of mixture,
          open (unit=1, file='comp.dat')

          ym= 0d0
          ypc= 0d0
          ytc= 0d0
          do 10 i=1, 15
          read (1,5) m(i), y(i), pc(i), tc(i)
00005     format (f6.3, 3x, f6.5, 3x, 2(f6.1, 3x))
          ym= ym+ y(i)* m(i)
          ypc= ypc+ y(i)* pc(i)
          ytc= ytc+ y(i)* tc(i)
00010     enddo
          close (1, status='keep')

C--->      Correction for Impurities, H2S, CO2
          cwa= 120d0*((y(2)+y(3))**0.9d0 - (y(2)+y(3))**1.6d0)+
        &             15d0*(dsqrt(y(3))-y(3)**4d0)
          saveytc= ytc
          ytc= ytc-cwa
          ypc= ytc*ypc/(saveytc+y(3)*(1d0-y(3))*cwa)

          return
          end

C--->      End of subroutine ppctpc


CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
C                                                                         C
C    Subroutine that brackets the root                                    C
C                                                                         C
C    Input: Ppr: Pseudo Reduced Pressure                                  C
C         Tpr: Pseudo Reduced Temperature                                 C
C                                                                         C
C    Output: x1: First point bracketing the root                          C
C          x2: Second point bracketing the root                           C
C                                                                         C
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC

          subroutine bracket (ppr, tre, x1, x2)
          implicit real*8 (a-h, o-z)
          integer j, ntry
          logical succes
          external func
          parameter (ntry=40, factor=1.6d0)

          if (x1 .eq. x2) pause ' you have to guess an initial range between
        &              x1 and x2 '
          f1=func(tre, ppr, x1)
          f2=func(tre, ppr, x2)
          succes= .true.
          do 11 j=1, ntry
          if (f1*f2 .lt. 0.) return
          if (abs(f1) .lt. abs(f2)) then
          x1=x1+factor*(x1-x2)
          f1=func(tre, ppr, x1)
          else
          x2=x2+factor*(x2-x1)
          f2=func(tre, ppr, x2)
          endif
00011     enddo
          succes= .false.
0100      pause  'no succes'
```

```
          return
          end

C---->    end of subroutine bracket


CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
C                                                                      C
C   Finds the root (Z-Factor)                                          C
C                                                                      C
C   Input: Ppr: Pseudo Reduced Pressure                                C
C       Tre: Reciprocal Pseudo Reduced Temperature                     C
C       x1 : First point bracketing the root                           C
C       x2 : Second point bracketing the root                          C
C                                                                      C
C   Output: Rtbis: Z-Factor                                            C
C                                                                      C
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC

          subroutine rootbis (ppr, tre, x1, x2, trbis)
          implicit real*8 (a-h, o-z)
          integer j, jmax
          external func
          parameter (ntry=40, factor=1.6, jmax=50, xacc=1.0d-06)

          fmid= func(tre, ppr, x2)
          f=func(tre, ppr, x1)
          if (f*fmid .ge. 0.) pause 'root must be bracketed in rtbis '
          if (f .lt. 0. )then
          rtbis=x1
          dx=x2-x1
          else
          rtbis=x2
          dx=x1-x2
          endif

          do 100 j=1, jmax
          dx=dx*.5d0
          xmid=rtbis+dx
          fmid=func(tre, ppr, xmid)
          if (fmid .le. 0.) rtbis=xmid
          if (abs(dx) .lt. xacc .or. fmid .eq. 0.) return
00100     enddo
          pause 'to many bisections'
          end

C--->     end of subroutine rootbis

CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
C                                                                      C
C   Hall-Yarborough Equation                                           C
C                                                                      C
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC

          function func (tre, ppr, y)

          implicit real*8 (a-h, o-z)
          func = -0.06125d0*ppr*tre*dexp(-1.2d0*(1.0d0-tre)**2)+
     &            (y + y**2 + y**3 - y**4)/(1.0d0-y)**3 -
     &            (14.76d0*tre-9.76d0*tre**2+4.58d0*tre**3)*y**2 +
     &            (90.7d0*tre-242.2d0*tre**2+42.4d0*tre**3)*
     &            y**(2.18d0+2.82d0*tre)
          return
          end

C--->     end of function


CCCCCCCCCCCCCC  Function Paverage   CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC

          function pave(p1 ,p2)
          implicit real*8 (a-h, o-z)

          pave= 2d0/3d0*(p1**3d0- p2**3d0)/(p1**2d0- p2**2d0)
          return
          end

C--->     end of function
```

A.3. Listing of Comp.dat

28.01	0.0345	493.0	227.0	N2
44.01	0.0130	1071.0	548.0	CO2
34.08	0.0000	1306.0	672.0	H2S
16.04	0.8470	668.0	343.0	CH4
30.07	0.0586	708.0	550.0	C2H6
44.10	0.0220	616.0	666.0	C3H8
58.12	0.0035	529.0	735.0	i-C4H10
58.12	0.0058	551.0	765.0	n-C4H10
72.15	0.0027	490.0	829.0	i-C5H12
72.15	0.0025	489.0	845.0	n-C5H12
86.18	0.0028	437.0	913.0	n-C6H14
100.20	0.0028	397.0	972.0	n-C7H16
114.23	0.0015	361.0	1024.0	n-C8H18
128.26	0.0018	332.0	1070.0	n-C9H20
142.29	0.0015	304.0	1112.0	n-C10H22

APPENDIX B

NATURAL GAS COMPRESSION

Gas compression process can be thermodynamically characterized into three types: isothermal compression, isentropic or adiabatic reversible compression, polytropic compression.

Isothermal compression occurs when the temperature is kept constant during the compression process. The pressure-volume behavior of gas is given by:

$$P_1V_1 = P_2V_2 = C \qquad \text{(B.01)}$$

where
P_1, P_2 = gas pressure at states 1 and 2
V_1, V_2 = gas volumes at states 1 and 2
c = constant

If the gas behaves as an ideal gas, no heat is added to or removed from the gas during compression, and the process is frictionless, then the compression process is adiabatic reversible or isentropic (constant entropy). The pressure-volume behavior of a gas under isentropic compression or expansion is given by:

$$P_1V_1^k = P_2V_2^k = C \qquad \text{(B.02)}$$

where k is the isentropic exponent, which is equal to the ratio of the specific heat constant pressure (c_p) and the specific heat at constant volume (c_v)

$$k = c_p / c_v \qquad \text{(B.03)}$$

For real gases under actual conditions (with friction and heat transfer), the compression process is polytropic, where the polytropic exponent *n* applies instead of adiabatic exponent *k*:

$$P_1V_1^n = P_2V_2^n = C \quad \text{(B.04)}$$

The fundamental relationship between flow rate and required ideal horsepower is based on the assumption that the process is ideal isentropic or perfectly reversible adiabatic. According to the general energy equation (Eq. 1.3.20) the theoretical work required to compress a unit of gas from pressure P_1 at state 1 to P_2 at state 2 is given by

$$W = \int_{P_1}^{P_2} VdP + \frac{\Delta u^2}{2g_C} + \frac{g}{g_C}\Delta z + W_{lost} \quad \text{(B.05)}$$

Neglecting frictional losses, and the changes in kinetic and potential energies, the energy balance equation can be written as:

$$W = \int_{P_1}^{P_2} VdP \quad \text{(B.06)}$$

Substituting *V* from Eq. B.2, we get:

$$W = C^{1/k} \int_{P_1}^{P_2} P^{-1/k} dP \quad \text{(B.07)}$$

Integrating this equation, Eq. B.7 becomes:

$$W = \frac{k}{k-1} C^{1/k} \left[P_2^{(k-1)/k} - P_1^{(k-1)/k} \right] \quad \text{(B.08)}$$

or

$$W = \frac{k}{k-1} P_1 \left(C / P_1\right)^{1/k)} \left[(P_2 / P_1)^{(k-1)/k} - 1 \right] \quad \text{(B.09)}$$

Substitute for C/P_1 from Eq. B.2, we get

$$W = \frac{k}{k-1} \left(P_1V_1\right) \left[(P_2 / P_1)^{(k-1)/k} - 1 \right] \quad \text{(B.10)}$$

From the ideal gas law, for an unit of mass:

$$P_1V_1 = \frac{RT_1}{M} \tag{B.11}$$

Substitution above equation into Eq. B.10 yields

$$W = \frac{k}{k-1}\left(\frac{RT_1}{M}\right)\left[r^{(k-1)/k} - 1\right] \tag{B.12}$$

where

$r = (P_2/P_1)$ is the compression ratio

W = compression work, ft-lbf/lbm

We usually need to compute the compression power per unit volume of gas flow, rather than the work W required per pound-mass of gas. Therefore ideal horsepower *(IHP)* is:

$$IHP = C_1 q_{SC}\left[r^{c's} - 1\right] \tag{B.13}$$

Eq. 13 can be rearranged as follows:

$$q_{sc} = \frac{IHP}{c_1 r^{c_2} - c_1} \tag{B.14}$$

where

IHP = required ideal compression power, hp

C's = constants to fit specific compressor properties

In literature, to improve flexibility of Eq. B.14 for modeling of compressor, this is usually formulated as: follows

$$q_{sc} = \frac{IHP}{c_1 r^{c_2} - c_3} \tag{B.15}$$

APPENDIX C

PRESSURE CONTROL VALVES AND REGULATORS

The velocity of a fluid through a restriction (valve of regulator can be considered restriction) may be expressed as follows:

$$u = \frac{K}{\left[1-\left(d_1/d_2\right)^4\right]^{0.5}}\left[2g\left(P_1 - P_2\right)/\rho\right]^{0.5} \qquad \text{(C.01)}$$

where K is a constant representing the entrance/exit loss due to the change in flow diameter, d_1 is diameter at the throat of the restriction device, d_2 is pipe diameter, and r fluid density.

Eq. C.1 generally written as:

$$u = C_d\left[2g\left(P_1 - P_2\right)\rho\right]^{0.5} \qquad \text{(C.02)}$$

where C_d is the coefficient of discharge and is a function of the shape of restriction. It represents irreversible losses and is usually correlated with experimental evaluations.

Application of Eq. C.2 to the case of single phase gas flow results in well known de Saint Venant equation, assuming that the gas is perfect and hat the flow is frictionless and adiabatic.

$$u_2 = c_d\left[\frac{2P_1 g_c}{\rho_1}\frac{k}{k-1}\left(1-\left(\frac{P_2}{P_1}\right)^{(k-1)/k}\right)\right]^{0.5} \qquad \text{(C.03)}$$

where k is the ratio of the specific heats for the gas (i.e. *cp/cv*), and subscripts 1 and 2 denote upstream and downstream side of choke, respectively.

Substituting for gas density, *r1=(28.97P1gg)/(RT1)*

$$u_2 = c_d\left[\frac{RT_1 g_c}{14.85\gamma_g}\frac{k}{k-1}\left(1-\left(\frac{P_2}{P_1}\right)^{(k-1)/k}\right)\right]^{0.5} \quad \text{(C.04)}$$

The gas velocity u_2 is related to the volumetric gas flow rate at standard conditions, q_{sc}:

$$q_{sc} = u_2 A_{sh}\left(\frac{T_{sc}}{P_{sc}}\right)\left(\frac{P_2}{Z_2 T_2}\right) \quad \text{(C.05)}$$

where A_{ch} is the cross sectional area of flow through the choke. Substituting for *Ach=(p/4dch2),* and assuming perfect gas *(z2=1)*

$$q_{sc} = u_2\left(\pi d_{ch}^2 / 4\right)\left(\frac{T_{sc}}{P_{sc}}\right)\left(\frac{P_2}{Z_2 T_2}\right) \quad \text{(C.06)}$$

For adiabatic expansion/compression process for a perfect gas, PV^k = *constant*. Therefore:

$$P_1 V_1^k = P_2 V_2^k \quad \text{(C.07)}$$

implying that

$$T_2 = T_1\left(P_2 / P_1\right)^{(k-1)/k} \quad \text{(C.08)}$$

substitution for T_2 from Eq. C.8 and u_2 from Eq. C.4, into Eq. C.6

$$q_{sc} = c_d\left[\frac{RT_1 g_c}{14.485\gamma_g} - \frac{k}{k-1}\left(1-\left(\frac{P_2}{P_1}\right)^{(k-1)/k}\right)\right]^{0.5}\left(\pi d_{ch}^2 / 4\right)\left(\frac{T_{sc}}{P_{sc}}\right)\left(\frac{P_2}{T_1\left(P_2 / P_1\right)^{(k-1)/k}}\right) \quad \text{(C.09)}$$

or in engineering units:

$$q_{sc} = 27.608 c_d P_1 d_{ch}^2 \left(\frac{T_{sc}}{P_{sc}}\right)\left[\frac{1}{\gamma_g T_1}\frac{k}{k-1}\left(\left(\frac{P_2}{P_1}\right)^{2/k} - \left(\frac{P_2}{P_1}\right)^{(k+1)/k}\right)\right]^{0.5} \qquad \text{(C.10)}$$

The flow through chokes (and flow restrictions in general) may be of two types: subcritical and critical.

Flow is called subcritical when the velocity of the gas through restriction is below the speed of sound in the gas. In subcritical flow regime, Eq. C.10 apply, and the flow rate depends on both the upstream as well as down stream pressure.

Flow is called critical when the velocity of the gas through restriction is equal to the speed of sound in the gas. The choke flow relationships represented by Eq. C.10 is valid only in the subcritical flow regime, up to critical flow when the maximum flow velocity (equal to the sound) is attained. If the pressure ratio at which critical flow occurs is represented by $(P_2/P_1)_c$, then from elementary calculus (differentiate Eq. C.10 with respect to P_2, and set the resultant expressions equal to zero) it can be shown that:

$$(P_2 / P_1)_c = [2/(k+1)]^{k/(k-1)} \qquad \text{(C.11)}$$

Flow is subcritical for $(P_2/P_1) > (P_2/P_1)_c$, and critical for $(P_2/P_1) \leq (P_2/P_1)_c$. If the operating pressure ratio is less than the critical pressure ratio, the pressure ratio in Eq. C.10 must be replaced by critical pressure ratio, because the maximum flow rate through the restriction is that which corresponds to critical flow. Then, Eq. C.10 becomes:

$$q_{sc} = 27.608 c_d P_1 d_{ch}^2 \left(\frac{T_{sc}}{P_{sc}}\right)\left[\frac{1}{\gamma_g T_1}\frac{k}{k-1}\left(\left(\frac{2}{k+1}\right)^{2/(k-1)} - \left(\frac{2}{k+1}\right)^{(k+1)/(k-1)}\right)\right]^{0.5} \qquad \text{(C.12)}$$

BIBLIOGRAPHY

Fatih CAN was born in İstanbul in 1968. He graduated from Technical University of İstanbul as Petroleum Engineer in 1989. He received his MBA equivalent degree in Financial Management from University of İstanbul in 1993. He worked in İstanbul Gas Distribution Inc., Corp., between 1990 and 1994 as Finance Chief. He is currently working in Tekfen Installation and Construction Inc., Corp., as Engineer.