Isentropic Efficiency in Depressuring 6

thread124-202829

Dear all,

Low temperature embrittlement due to system blowdown shall always be considered during material selection study. During Basic Engineering phase, normally depressuring unit in HYSYS and / or PRO-II will be used to carry out blowdown and it low temperature effect. One of the parameter seriously affect the results especially temperature is ISENTROPIC EFFICIENCY.

The higher the isentropic efficiency, the lower the final temperature. In some case , when we use Isen. Eff = 80%, its final temperature is lower than the pre-selected material (LTCS) low temperature limit (-46 degC) and a much expensive material (SS) is required. If we apply lower isen. eff=50%, its final temperature is still higher than the CS LT limit.

I have gone through several project. Some project use isen. eff= 50%, some use 80%, etc. Some use 100% for gas system and 50% for vapor-liquid system, etc...

I really would like to take this opportunity to gather some informations, thoughts and advices from all of you.

Looks forward your advice.

JoeWong

Hi Joe,

In my opinion, isentropic efficiency is closely related to the ratio of compression work VS friction losses during depressuring process. When estimated efficiency is high (close to 100%), fluid temperature falls down to the lowest expectable values. This happens because no amount of energy is transfered to heat. But maybe my assumption is not correct.

I think it is very hard to estimate isentropic efficiency during depressuring process, which is dynamic in its nature. During first stage calculations, I always use the most conservative approach (98%), because it will result in the most safe (but not cost effective, sometimes) design approach.

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http://antwrp.gsfc.nasa.gov/apod/astropix.html

Heat transfer to the control volume in question will keep the temperature above that of an isentropic process. If the process is rapid, then the isentropic process should be considered. Otherwise find a program that incorporates the effect of heat transfer.

Regards

EmmanuelTop,
Thanks for your inputs.

I do agree with you that it is hard to estimate isentropic efficiency during depressuring process as it is dynamic in nature.
Using isen. eff. of 98% (or even 100%) no doubt is most safe and conservative but costly approach...

sailoday28,
Thanks for your inputs.

Yes. Heat transferred from metal mass potentially prevent the fluid temperature drop too low. My opinion would be heat transfer (heat transfer coefficient, heat transfer efficiency, heat potential from metal mass, etc)is another factor by itself from cold depressuring perspective. Weak relationship between heat transfer and isen. eff. (just opinion).

JoeWong

There has been significant experimental work over many years by vendors of compressors, pumps, and turbines to measure the isentropic efficiency of their products. Of course, they had to do this to sell their products. Plus, the isentropic efficiency of a compressor is a lumped parameter of just the compressor. This makes it easier to measure.

But, to blowdown a pressure vessel or pipeline, all that is needed is a valve and some controls. Since the valve and controls do not play much of a role in determining the isentropic efficiency of the blowdown process, similar vendor data is not readily available. And, the isentropic efficiency of a blowdown process depends on the fluid, the vessel, the pipe, if the vessel is insulated, if the piping is insulated, its surroundings, etc. It's a much more complex distributed parameter problem. Wall friction, fitting losses, heat transfer, relative amounts of fluid and steel, and shock effects, if present, will cause deviations from isentropic behavior.

Over the last 10-20 years there does seem to be some limited literature articles on this, and they do refer to some experimental data. The references I found quickly are:

Rapid depressurization of pressure vessels, Journal of Loss Prevention in the Process Industries, Volume 3, Issue 1, January 1990, Pages 4-7, Afzal Haque, Stephen Richardson, Graham Saville and Geoffrey Chamberlain.

Modelling of two-phase blowdown from pipelines—I. A hyperbolic model based on variational principles, Chemical Engineering Science, Volume 50, Issue 4, February 1995, Pages 695-713, J. R. Chen, S. M. Richardson and G. Saville.

Modelling of two-phase blowdown from pipelines—II, A simplified numerical method for multi-component mixtures Chemical Engineering Science, Volume 50, Issue 13, July 1995, Pages 2173-2187, J. R. Chen, S. M. Richardson and G. Saville.

A numerical blowdown simulation incorporating cubic equations of state, Computers & Chemical Engineering, Volume 23, Issue 9, 1 November 1999, Pages 1309-1317, Haroun Mahgerefteh and Shan M. A. Wong.

None of these articles contain the single source answer to this question, so a literature search and study will be needed by those who have a need to understand this issue. I also saw a reference to more experimental data by Overa, Stange, and Salater in 1994 in one of the above references, but could not find it in the databases available to me. Maybe others can find it.

Good luck,
Latexman

It would also be interesting to have the definition of the efficiency for the blowdown process.

Latexman,
Thanks for your great inputs to this subject.

sailoday28,
My understanding of isentropic efficiency in depressuring process...

Isentropic efficiency for an expansion process is defined as

Isen. Eff. = Actul work / Isentropic work

Depressuring is an dynamic expansion process and i view it as step wise expansion as the vessel pressure is gradually decreased. Isen. eff. will be used as constant throughout the depressuring...

JoeWong

Thanks Latexman. Great inputs from your side, as usually.

For the purpose of estimating minimum temperature excursions during depressurization of process vessel or pipeline, I think there is no single source or criterion that can be applied without risk of getting insufficiently accurate results. To many factors are involved, and for each system very rigorous modeling (if possible) should be performed - in order to predict fluid and metal behavior during blowdown. At this point, one can realize that having too many factors/criteria to be considered is as confusing as having no criterion at all. Hand-on-experience and "sixth sense" can play a master role in this kind of calculations.

Every time I encounter extremely low temperatures in software simulation, I try to recheck them manually - assuming 100% conversion of energy without degradation to heat. And I play it safe, specifying MOC which is suitable for such temperature levels. This way I know the system will work 100% safe, and I sleep quietly at night.

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http://antwrp.gsfc.nasa.gov/apod/astropix.html

EmmanuelTop,

Sage advice!

Good luck,
Latexman

If material selection is the main concern as a result of low temperatures during a blowdown, then conservative analyses whether using moc or quasi steady can be done. However, one should also remember that if the process is considered adiabatic with regard to the fluid, then the material is not undergoing a temperature transient.
If one considers the heat transfer effects, then a more realsitic model should include temperature gradients in the structural material.
For example, blowdown of a long hollow cylinder with heat transfer, considering radial gradients as governing should include solving DEL^4 phi, the biharmonic equation.

EmmanuelTop,
Yeap...there's no single source can be applied without risk of getting insufficiently accurate results. That's the main purpose of this post to gather information, practices, thought & experiences from all.

ALL,
From low temperature embrittlement and material selection perspective, taking Isen. eff. of 100% is rather conservative.

Well...from depressuring rate & flare capacity design, Isen. eff. of 100% may not be conservative. What's do you think from fire depressuring perspective ?

Some information you may already awared. There are at least 2 softwares in the market available for depressuring study. They base on rigorous model.

1) LNG-DYN from TECHNIP
2) BLOWDOWN from IMPERIAL COLLEGE.

Personally i have used the LNG-DYN. Good (and also bad thing) is NO Isen. Eff. required.

JoeWong

The practical side of me suggests if the blowdown lasts on the order of an hour duration or longer, metal temperatures should approach isentropic, and if the blowdown lasts on the order of seconds, metal temperatures will not approach isentropic. This leaves us to struggle with blowdowns that last minutes, which is probably the majority of them.

Good luck,
Latexman

Latexman (Chemical)Are there typos in you last post?
If the blowdown is rapid, lasting seconds, there should be little Q and process should be approaching isentropic.
Regards

remember, during blowdown, there is reduced hoop stresses. The most critical thing to watch is stress due to contraction.

If you look at blowdown of a saturated liquid, you can only have 100% efficency as the boiling liquid needs lots of energy to vaporize. In long pipelines, the probability of failure from cryogenic temperatures during a blowdown is not much of an issue.

I still would like the formal definition of efficiency during a blowdown process.

There isn't really an efficency, the delta H is zero across a valve or port. Efficency is the change in ethalphy. The efficency would be based on the heat transfer rate from the surroundings into the system. If you insulated the system, then no heat transfer, no delta H 100%.

sailoday28,

No typos. I was specifically talking about **metal temperatures**, not process temperatures.

Good luck,
Latexman

Thanks to all active involvement in this discussion...

Latexman,
Please see my 2-cents opinion...

From metal perspective, quick depressuring will cause latent heat in metal have insufficient time to transmit to fluid. If depressuring is slow enough (infinite time), sufficient heat transfer and approaching "isentropic" (not sure if this term apply here).

From process perspecitve, rapid expansion put system in metastable state where expansion should approach isentropic expansion. If depressuring is slow enough (infinite time), then the process will not be isentropic.

Please correct or confirm my understanding.

dcasto,
Please correct me if i wrongly interpreted your post.

The efficiency that you mentioned is heat transfer efficiency from surrounding to fluid. Whilst the Isentropic efficiency is related to work efficiency due to expansion.

Isen. Eff. = Actul work / Isentropic work

Assuming a vessel is perfectly insulated (system is perfectly isolated from surrounding), during depressuring, fluid temperature drops and latent heat in the metal will transfer from metal to fluid. As liquid having very high transfer coefficient, metal temperature (liquid contact part) is merely same as fluid temperature. Thus, the heat transfer efficiency is high (theoretically close to 100%) in liquid contacted part. However, as vapor is having very low heat transfer coefficient, latent heat in metal (vapor contacted part) have difficulties in transferring heat to vapor. Thus, the heat transfer efficiency is low (theoretically close to 0%). One of the valid real world example is we normally notice icing formed at the bottom of depressured vessel.

In my opinion, the pipeline example would have less low temperature problem if it is subsea pipeline. Nevertheless, most (if not all) subsea pipelines are wrapped with multiple coating which will act as insulator. It will decrease heat transfer efficiency from surrounding to pipeline / fluid.

If the pipeline is expose to ambient air, my opinion is the air will have a very low heat transfer efficiency. Thus heat contribution from ambient to the pipeline would be low especially the depressuring is quick in nature.

In my opinion, the great contributor of heat (metal temperature do not drop too low) is the latent heat from the metal itself.

One of the example is the long distance subsea pipeline transfer production gas, condensate or full-well stream fluid, pipeline depressuring may take upto few hours and not compliance to API Std 521 of 15 minutes.

You have highlighted a valid point. "During blowdown, there is reduced hoop stresses. The most critical thing to watch is stress due to contraction.".

sailoday28,
I have uploaded some definition of "PV work contribution term" used in depressuring unit (HYSYS)... **http://files.engineering.com/getfile.aspx?folder=874e8a72-cb10-4677-bd5e-034370e22ce9&file=Optionpage_Isen_Eff.PNG**

I believe the efficiency is referring to Isentropic efficiency as stated in previous post.

JoeWong

there is no work, so Eff = 0 / 0 = infinite efficency.

Now lets get real life what the pipeline wall temperature will be. I've blowndown lots of pipelines. If its gas, the pipe will get to the isentropic temperature (or the JT coefficient temp). If its a liquid line, you'll get the bubble point temperature.

I read through this thread and only at the end does dcasto finally mention the real issue that perplexes me: What sort of a normal depressuring process recovers the pressure drop as shaft work such that isentropic efficiency would become an issue in the calculation?

I may have it wrong, but the whole issue of isentropic efficiency does even seem neccessary to be applied to normal depressuring via a valve. When throttled across a valve, the energy from the pressure drop must be contained in the outlet fluid per standard engineering throttling model, although in practice some pressure energy may be dissappated as velocity, noise, vibration, etc. If you really want to exploit the possibility of low temperature at the outlet you must extract shaft work, but this is not normally a desired objective of depressuring.

Isentropic efficiencies of 80% to 100% (as cited above for calculations) require the extraction of shaft work via such equipment as an expander. This equipment achieves low temperatures in a pressure letdown process by removing the extra energy of the pressure drop as shaft work.

In otherwords, I think you are making the issue of downstream temperature in the depressuring line more complicated than it need be for vapor depressuring. With respect to cold temperature (ice cited above) forming in an upstream vessel being depressurized, this is usually due to vaporizing liquid in the vessel. Vaporization requires heat which is taken from the environment. The temperature (and corresponding boiling pressure) obtained inside the vessel is a function of heat transfer and has nothing (that I can see) to do with the notion of isentropic efficiency.

best wishes,
sshep

During depressuring, like in any other gas expansion case, the work against external (downstream) environment is performed - it is just not used for anything. Remember R. Meyer's experiment for determining Cp & Cv? I found it to be very similar to depressuring, but maybe I missed the point. Observing things in that way leads me to the conclusion that efficiency in our case is nothing more than:

EFF = 1 - (friction and other losses divided by energy difference between initial and final state of the fluid)

Dcasto, one big star for you. That is exactly what we have been looking for - practical experience and inductive way of thinking. Thanks for sharing!

Regards,

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http://antwrp.gsfc.nasa.gov/apod/astropix.html

ALL,

Thanks for your inputs...

Work
My understanding of work is...

Let see the following **image.**
When system change from state 1 (P1) to state 2 (P2), work (thermodynamic) is done when boundary is move from boundary 1 (V1) to boundary 2 (V2). See work definition in **wikipedia** . (area under curve)

When P1 approaching ATMOSPHERIC, then work (thermodynamic) will be integrated from P1 to ATM. Above explained the work for expansion process (e.g. valve throttling, depressuring, etc).

Deviation
However, moving from P1 to P2 or ATM may take different path such as isothermal, adiabatic or between isothermal and adiabatic. The process may be reversible and irreversible.

Isentropic process is adiabatic and reversible process.
Isentropic work will be work done by the system by expansion without any heat input/withdraw and reversible

However, in real life there will be heat input from surrounding (e.g. metal and ambient heat input in depressuring process) , so the depressuring process is not adiabatic.

According to Prof. Haroun Mahgerefteh and Shan M. A. Wong in their paper **"A numerical blowdown simulation incorporating cubic equations of state"**, Computers & Chemical Engineering, Volume 23, Issue 9, 1 November 1999, Pages 1309-1317, "Although the rapid expansion of a gas in a vessel may initially follow an isentropic path, heat transfer from the vessel walls ensures that the gas temperature will never reach the isentropic value."

Private communication with **Prof. S.M. Richardson** that " The fluid expansion in the vessel is (nearly) reversible...As blowdown is not adiabatic (involve heat transfer), it is pseudo-isentropic and this has led to use of isentropic efficiency." Isentropic efficiency would be used to quantify how far the actual work deviate from Isentropic work.

Thanks to sshep (a star for you). sshep has triggered to rethink why HYSYS used "PV work contribution term" and the statement "PV work contribution term is used to approximate isentropic efficiency...". This "Isentropic efficiency" is not identical to the isentropic efficiency that we used in turbine.

Additional literature :

i) Richardson, SM, Saville, G, Blowdown of LPG pipelines, PROCESS SAF ENVIRON, 1996, Vol: 74, Pages: 235 - 244, ISSN: 0957-5820

ii) HAQUE, MA, RICHARDSON, SM, SAVILLE, G, BLOWDOWN OF PRESSURE-VESSELS .1. COMPUTER-MODEL, PROCESS SAF ENVIRON, 1992, Vol: 70, Pages: 3 - 9, ISSN: 0957-5820

iii) HAQUE, MA, RICHARDSON, SM, SAVILLE, G, et al , BLOWDOWN OF PRESSURE-VESSELS .2. EXPERIMENTAL VALIDATION OF COMPUTER-MODEL AND CASE-STUDIES, PROCESS SAF ENVIRON, 1992, Vol: 70, Pages: 10 - 17, ISSN: 0957-5820

JoeWong

http://files.engineering.com/getfile.aspx?folder=f75efd4f-1bc8-4425-9697-5c

Emmanual,

I respectfully must disagree that PV work is like any other (i.e. shaft) work. A lot of historical effort went in to defining the concept of enthalpy and calculating tables of it for real fluids.

Sure we could use internal energy and include PV work in every pressure drop calculation, but no practicing chemical engineer does this. Rather we take the up and downstream enthalpy to be equal in an adiabatic throttling process. The enthalpy concept makes the downstream temperature easy to calculate, even when heat transfer is included. Other energy outlets like velocity, noise, etc can usually be neglected.

This sure became a long thread for a simple concept, but that is my opinion anyway.

best wishes,
sshep

I'm still waiting for the definition (not opinions) for effeciency during the blowdown process.
EXERGY is a way to releate to efficieny of a process.
I'm not expert in exergy, but a google search will give many examples. See for example
http://berrygroup.uchicago.edu/papers/340.Mironova'94%20JAP00629.pdf

Regards

Facts is facts, there is no work across a valve. The diagram is showing a piston moving and removeing work! What it shows is an expander, not a "blowdown".

If you are looking for expanders, then most high speed turbo expanders can run at 80% eff. As the blowdown continues the turbo expander effiency will drop to 0% when the delta P approaches 0 psi, for a net 40%. A piston may run about the same initial eff, but the overal would be slightly higher at say 50%

JoeWong,

Is the definition you gave from depressuring unit documentation in HYSYS or PRO-II?

What is "latent heat in metal"? Did you mean sensible heat?

Good luck,
Latexman

Latexman,
I am having difficulties in getting the exact definition of "PV contribution term" in HYSYS and "isentropic efficiency" in PRO-II.

There is NO exact definition of isentropic efficiency either in HYSYS nor PRO-II manual.

HYSYS used "PV contribution term" which approximate the Isentropic efficiency...see **"PV work contribution term"**

PRO-II stated "The gas is depressured isentropically using either a user-defined isentropic efficiency value or the default value of 1.0....."

That's all i managed from my search. I am hoping Che Jedies in this forum can assist.

Meanwhile i will try to contact HYSYS support on this issue.

To be exact, it is **sensible heat** of the metal. Apologize for my mistake.

JoeWong

There is such factor included in the WinSim depressurizer. It does allow the user to add heat to the system (ie work)which would equivalent to isentropic effiency I suppose.

The PV Work Contribution Term sounds like it may account for what my old thermo textbook called "lost work". In this case, the loss in ability of the gas to do PV work. Besides the irreversible expansion and friction, there are at least two other changes in entropy that would not account for - heat transfer and shock waves (if you reach Mach 1). This is what has me concerned, and probably the others too. It isn't clear nor does the documentation explain how to make this functionality work for you. I guess one could figure up an equivalent total "lost work" associated with all these components and use the PV Work Contribution Term as a correction factor, but that seeems to me to be a huge letdown when you are using a sophisticated tool like HYSYS or another software. For example, it is intuitive that a reversible, adiabatic, and frictionless blowdown would have a PV Work Contribution Term of 100%, but what amount of irreversibility, friction, shock waves, and heat transfer align to 0%, and what does that mean?

Good luck,
Latexman

"For example, it is intuitive that a reversible, adiabatic, and frictionless blowdown would have a PV Work Contribution Term of 100%, but what amount of irreversibility, friction, shock waves, and heat transfer align to 0%, and what does that mean? "

That was exactly my point in the previous post, and thank you for clarifying this issue. This is pure thermodynamic question - full stop. PV work contribution therm is relating to that amount (percent) of initial fluid energy that has not been lost through friction, shock wave etc.

0% is just a theoretical state, in my opinion - in the same way as 100% is.

One big star for you, Latexman.

http://antwrp.gsfc.nasa.gov/apod/astropix.html

I believe that thermo efficiency relations are typically for a cylic process or a process which is steady state.
The isentropic temp during blowdown is dependent upon the amount of mass in the vessel and clealy changes with time.

Private communication with Aspen HYSYS support :
"The PV Work Term Contribution refers to the isentropic efficiency of the process. A reversible process should have a value of 100% and an isenthalpic process should have a value of 0%."

JoeWong88 (Chemical)What if the heat is transferred to the vessel in a reversible isothermal process.
dq=Tds

There you go Joe, just what we have said.

Could you convert the heat that is transferred, Q, to an equivalent PV work and combine that with the other PV work terms like the expansion and friction? A shock wave could be treated similarly except the formula may be a little different algebraically.

Looks like you have to convert any non-isentropic component into an equivalent PV work term and subtract that from the ideal, 100% isentropically efficient work possible. Would it be something like this:

PV Work term in % = 100 x $((PV_{100\%\ eff.} - PV_{expansion} - PV_{friction} - PV_{heat\ transfer\ equivalent} - PV_{shock\ wave})/PV_{100\%\ eff.})$

Good luck,
Latexman

I have received definition for "PV contribution terms" in HYSYS depressuring unit.

> **Quote:**
>
> The PV work term (or isentropic efficiency) represents the work done on the surroundings by the expanding fluid. It is part of the dynamic energy balance [1]:
>
> F0 Cp0 (T0 -Tref) + UA(Tbulk - Twall) + d(PV)/dt = (M Cp)holdup d(Tbulk)/dt [1]
>
> Energy Flow Out of Vessel + Wall Effects + PV Work of Expanding Fluid = Rate of change of energy of fluid in vessel.
>
> In HYSYS the d(PV)/dt term above is actually calculated as:
>
> d(PV)dt ~ (VesselHoldupPressure@CurrentTimeStep - VesselPressure@LastTimeStep) / Density * fluidWorkFactor [2]
>
> where:
>
> fluidWorkFactor = PV Work Term Contribution/100
>
> This correction is included so that the user can "tune" the depressuring utility to match plant or measured data.

I can see HYSYS intention but the PV contribution term and d(PV)/dt work term seem does not carry much thermodynamic meaning.

I guess we need a new term to account for energy lost due to friction, movement of liquid in the vessel, etc. Latexman suggestion may be a good start for it.

Latexman,

Do you mind to advice me the following :
i) what's shock wave in this subject ?
ii) How shock wave is formed ?
iii) Is it formed at the exit nozzle ?
iv) Any reference that i can read further ?

Thanks in advance.

JoeWong