ENGINEERING TOMORROW

Technical Paper

Danfoss – The Pioneer in Electric Expansion Valve Control

When Danfoss introduced it's first microprocessor based ADAP-KOOL® controller back in 1987 it was also the first controller with adaptive (self learning) Superheat control.

Danfoss had been gaining experience since 1980 whilst developing analogue controllers for thermostatically activated expansion valves and suction pressure valves.

With the microprocessor technology new "doors" were opened to develop smarter control algorithms utilising the high level of refrigeration expertise within the Danfoss Group. Based on the Minimum Stable Superheat signal (MSS principle), which was developed by the Danfoss Refrigeration Laboratory, a new adaptive superheat control algorithm was invented.

Today's ADAP-KOOL® evaporator controllers for display cases and cold rooms include the 4'th generation of intelligent and adaptive control where it has also been possible to make efficient electronic injection control within CO_2 applications with direct expansion.

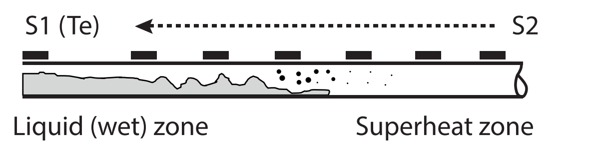


Fig. 1a

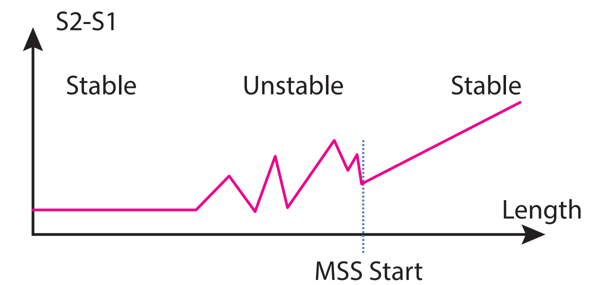


Fig. 1b

Fig. 1a is a schematic presentation of the process that is taking place in an evaporator where the evaporator is viewed as a long tube with injection of liquid at one end.

As a result of the exterior thermal load, evaporation takes place along the evaporator. During evaporation the refrigerant is converted to refrigerant gas. In the first part of the evaporator, only a small part of the refrigerant has been transformed into gas, while the bulk of it is still liquid. As the evaporation progresses, this condition changes, as the amount of gas is increased and the amount of liquid is reduced. While the gas takes up much more room than the liquid, the velocity increases, resulting in more and more instability. Drops of liquid are whirled around in the gas and will evaporate leaving nothing but pure superheated gas at the end of the evaporator.

Importance of proper superheat control

Injection of liquid into dry evaporators is typically controlled by mechanical expansion valves (TXV) or electric valves (EEV) based on the superheat signal. In order to obtain the best possible regulation of liquid injection, it's necessary to provide a superheat signal which is optimum during all operating conditions.

Excess superheat means poor utilisation of the evaporator area, as a large part of this area is used for creating this superheat. Too little superheat produces the risk of liquid passing through the evaporator resulting in reduced efficiency (COP) and risk of liquid hammer and damage of the compressors.

How to establish optimum superheat

In order to establish the optimum superheat it's essential to have an understanding of what is going on inside the evaporator.

Fig. 1a/b shows the temperature signal from two sensors, sensor S1 is placed directly after the expansion valve. The S2 sensor may be placed in different positions along the evaporator tube. In the superheat zone the S2 signal is very stable, but the closer the S2 sensor gets to the "unstable zone" the more unstable the signal will be, on account of the increasing amount of liquid compared to gas. When the S2 sensor approaches the S1 sensor, the signal will again become stable because the S2 sensor now is situated in the liquid zone and consequently measures a constant temperature.

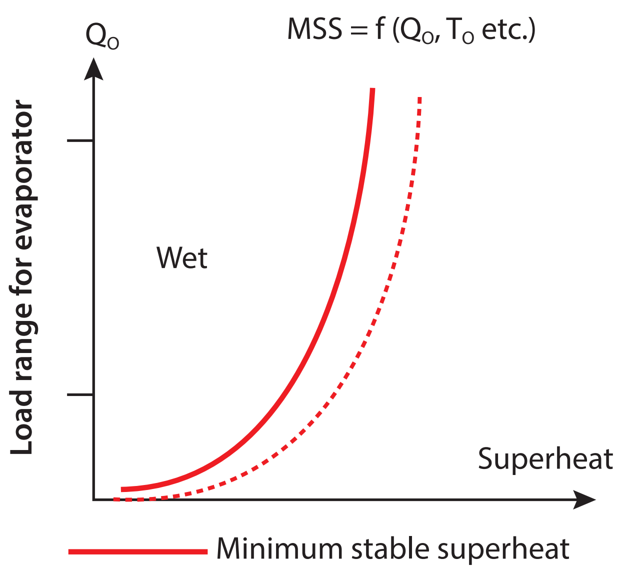


Fig. 2a

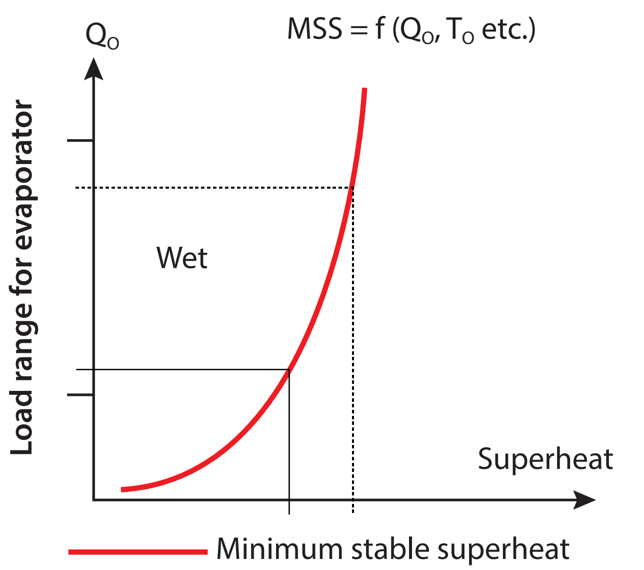


Fig. 2b

The borderline between the stable and unstable superheat signal is called MSS (Minimum Stable Superheat signal). Along the MSS curve the optimum superheat can be found resulting in the highest COP factor as well as highest capacity of an evaporator. But for different types of evaporators and for variation in suction pressures the MSS curve changes (Fig 2a), and for variations in load of the evaporator the optimum superheat changes as well (fig 2b). **If superheat is too small (entering the wet area) there is potential damage to the compressors!**

Superheat control with thermostatic expansion valves (TXV)

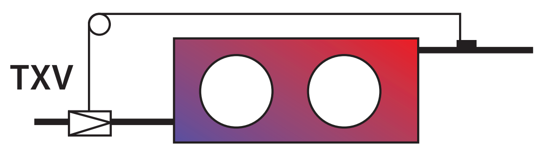


Fig. 3

A typical TXV need a certain static superheat "SS" (see Fig. 4) to be able to start opening, and in addition to this a certain working superheat "WS" in order to provide a certain capacity. As the capacity curve of a TXV is linear (actual superheat) it's only possible to adjust the optimum superheat at one operating point (see Fig. 4). At all other operating conditions the superheat will no longer be at it's optimum.

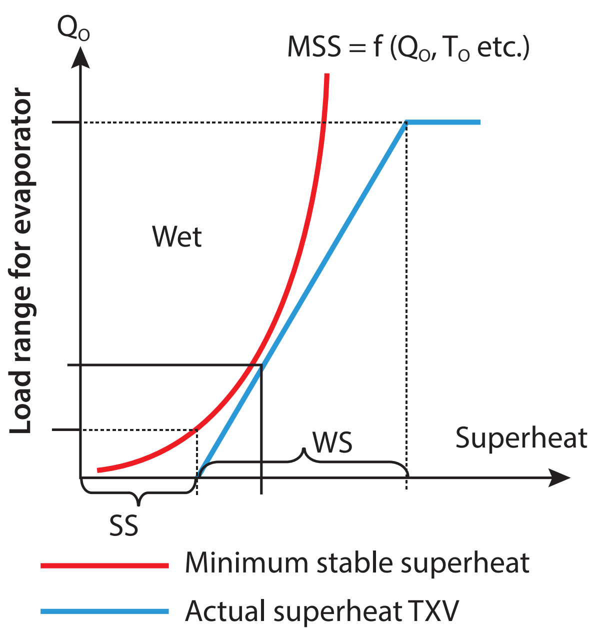


Fig. 4

As mentioned earlier, variation in suction pressure as well as different types of evaporator can change the MSS curve (see Fig. 5), why it's important to adjust the static superheat setting high enough to secure sufficient superheat at all load conditions to avoid liquid in the suction line.

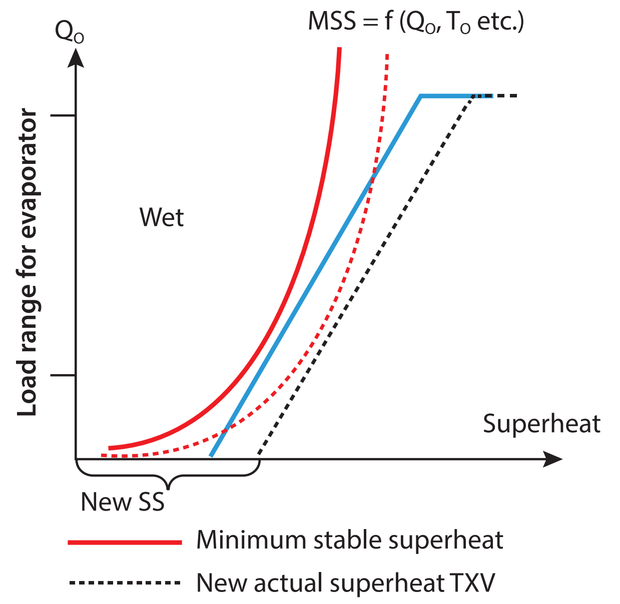


Fig. 5

By reducing condensing pressure the capacity of a TXV is also reduced (capacity curve changing slope in Fig. 6) because of the lower differential pressure across the valve. Equally change in slope of capacity curve can be seen by reducing the orifice in a TXV.

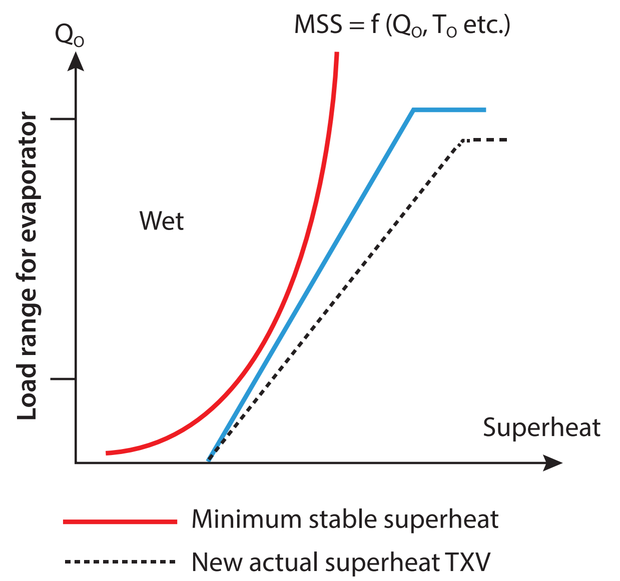
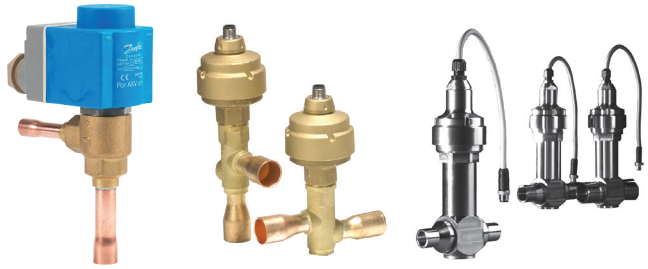


Fig. 6

Concluding on TXV
It's only possible to adjust the optimum superheat at one operating point. At all other operating conditions the superheat will no longer be optimum, as either the characteristics of the TXV or MSS will change.

Superheat control with electric expansion valves (EEV) and ADAP-KOOL®



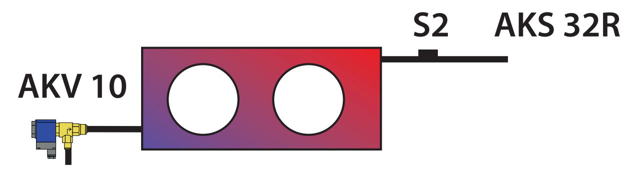


Fig. 7

By means of intelligent software Danfoss has developed an adaptive superheat algorithm which in all load conditions enables an electric expansion valve (AKV / ETS / CCM) to run with the lowest possible superheat, following the MSS curve (Fig. 8) as well as this it will adapt to changes in the location of the MSS zone.

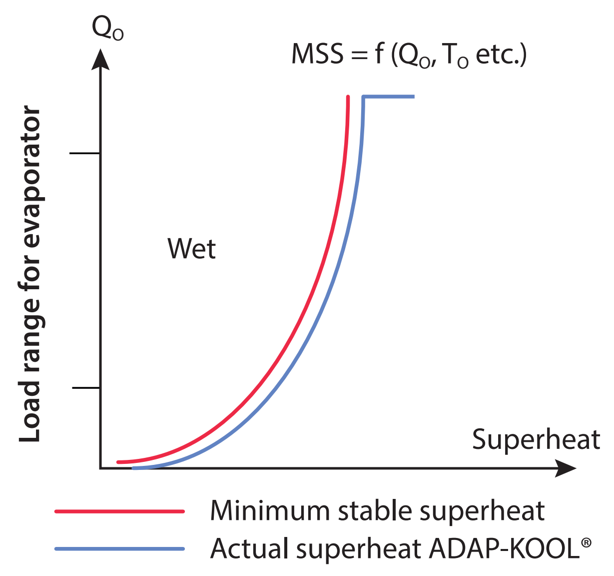


Fig. 8

At start-up the adaptive superheat control algorithm reduces the superheat from a reference it has learned until it measures instability in the superheat signal.

The superheat reference is gradually increased until stability is measured and shortly after reduced until instability is again found (Fig 9). This procedure is continuously ongoing enabling the system always to perform with the highest possible COP and highest possible capacity of the evaporator. As the system is adaptive (self learning) no manual adjustment of the valve is required, and the most important advantage - regulating parameters are adjusted automatically according to actual load conditions avoiding liquid in suction line whilst ensuring lowest possible energy consumption.

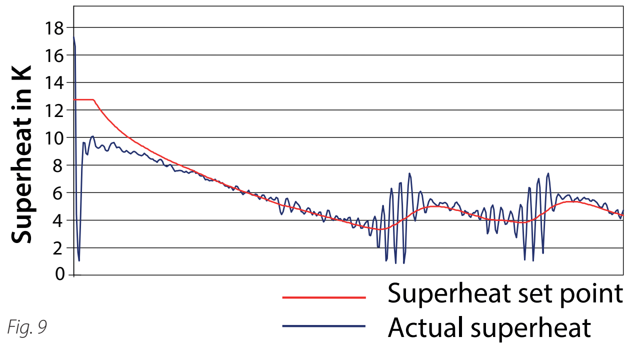


Fig. 9

Typical competitor solutions
Several manufacturers in the refrigeration industry today have controllers for EEV. A number of them do a poor job in controlling superheat – often mechanical thermostatic expansion valves perform better! First of all the superheat is normally a fixed value which has to be setup at commissioning time in addition with manual tweaking of one or more P-I or P-I-D control loops for pull down, normal running condition, or MOP. Furthermore the opening percentage at start up has to be manually setup along with a number of other special regulation parameters making the commissioning difficult and time consuming, even for trained staff.

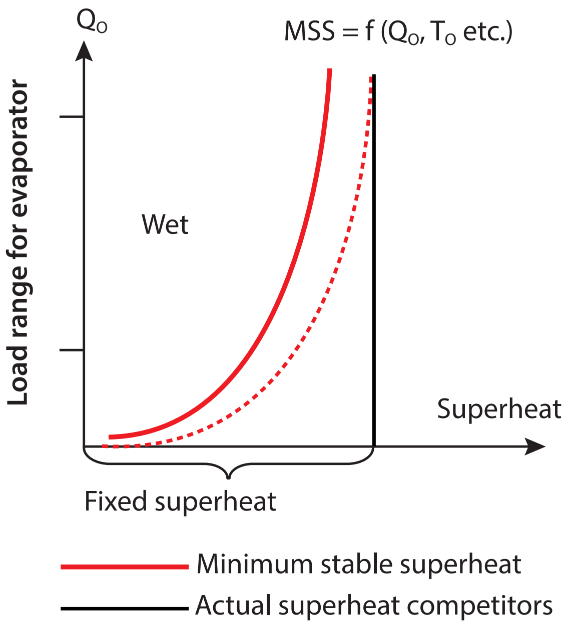


Fig. 10

To avoid compressor damage because of too low superheat most competitor systems have to be setup with a safety margin also to match worst case conditions (see Fig. 10) resulting in poor performance of the system and consequently resulting in high energy consumption.

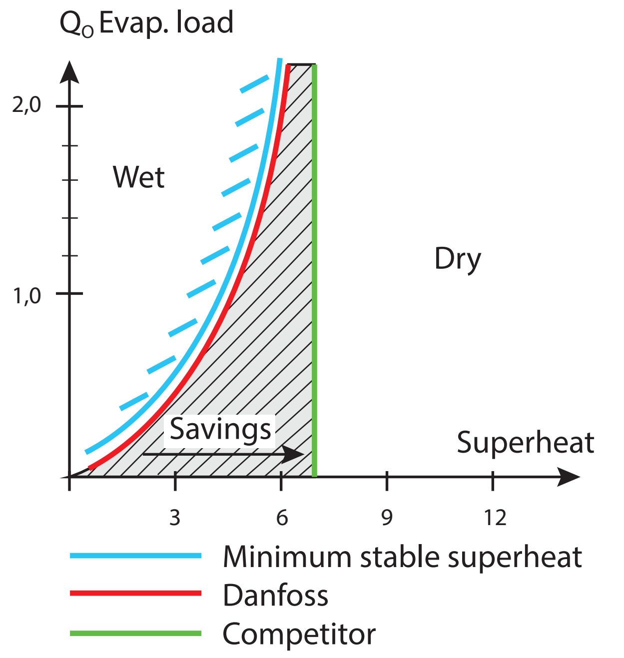


Fig. 11

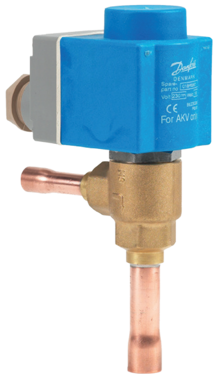
The smartness of intelligent ADAP-KOOL® software makes the difference
Adaptive (self learning) control algorithms have, ever since introduction of ADAP-KOOL® in 1987, been the core of the Danfoss refrigeration control and monitoring system. Today's 4th generation of superheat control algorithm has been optimised also to control liquid injection of CO_2. When Comparing basic competitor systems with Danfoss adaptive superheat control (See Fig. 11) improved superheat values of 2-3 Kelvin can be realised with ADAP-KOOL® systems resulting in 2-3 K higher suction temperature or reduced condensing temperature (pressure).

As a rule of thump 2-3% energy saving can be realised for each 1 K the suction temperature is increased, and 2-3% energy saving for each 1 K the condensing temperature is decreased.

When combining adaptive superheat control and electric expansion valve control with suction pressure optimisation and floating condensing pressure control significant energy savings can be achieved by ADAP-KOOL® control and monitoring systems, while maintaining high performance during all load conditions.

Danfoss adaptive control functionality of liquid injection in dry evaporators is protected by numerous patents!

Advantage of electric expansion valve type AKV10
Given that EEV's are activated by means of electricity they do not normally need a minimum static superheat to open but could open at zero pressure differential across the valve. In addition the opening degree of the valve is not influenced by changing suction or condensing pressure but just depending on the electrical output from the controller.



An AKV is based on Pulse Width Modulating (PWM) principle – a combined solenoid valve and expansion valve in one device. Within an established period of 6 seconds (Fig. 12) the valve will open and close once. The advantage of this principle is that the AKV can be governed to be open only for a fraction of the 6 seconds corresponding to a very small degree of opening, and a change in capacity from 0 % to 100 % or from 100 % to 0 % can be achieved within milliseconds.

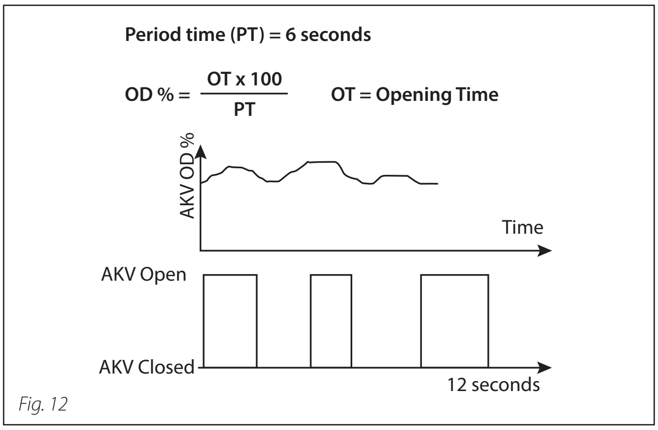


Fig. 12

The simple electrical interface is the same as in standard solenoid valves 24/120/230 V a.c. and a huge advantage is the combination of integrated solenoid valve and expansion valve enabling Normally Closed functionality, especially at case cleaning or when power is lost to the controller to prevent damage of compressors.

Dedicated control solutions for dedicated applications
Various applications are very different in control dynamics and thereby have very different optimisation characteristics. Danfoss has developed a variety of controllers and electrical operated valves dedicated for a number of refrigeration applications eg:

Evaporator controller for display cases and cold rooms	AK-CC 550A/AK-CC 750 and AKV10 / AKVH10 PWM valves
Injection controller for HFC/ CO_2 cascade systems	EKC 313 and ETS / CCM stepper valves
Superheat controller for industrial evaporators	EKC 315 and ICM-ICAD motor valve / AKVA15 / 20 PWM valves
Evaporator controller for water (brine) chillers	EKC 316 / EKD316 and ETS Stepper valves
CO_2 gas pressure controller for high pressure control in CO_2 trans-critical systems	EKC 326a and ICMTS-ICAD motor valves / CCMT stepper valves

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